Springer Series on Epidemiology and Public Health

Michael F. Leitzmann
Carmen Jochem
Daniela Schmid *Editors*

Sedentary Behaviour Epidemiology

Second Edition

Springer

Springer Series on Epidemiology and Public Health

The series has two main aims. First, it publishes textbooks and monographs addressing recent advances in specific research areas. Second, it provides comprehensive overviews of the methods and results of key epidemiological studies marking cornerstones of epidemiological practice, which are otherwise scattered across numerous narrow-focused publications. Thus the series offers in-depth knowledge on a variety of topics, in particular, on epidemiological concepts and methods, statistical tools, applications, epidemiological practice and public health. It also covers innovative areas such as molecular and genetic epidemiology, statistical principles in epidemiology, modern study designs, data management, quality assurance and other recent methodological developments. Written by the key experts and leaders in corresponding fields, the books in the series offer both broad overviews and insights into specific areas and topics. The series serves as an in-depth reference source that can be used complementarily to the "The Handbook of Epidemiology," which provides a starting point of orientation for interested readers (2nd edition published in 2014 http://www.springer.com/public+health/book/978-0-387-09835-7). The series is intended for researchers and professionals involved in health research, health reporting, health promotion, health system administration and related aspects. It is also of interest for public health specialists and researchers, epidemiologists, physicians, biostatisticians, health educators, and students worldwide.

Michael F. Leitzmann • Carmen Jochem • Daniela Schmid
Editors

Sedentary Behaviour Epidemiology

Second Edition

Springer

Editors
Michael F. Leitzmann
Epidemiology and Preventive Medicine
Universität Regensburg
Regensburg, Germany

Carmen Jochem
Epidemiology and Preventive Medicine
Universität Regensburg
Regensburg, Germany

Daniela Schmid
Department of Public Health, Health
Services Research and Health Technology
Assessment
UMIT - University for Health Sciences,
Medical Informatics and Technology
Hall in Tirol, Tirol, Austria

ISSN 1869-7933 ISSN 1869-7941 (electronic)
Springer Series on Epidemiology and Public Health
ISBN 978-3-031-41880-8 ISBN 978-3-031-41881-5 (eBook)
https://doi.org/10.1007/978-3-031-41881-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

Preface

In contemporary society, increasing media use coupled with less physically demanding occupations has given rise to prolonged sedentary behaviour. Scientific evidence demonstrates that adults currently spend more than half of their day in sedentary pursuits. Sedentary behaviour takes place in numerous areas of daily living and includes recreational, occupational, transport-related, and social activities. The essence of this book is that it recognises sedentariness as a significant clinical and public health problem in all its facets and evaluates the potential of decreasing the time spent sedentary to avert chronic disease risk and enhance quality of life.

Sedentary Behaviour Epidemiology is organised into three major parts that build on one another to expand the readers' comprehension of the multifaceted problem of sedentariness. The book begins by providing an introduction to fundamental issues and key concepts regarding sedentary behaviour. After laying the foundation, Part II offers a comprehensive account of the organism's physiological responses to sedentariness. Drawing on evidence from basic science, clinical studies, and epidemiologic research, the text provides the latest evidence on the harmful consequences of sedentary behaviour on the development of numerous health conditions and diseases. Part III proceeds with conveying the knowledge base on psychological, cultural, and social factors associated with sedentary behaviour. This sets the stage for providing evidence-based intervention strategies to reduce the time spent sedentary at the individual, community, environmental, and policy levels. The book closes with a discussion of future challenges and opportunities in sedentary behaviour research. For each topic presented, the book features the necessary background information, outlines pertinent study findings, identifies current research gaps, and highlights areas for additional investigation.

How This Book Is Organised

The second edition of *Sedentary Behaviour Epidemiology* presents important updates to nearly all chapters included in the first edition of this book in 2018. In addition, it contains a new chapter on global and planetary health aspects of sedentary behaviour (Chap. 27) and another new chapter on ergonomic support for physiologically correct sitting (Chap. 28). The book is organised into three parts and 29 chapters.

Part I Fundamentals of Sedentary Behaviour Epidemiology
Part I provides an introduction to fundamental issues and key concepts in sedentary behaviour epidemiology, including the human evolution of sedentary behaviour, measurement techniques of sedentary behaviour, analysis and interpretation of sedentary behaviour data, and the descriptive epidemiology of sedentary behaviour.

Chapter 1 opens with a conceptual definition of sedentary behaviour, followed by a discussion of the human evolution of sedentary behaviour and the influence of specific sociocultural factors on sitting. In addition, it offers an overview of recommendations on sedentary behaviour developed by different countries and organisations, highlighting potential limitations of current guidelines. In its updated version, the chapter includes an update of current sedentary behaviour recommendations for health, classified according to country/geographic region, age group, and institution issuing the recommendation. It also features recently developed consensus definitions for sedentary behaviour that provide standardised terminology in sedentary behaviour research.

In Chap. 2, the descriptive epidemiology of sedentary behaviour is presented. There is also a discussion of correlates of sedentary behaviour, including sociodemographic and environmental factors such as age, education, income, health status, sleep, obesity, physical activity, use of tobacco and alcohol, housing type and size, neighbourhood safety and walkability, dog ownership, and accessibility of play spaces and playground density. The updated chapter exhibits novel surveillance prevalence estimates for sedentary behaviour in population studies and provides new perspectives on monitoring and surveillance of sedentary behaviour, including considerations regarding cut points for high sitting volumes and combinations of high sitting time and low physical activity.

In Chap. 3, measurement techniques of sedentary behaviours are presented, including questionnaires, pedometers, smartphone applications, and integrated motion and posture sensors that assess time spent in sitting or reclining postures. Innovative methods to score accelerometer outputs and to enable pattern recognition of sedentary behaviour types are covered.

Chapter 4 focuses on comprehensive sedentary behaviour datasets that have become available using widespread use of wearable movement sensing technology. The chapter describes the importance of selecting the appropriate statistical method based on the specific data structure and the research question at hand. Also, it reviews principles of causality in sedentary behaviour epidemiology. The updated chapter informs of recent progress achieved in analysing sedentary behaviour data, including compositional data analysis, machine learning, and testing equating. It also delves into new challenges that have emerged, such as noise introduced to the data due to most measurement devices being worn on the wrist, making it challenging to determine intensity cut points.

Part II Health Effects of Sedentary Behaviour

Part II focuses on the organism's physiological responses to sedentary behaviour. Drawing on evidence from basic science, clinical studies, and epidemiologic research, the chapters in this part discuss the evidence on the harmful consequences of sedentary behaviour on the development of morbidity and mortality, including important health conditions such as obesity, diabetes and the metabolic syndrome, cardiovascular disease, cancer, depression, psychosocial health, quality of life, physical function, mental health, and cognition.

Chapter 5 opens with a discussion of physiologic responses to sedentary behaviour in animal and human studies. The influence of sedentary behaviour on the hormonal regulation of appetite, dietary intake, and energy balance is discussed. The updated chapter reviews the growing number of new studies on the role of interrupting sitting for improving postprandial glycemia and insulinaemia, and vascular function. It also showcases new studies on prolonged sitting in relation to brain function and cognitive performance, musculoskeletal pain/discomfort and fatigue, and oxidative stress and inflammatory markers.

In Chap. 6, the genetics of sedentary behaviour is reviewed. The potential for family and twin studies and molecular genetic studies to uncover causal relations is outlined. The challenges of conducting genetic studies of sedentary behaviour are highlighted, including limited sample sizes, heterogeneity in the age ranges studied, and imperfect measures of sedentary behaviour. The updated chapter newly confirms the significant contribution of genetics to individual differences in sedentary behaviour, with polygenetic risk scores explaining up to 15% of variance in sedentary behaviour. The chapter shows that Mendelian randomisation studies support a causal role of sedentary behaviours in obesity and cardiovascular disease.

In Chap. 7, the relation of sedentary behaviour to risk of type 2 diabetes and the metabolic syndrome is examined. This includes a discussion of the impact of prolonged sedentary time on circulating levels of glucose, HbA1c, insulin, and measures of insulin resistance. Also, observational and experimental evidence regarding the influence of breaks in sedentary time on markers of the metabolic syndrome is presented. The updated chapter draws attention to the fact that the consistent strong relation of sedentary behaviour to type 2 diabetes forms the basis for demonstrating that when replacing sedentary behaviour, any type of movement counts. Also, it points out that behaviours such as sleep, sedentary behaviour, and activities of different intensities are now recognised as being co-dependent.

Chapter 8 provides an account of the influence of sedentary behaviour on cardiovascular disease based primarily on evidence from cross-sectional and prospective observational studies of objectively assessed sedentary behaviour or self-reported sitting. Numerous methodological issues in this research area are discussed, including measurement error, confounding, and heterogeneity in the design of previous studies. The updated chapter discusses novel data on how many hours of sitting per day are associated with elevated cardiovascular disease risk and how much moderate-to-vigorous activity per day is needed to attenuate that relation. Further, it offers an outlook on emerging studies of actual posture that hold promise to advance the field in the future.

In Chap. 9, the evidence on sedentary behaviour in relation to overall and site-specific cancer incidence and mortality is summarised. Potential biological mechanisms are discussed, while it is recognised that the cellular processes linking sedentary behaviour to carcinogenesis are incompletely understood. These include endogenous sex hormones, metabolic hormones, inflammatory adipokines, and immune function. The updated chapter summarises the evidence from nearly 100 new studies on sedentary behaviour and cancer added since the first edition of this book. Based on that literature, the relation of sedentary behaviour to cancer risk has become weaker, in particular for endometrial and ovarian cancers.

Chapter 10 presents evidence regarding the association between sedentary behaviour and depression based largely on observational data. It includes a review of hypotheses regarding the impact of sedentary time on psychobiological mechanisms, such as inflammation and the acute phase response, the hypothalamic–pituitary–adrenal axis, and neurotransmitter function. The updated chapter looks into the current literature on sedentary behaviour and mental health, touching on recent work that has successfully deployed device-based assessments of sedentary time to overcome some of the limitations of self-report, albeit using cross-sectional as opposed to longitudinal study designs.

In Chap. 11, the evidence on prolonged time spent sedentary in relation to the risk of developing adiposity in children, adolescents, and adults is presented. Information is based on data from systematic reviews and meta-analyses of cross-sectional studies, prospective studies, and randomised controlled trials. The possibility of a bidirectional association between sedentary behaviour and adiposity in adults is alluded to. The updated chapter provides novel evidence regarding the association between sedentary behaviour and adiposity, highlighting the need for future studies to employ device-based methods to generate more definitive conclusions about the associations between sedentary behaviour and adiposity in different population subgroups.

In Chap. 12, the understudied area of sedentary behaviour in relation to psychosocial health is reviewed, with particular attention being paid to bullying/victimisation, self-esteem, prosocial behaviour, and mental conditions such as bipolar disorder, anxiety, and stress. The chapter includes a discussion of the possibility that observed associations may be confounded by factors such as physical activity and socio-economic status.

Chapter 13 presents the association between sedentary behaviour and ageing, covering a broad range of functional limitations and distinguishing between individuals who live independently and those who live in residential settings or in hospital. The relevance of conducting interventions aimed at reducing sedentary behaviour rather than increasing physical activity in the elderly is discussed. The updated chapter examines the latest systematic reviews and meta-analyses on the effectiveness of interventions aimed at reducing sedentary time in community-dwelling older adults. Further, it summarises the relations of sedentary behaviour to bone health, cognitive function, obesity, and activities of daily living in older adults.

In Chap. 14, the relations of domain-specific sedentary behaviours to all-cause mortality, cardiovascular disease mortality, and cancer mortality are presented. The data originate from prospective cohort studies and meta-analyses. The chapter also includes a discussion of whether observed associations with mortality risk are independent of physical activity level and whether they are mediated by body fat mass. The updated chapter discusses new original studies and meta-analyses on sedentary behaviour in relation to mortality, alluding to a framework in which the deleterious health consequences of too much sitting are seen being an addition to, and not an alternative, the well-recognised benefits of participation in health-enhancing moderate-to-vigorous physical activity.

Part III Understanding Sedentary Behaviour and Promoting Reductions in Time Spent Sedentary

Part III uses theories and models of sedentary behaviour as a framework for developing effective and evidence-based strategies to reduce the time spent sedentary at the individual, community, environmental, and policy levels. Individual chapters focus on interventions directed at children and adolescents, the workplace, the elderly, persons with pre-existing disease or disability, overweight and obese individuals, and ethnic minorities and immigrants. The final chapter discusses challenges and opportunities in sedentary behaviour research, including new paradigms to better understand sedentary behaviour and the genetics of sedentary behaviours.

Chapter 15 outlines how the behavioural epidemiology framework and an ecological model of sedentary behaviour can be utilised to provide an enhanced understanding of the multifaceted determinants of sedentary behaviour. An example of an intervention study designed using an ecological model of sedentary behaviour that targets sedentary behaviour in the occupational setting is presented. The updated chapter newly explores associations of sedentary time in different environmental settings with health risk biomarkers and mental health indices. Also, it investigates recent intervention trials in the workplace setting that employed environmental and ecological approaches and targeted multiple levels of influence.

In Chap. 16, individual-level approaches to reduce sedentary behaviour are reviewed. The chapter opens with a discussion of variables related to sedentary behaviour and barriers to sedentary behaviour change. In addition to covering current behavioural theories and theoretical models, the chapter introduces alternative perspectives that include concepts of behavioural economics, habit, and nudging. The updated chapter notes that despite the increasing recognition of the complexity of sedentary behaviours, newer devices such as smartphones remain understudied in this context. It discusses dual-process approaches, including automatic processing frameworks, as emerging theoretical developments in sedentary behaviour research.

Chapter 17 examines interventions targeting sedentary behaviour in children and adolescents. The chapter provides a conceptual framework for sedentary behaviour interventions and discusses interventions that have focused on reducing screen time, sedentary transport, and sitting in the school and home settings. Examples of real-world translatability of intervention programmes are given. The updated chapter sheds additional light on effective strategies for sedentary behaviour interventions to reduce sitting time, pointing to theoretical models and frameworks for guiding effective implementation and better utilisation of knowledge about strategies and mechanisms that influence outcomes.

In Chap. 18, the focus is on workplace programmes to reduce occupational sitting. The chapter provides a summary of the amount of time workers sit. Best practice programmes for addressing extended workplace sitting time are given. Interventions directed at reducing workplace sitting time are discussed. Limitations and future research needs in the area of occupational sitting are highlighted. The updated chapter supplies new evidence on effective approaches to reduce prolonged sitting time at work, with consideration of the impact of workplace-delivered interventions on activity outside of work hours. It also acknowledges the impact of major work disruptors, such as the COVID-19 pandemic, on understanding and influencing behaviour during work time.

Chapter 19 presents approaches to decrease sedentary behaviour among the elderly. The design characteristics of intervention studies and the methodologies employed to assess sedentary behaviour intervention response are discussed. In addition, the chapter examines the effectiveness of interventions that focus on increasing physical activity but also decrease sedentary behaviour. The updated chapter synopsises interventions aimed at reducing or disrupting sedentary time, the number and quality of which have more than doubled since the last version of this book. Interventions have also shifted their focus from cardiometabolic markers to functional and quality of life indicators.

In Chap. 20, the evidence from intervention studies to decrease sedentary behaviour among persons with pre-existing disease or disability is reviewed. The chapter also contains a brief synopsis of interventions that have been registered, and it provides concepts for developing future trials. The remainder of the chapter focuses on potential areas of future investigation and associated methodological issues.

Chapter 21 summarises the information from the small number of available studies on sedentary behaviour reduction in individuals with overweight and obesity. In addition, qualitative studies exploring facilitators and barriers to sedentary behaviour reduction in overweight and obese individuals are described, and methodologic issues regarding the measurement of sedentary behaviour outcomes are presented. The updated chapter includes studies published in the past five years. Approaches to reduce sedentary time are discussed based on sample size, effectiveness, and intervention duration.

In Chap. 22, the focus is on interventions targeting sedentary behaviour among racial/ethnic minority groups. Information on the prevalence of sedentary behaviour in racial/ethnic minorities is provided, along with strategies on how to make future progress in successfully reducing sedentary behaviour using culturally appropriate approaches.

Chapter 23 presents sedentary behaviour interventions across multiple community settings, such as schools, workplaces, and local neighbourhoods. Within each of these settings, the chapter discusses factors that impact on sedentary behaviour, summarises intervention studies that target sedentary behaviour, and provides recommendations for future steps. The updated chapter deals with the impact of the COVID-19 pandemic on sedentary behaviours in schools, workplaces, and neighbourhoods. It further discusses evidence on the neighbourhood environment and sedentary behaviour, community-based interventions targeting sedentary behaviour, and the role of technology and media in decreasing sitting time.

In Chap. 24, social and physical environmental factors that track with sedentary behaviour are described. The evidence for the effectiveness of environmental interventions on sedentary behaviour is evaluated. The chapter addresses potentially relevant theoretical perspectives, such as social cognitive theory, habit theory, social network analysis, and systems theory. The updated chapter newly unravels the influence of social and physical environments on sedentary behaviour by distinguishing between early years and school-aged children, given the differential nature of sedentary behaviour across those age groups. The chapter also includes an expanded section on older adults, and it encompasses more correlates across the lifespan.

Chapter 25 presents policy-level approaches to reduce sedentary behaviour. This involves an evaluation of numerous settings where sedentary behaviour reduction can be addressed at a policy level. Current sedentary behaviour recommendations and stakeholder guidelines are summarised.

In Chap. 26, new paradigms combining a life course perspective and complexity science to better understand sedentary behaviours are introduced. The chapter presents novel methodologies for data collection (big data) and analysis (probabilistic modelling techniques) as well as innovative interventions including natural experiments and solutionist and participatory approaches. The updated chapter adds a realist perspective to deal with complex behaviours such as sedentary behaviour. Also, it introduces ecological momentary assessment to acquire context-specific sedentary behaviour data. In addition, the chapter features the development and implementation of just-in-time adaptive interventions to reduce sedentary behaviour.

Chapter 27 represents an entirely new addition to the book. It considers sedentary behaviour epidemiology from a public, global, and planetary health perspective, with a focus on health-promoting workplaces and active transportation as win-win strategies for well-being societies. It also discusses COVID-19 as a global health challenge for sedentary behaviour.

Chapter 28 is also an entirely new addition to the book. It outlines how non-physiological positioning of the body during sitting adversely affects musculoskeletal health, subsequently describing how physiologically correct sitting can be supported by ergonomically designed office furniture and car seats. It provides an example of a comprehensive home office unit.

Chapter 29 uses a behavioural epidemiology framework to outline gaps in sedentary behaviour research and to highlight future research opportunities. This includes improving current knowledge about sedentary behaviour and health, enhancing sedentary behaviour measures, better characterising correlates and determinants of sedentary behaviour, refining interventions of sedentary behaviour, and translating results into practice.

Regensburg, Germany — Michael F. Leitzmann
Regensburg, Germany — Carmen Jochem
Hall in Tirol, Austria — Daniela Schmid

Contents

Part I
Fundamentals of Sedentary Behaviour Epidemiology

Chapter 1
Introduction to Sedentary Behaviour Epidemiology

Carmen Jochem, Daniela Schmid, Andrea Weber, and Michael F. Leitzmann

Abstract Sedentary behaviour epidemiology is the study of the distribution, determinants and health consequences of sedentary behaviours in the population. It seeks to identify biological, psychosocial, environmental and genetic factors that affect sedentary behaviour. The term sedentary behaviour describes any waking behaviour characterised by an energy expenditure <1.5 metabolic equivalents of task (METs) while in a sitting or reclining posture. From an evolutionary perspective, sedentary behaviour is a relatively new phenomenon in human history, and it is strongly linked to the technical advances of the Industrial Revolution. In addition, sociocultural aspects fundamentally influence our understanding and perception of sedentary behaviours. Understanding these influences on modern sitting behaviour is crucial for successfully developing and implementing sedentary behaviour recommendations. Several countries have provided guidelines on sedentary behaviour for health. In 2020, the World Health Organization (WHO) incorporated recommendations on sedentary behaviour in the current Guidelines on Physical Activity and Sedentary Behaviour. These guidelines provide recommendations for all age groups and for specific population subgroups such as pregnant women or adults living with chronic conditions. Strengthening the evidence base regarding quantified thresholds for sedentary time or regarding sedentary break and bout accumulation patterns is critical for future sedentary behaviour recommendations.

C. Jochem (✉) · A. Weber · M. F. Leitzmann
Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany
e-mail: carmen.jochem@ukr.de; andrea.weber@ukr.de; michael.leitzmann@ukr.de

D. Schmid
Department of Public Health, Health Services Research and Health Technology Assessment, UMIT - University for Health Sciences, Medical Informatics and Technology, Hall in Tirol, Austria
e-mail: Daniela.Schmid@umit-tirol.at

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_1

What Is New?

- The field of sedentary behaviour research continues to evolve, and it increasingly emphasises the relevance of sedentary behaviour epidemiology.
- Consensus definitions for sedentary behaviour and related terms have been formulated, providing standardised terminology in sedentary behaviour research.
- The recent Guidelines on Physical Activity and Sedentary Behaviour published by the World Health Organization (WHO) in 2020 for the first time include recommendations on sedentary behaviour and address all age groups as well as population subgroups, such as pregnant women or adults living with chronic conditions.
- The first setting-specific recommendations for school-related sedentary behaviours were published.
- When sitting is unavoidable, it should be dynamic, limited to 20–30 min bouts and interspersed with standing and physical activity of any intensity.

1.1 What Is Sedentary Behaviour?

1.1.1 Definition of Sedentary Behaviour

The current section provides a conceptual definition of sedentary behaviour, making clear the distinction between sedentary behaviour (too much sitting) and physical inactivity (too little exercise). Sedentary behaviour (Latin: sedere: 'to sit') is defined as [1] 'any waking behavior characterised by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture' and comprises sitting in the context of occupational, educational and home settings, and during commuting. Examples of sedentary behaviours are television (TV) viewing, video game playing, computer use, reading, talking on the telephone and sitting while commuting by automobile, bus, train, plane, ferry, etc. Those activities show an energy expenditure between 1.0 and 1.5 metabolic equivalents (METs) [2]. Hence, sedentary behaviours comprise those that involve sitting and a low amount of energy expenditure.

However, certain activities such as screen-based behaviours (e.g. TV, computer, mobile devices) can be performed while being sedentary or physically active. The Sedentary Behavior Research Network provides further details on key terms that are relevant for sedentary behaviour research (Table 1.1).

Table 1.1 Final definitions, caveats and examples of key terms from the Sedentary Behavior Research Network (SBRN) Terminology Consensus Project (reproduced with permission of SBRN)

Term	**1. Physical inactivity**
General definition	An insufficient physical activity level to meet present physical activity recommendations
Caveats	General definition applies to all age and ability groups
Examples	• Toddlers and preschoolers (1–4 years): not achieving 180 min of physical activity of any intensity per day • Children and youth (5–17 years): not achieving 60 min of moderate- to vigorous-intensity physical activity per day • Adults (≥18 years): not achieving 150 min of moderate-to-vigorous-intensity physical activity per week or 75 min of vigorous-intensity physical activity per week or an equivalent combination of moderate- and vigorous-intensity activity
Term	**2. Stationary behaviour**
General definition	Stationary behaviour refers to any waking behaviour done while lying, reclining, sitting or standing, with no ambulation, irrespective of energy expenditure
Caveats	• Stationary time: the time spent for any duration (e.g. per day, per week), in any context (e.g. at school/work) and at any intensity (e.g. standing in a line, working on an assembly line with no ambulation, working at a standing desk, sitting in a classroom) in stationary behaviours • Stationary bout: a period of uninterrupted stationary time • Stationary interruptions/breaks: a nonstationary bout in between two stationary bouts (applies to all age and ability groups except infants)General definition applies to all age and ability groups except for infants (<1 year to pre-walking) and people with a mobility impairment who are unable to stand
Examples	• Use of electronic devices (e.g. TV, computer, tablet, phone) while sitting, reclining or lying; reading/writing/drawing/painting/talking while sitting; sitting at school/work; sitting in a bus, car or train • Standing in a line; standing at church; standing for a hallway discussion; writing a text message while standing; using a standing desk • Being carried/held/cuddled by someone
Term	**3. Sedentary behaviour**
General definition	Sedentary behaviour is any waking behaviour characterised by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture
Caveats	• Sedentary time: the time spent for any duration (e.g. minutes per day) or in any context (e.g. at school or work) in sedentary behaviours • Sedentary bout: a period of uninterrupted sedentary time • Sedentary interruptions/breaks: a nonsedentary bout in between two sedentary bouts • Infants (<1 year or pre-walking): any waking behaviour characterised by low-energy expenditure while restrained (e.g. stroller/pram, high chair, car seat/capsule) or when sedate (e.g. reclining/sitting in a chair with little movement but not restrained) Time spent in the prone position ('tummy time') is not considered a sedentary exposure • Toddlers and preschoolers (1–4 years), children and youth (5–17 years) adults (≥18 years) and all ability groups: the same as the general definition

(continued)

Table 1.1 (continued)

Examples	• Infants (<1 year or pre-walking): lying awake in the bed with minimal movement; sitting in a baby chair/high chair/stroller/car seat with minimal movement; being carried/held/cuddled by someone • Toddlers and preschoolers (1–4 years): use of electronic devices (e.g. TV, computer, tablet, phone) while sitting, reclining or lying; reading/drawing/painting while sitting; sitting in stroller; sitting in baby chair or couch while eating a meal; sitting in a bus, car or train • Children and youth (5–17 years): use of electronic devices (e.g. TV, computer, tablet, phone) while sitting, reclining or lying; reading/writing/drawing/painting while sitting; homework while sitting; sitting at school; sitting in a bus, car or train • Adults (≥18 years): use of electronic devices (e.g. TV, computer, tablet, phone) while sitting, reclining or lying; reading/writing/talking while sitting; sitting in a bus, car or train • People who use a manual wheelchair or a power chair: use of electronic devices (e.g. TV, computer, tablet, phone) while sitting, reclining or lying; reading/writing/drawing/painting/talking while sitting; sitting in a bus, car or train; moving from place to place in a power chair; being pushed while passively sitting in a manual wheelchair
Term	**4. Standing**
General definition	A position in which one has or is maintaining an upright position while supported by one's feet
Caveats	• Active standing: active standing refers to any waking activity in a standing posture characterised by an energy expenditure >2.0 METs, while standing without ambulation, whether supported or unsupported • Passive standing: passive standing refers to any waking activity in a standing posture characterised by an energy expenditure ≤2.0 METs, while standing without ambulation, whether supported or unsupported • Standing time: the time spent for any duration (e.g. minutes per day) or in any context (e.g. at school/work) while standing • Standing bout: a period of uninterrupted time while standing • Standing interruptions/breaks: a non-standing bout in between two standing bouts • Infants (<1 year or pre-walking), toddlers and preschoolers (1–4 years), children and youth (5–17 years), adults (≥18 years) and people who use a manual wheelchair or a power chair: the same as the general definition • People who are unable to stand: not applicable
Examples	• Active standing: standing on a ladder; standing while painting; standing while washing dishes; working an assembly line while standing; standing while juggling; standing while lifting weights • Passive standing: standing in a line; standing for a hallway discussion; use of electronic devices (e.g. TV, computer, tablet, phone) while standing; standing at church • Supported standing: standing while holding a couch, chair or a parent's hand; standing with the aid of crutches, a cane, standing frame or body weight support
Term	**5. Screen time**
General definition	Screen time refers to the time spent on screen-based behaviours. These behaviours can be performed while being sedentary or physically active

(continued)

Table 1.1 (continued)

Caveats	• Recreational screen time: time spent in screen behaviours that are not related to school or work • Stationary screen time: time spent using a screen-based device (e.g. smartphone, tablet, computer, TV) while being stationary in any context (e.g., school, work, recreational) • Sedentary screen time: time spent using a screen-based device (e.g. smartphone, tablet, computer, TV) while being sedentary in any context (e.g. school, work, recreational) • Active screen time: time spent using a screen-based device (e.g. smartphone, tablet, computer, television) while not being stationary in any context (e.g. school, work, recreational) • General definition applies to all age and ability groups
Examples	• All age and ability groups: watching TV, using a smartphone/tablet, using a computer • Active screen time: playing active video games, running on a treadmill while watching TV
Term	**6. Non-screen-based sedentary time**
General definition	Non-screen-based sedentary time refers to the time spent in sedentary behaviours that do not involve the use of screens
Caveats	• Recreational non-screen time: time spent in non-screen-based sedentary behaviours that are not related to school or work • General definition applies to all age and ability groups
Examples	• Infants ($<$1 year or pre-walking): lying supine on a mat while sedate; sitting in a stroller or car seat with little movement • Toddlers and preschoolers (1–4 years): Sitting in a child seat, chair or car seat; sitting idle in the sandbox or on the floor; reading a non-electronic book or playing a board game while seated • Children and youth (5–17 years): sitting at school; sitting doing homework or art work; reading a non-electronic book; playing a board game; sitting in a car • Adults ($\geq$18 years): reading a non-electronic book; playing a board game; sitting in a car • People who use a manual wheelchair or a power chair: reading a non-electronic book; playing a board game; sitting in a car; being pushed while passively sitting in a manual wheelchair
Term	**7. Sitting**
General definition	A position in which one's weight is supported by one's buttocks rather than one's feet and in which one's back is upright
Caveats	• Active sitting: active sitting refers to any waking activity in a sitting posture characterised by an energy expenditure $>$1.5 METs • Passive sitting: passive sitting refers to any waking activity in a sitting posture characterised by an energy expenditure $\leq$1.5 METs • General definition applies to all age and ability groups
Examples	• Active sitting: working on a seated assembly line; playing guitar while seated; using devices that engage ones feet/legs while seated; doing arm ergometry while in a wheelchair • Passive sitting: refer to sedentary behaviour examples while sitting
Term	**8. Reclining**
General definition	Reclining is a body position between sitting and lying

(continued)

Table 1.1 (continued)

Caveats	General definition applies to all age and ability groups Reclining behaviour can be either passive (≤1.5 METs) or active (>1.5 METs)
Examples	Passive reclining (all age and ability groups): lounging/slouching on a chair or couch while sedentary Active reclining (all age and ability groups): recumbent cycling
Term	**9. Lying**
General definition	Lying refers to being in a horizontal position on a supporting surface [3]
Caveats	General definition applies to all age and ability groups Lying behaviour can be either passive (≤1.5 METs) or active (>1.5 METs)
Examples	Passive lying (all age and ability groups): lying on a couch, bed or floor while sedentary. Active lying (all age and ability groups): isometric plank hold
Term	**10. Sedentary behaviour pattern**
General definition	The manner in which sedentary behaviour is accumulated throughout the day or week while awake (e.g. the timing, duration and frequency of sedentary bouts and breaks)
Caveats	General definition applies to all age and ability groups
Examples	Prolonger: someone who accumulates sedentary time in extended continuous bouts Breaker: someone who accumulates sedentary time with frequent interruptions and in short bouts

MET = metabolic equivalent corresponding to resting metabolic rate of the population under study. A metabolic equivalent is deemed to be 3.5 ml O_2/kg/min in adults without mobility impairment or chronic disease. A metabolic equivalent is generally higher in children and in those with conditions that elevate muscle activity or metabolism and is generally lower in those with paralysis, small muscle mass or wasting conditions. The interpretation of MET values should be made with attention to the population under study and the definitions and caveats above applied accordingly

1.1.2 Sedentary Behaviour Epidemiology

Sedentary behaviour epidemiology is the study of the distribution, determinants and health consequences of sedentary behaviours in the population. It examines the relations of sedentary behaviour to diseases and other health conditions and seeks to identify biological, psychosocial, environmental and genetic factors that affect sedentary behaviour. The knowledge acquired from sedentary behaviour epidemiology is applied to intervention programmes for disease prevention and health promotion, including population surveillance. The expanding field of sedentary behaviour research stresses the relevance of sedentary behaviour epidemiology.

1.1.3 Is Too Much Sitting the Same as Too Little Exercise?

The past decade has witnessed a sizeable increase in research associated with the health effects of sedentary behaviour. A growing body of epidemiologic evidence now shows that persons who engage in a high volume of sedentary behaviour exhibit increased risks of morbidity and mortality, irrespective of their level of moderate-to-vigorous physical activity [4, 5]. Only large amounts of moderate-to-vigorous physical activity (i.e. more than 300 min/week) can largely offset the mortality risks associated with high levels of sedentary behaviour [6].

In addition, it has been recognised that the correlation between sedentary behaviour and moderate-to-vigorous physical activity is low [7] and that an individual can accumulate substantial amounts of both sedentary behaviour and moderate-to-vigorous physical activity in the course of a day [8]. For example, an office worker may spend long, uninterrupted blocks of time sitting at a computer but then engage in a vigorous workout at the gym after work. Also, time spent in sedentary behaviours shows correlates that are distinct from those related to moderate-to-vigorous physical activity [9]. Thus, too much sitting and too little physical activity represent fundamentally distinct concepts. Physical inactivity, i.e. too little exercise, is defined as 'an insufficient physical activity level to meet present physical activity recommendations' [1].

However, in the past, there have been inconsistencies in the literature regarding the definition of the term sedentary. In the sedentary behaviour literature, the term sedentary refers to time spent sitting or lying (while awake) with low-energy expenditure [1]. Thus, an individual may be defined as sedentary if they exhibit a large volume of sedentary behaviour. By comparison, in the exercise literature, the term sedentary has often been used to characterise the lack of some threshold of moderate-to-vigorous physical activity [10]. In that context, researchers frequently describe a subject as sedentary because they do not achieve the physical activity recommendations. For example, exercise studies may contain a 'sedentary' control group because of their absence of physical activity without having formally assessed their amount of sedentary behaviour.

Acknowledging the divergent characteristics of sedentary behaviour and physical activity is particularly relevant for appropriate planning and implementation of intervention studies [11]. Sedentary behaviour typically takes place in regular prolonged bouts with infrequent breaks, typically in the evening and on weekends (for domestic sedentary behaviour such as TV viewing) and on weekdays (for occupational sedentary behaviour such as workplace sitting). It tends to be of long duration, in bouts of 2–3 h for TV viewing and 6–7 h for workplace sitting. It involves a low level of effort or conscious planning and is highly habitual. Important determinants include social norms and the physical environment, such as domestic and workplace furniture arrangements. By comparison, moderate-to-vigorous physical activity often takes place in irregular intervals of short duration, and it involves some level of effort and conscious planning. Determining factors include individual-level motivation and a supportive physical environment. Thus, while physical activity interventions typically place a focus on conscious decision making, sedentary behaviour interventions might benefit from focusing on unconscious decision-making [12]. Although interventions aimed at decreasing sedentary behaviour and those targeted at increasing physical activity both share a common objective of reducing the burden of chronic diseases in the population by promoting enhanced levels of physical activity, sedentary behaviour interventions focus on shifting a certain amount of participants' time spent sedentary to activities of light intensity, whereas physical activity interventions are designed to encourage study subjects to increase their amount of activities of moderate-to-vigorous intensity. More detail on the differences between sedentary behaviour and physical activity is provided in Sect. 14.2.

1.1.4 Summary

The current section provides a conceptual definition of sedentary behaviour, emphasising the distinction between sedentary behaviour (too much sitting) and physical inactivity (too little exercise). A high amount of sedentary behaviour may coexist with high levels of moderate-to-vigorous physical activity, and correlates of time spent sedentary are distinct from those related to moderate-to-vigorous physical activity. However, these two entities may nevertheless mutually impact upon each other in terms of their behavioural and biological effects. Acknowledging the divergent characteristics of sedentary behaviour and physical activity is particularly relevant for appropriate planning and implementation of intervention studies.

1.2 Human Evolution and Sedentary Behaviour

1.2.1 Introduction

Research on human sedentary behaviour is a relatively young scientific discipline. It evolved as a consequence of the increasing prevalence of sedentary behaviour—which, likewise, is a fairly new phenomenon. When considering the long evolutionary history of *Homo sapiens*, sedentary behaviour makes up only a small fraction of time. Even though sitting was prevalent among our early ancestors, it became an omnipresent mass phenomenon only in the past few centuries. Changes in our recent environment that are mainly due to advances in communication, media and entertainment technologies altered workplace settings, and passive modes of transportation now contribute to a predominantly sedentary lifestyle. This contrasts sharply with the lifestyle of our hunter-gatherer ancestors, whose activity patterns were driven by motivating factors such as hunger and thirst. The current section briefly describes sedentary behaviour from the viewpoint of human evolution and within the context of specific sociocultural aspects.

1.2.2 *An Evolutionary Perspective on Human Sedentary Behaviour*

How Sedentary Were Our Ancestors?

We do not know how sedentary our early ancestors really were. When searching the Internet and biomedical databases such as PubMed or Web of Science for ‘sedentary behavio(u)r’, ‘sedentariness’, ‘sitting’ or ‘sedentary’ in human history, these terms appear primarily in the context of sedentary versus mobile (population) groups. In contrast, the physical activity patterns of our ancestors are well understood. The following section briefly describes how and when sitting became an omnipresent mass phenomenon in Western societies. We take two perspectives: an evolutionary viewpoint and a sociocultural viewpoint.

A Brief Overview of Human Evolution: The Genus *Homo*

More than 1.8 million years ago, the genus *Homo* appeared in the East African Rift Valley [13]. In comparison with that early ancestor, the evolution of *Homo erectus* was characterised by a large increase in brain size, changes in anatomy which favoured hunting and long-distance running and the ability to make tools [13]. Although the sedentary behaviour of our ancestors is not well studied, we know that being physically active was crucial for their survival and that their body was therefore adapted to a high degree of physical activity. Several anatomic characteristics such as long legs, relatively small feet with short toes, long spring-like tendons and large gluteus maximus muscles provided stabilisation and enabled bipedalism [14]. Meeting basic needs such as hunger and thirst or reacting to threats such as danger were the principal motivating factors for members of the early *Homo* to be physically active. The evolution of *Homo sapiens* about 100,000 years ago was characterised by changes in social and cultural behaviour and improved locomotion. Thus, the life of our early ancestors during the Palaeolithic Era was characterised by a highly physically active lifestyle based on gathering and hunting, the use of tools and a predominantly mobile lifestyle. However, with beginning of the Neolithic Era about 10,000 years ago, human lifestyle changed substantially. Humans gave up their mobile lifestyle and began domesticating animals and plants to produce food. Although physical activity patterns changed and hunting was replaced by agricultural activities, it was still a predominantly physically active lifestyle.

The Industrial Revolution or the Origins of Sedentary Behaviour

Food acquisition and a physically active lifestyle were strongly linked until the end of the eighteenth century when the Industrial Revolution started. Technological developments and innovations dramatically changed the environment and the

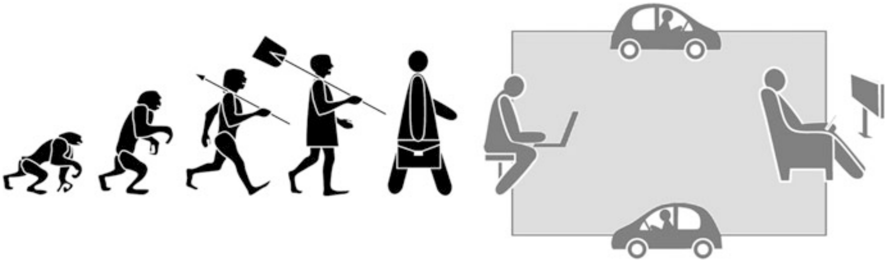

Fig. 1.1 The evolution of *Homo sedens*. *Homo erectus* replaced the quatripedal posture with an upright and bipedal locomotion. Modern *Homo sapiens* spends a large amount of his waking time in sedentary behaviours and increasingly becomes a *Homo sedens*. Figure from Simone Thiemer

ordinary lives of people. Machines replaced the tools that were previously used. The Industrial Revolution fundamentally changed the modes of manufacturing, transportation and communication and introduced mechanical power—all of which gave rise to an increasingly physically passive lifestyle and sedentary behaviour in all domains of human life. To give an example, nowadays we cannot imagine life without cars or computers. Nevertheless, the invention of the car took place less than 150 years ago, and modern digital computers have only been around for less than 100 years—a small fraction of the large time frame during which our human species developed. As outlined above, our body is designed to walk, to move and to be physically active, and it is not designed to sit—at least not for extended periods of time (Fig. 1.1).

1.2.3 Sociocultural Aspects of Human Sitting Behaviours

> Unruliness consists in independence of law. By discipline men are placed in subjection to the laws of mankind, and brought to feel their constraint. This, however, must be accomplished early. Children, for instance, are first sent to school, not so much with the object of their learning something, but rather that they may become used to sitting still and doing exactly as they are told. And this to the end that in later life they should not wish to put actually and instantly into practice anything that strikes them. Immanuel Kant, Kant on Education (1803)

The evolution of human sedentary behaviour should perhaps be considered in the context of specific sociocultural aspects rather than in the framework of biologically centred human evolution. Indeed, one may ask if sedentary behaviour is equally present across the entire life span of an individual and if it was equally present across human history. Chapter 2 highlights the descriptive epidemiology of sedentary behaviour in children and adolescents.

Even though the amount of time spent sedentary—especially screen-based media time—is large in children and adolescents, it is obvious that sitting time per day increases sharply when children enter school. When observing the natural behaviour of young children before they enter school, they are physically active and move about most of the time, and periods of sitting–for example, when playing on the ground—are frequently interrupted by short intervals of standing or walking. It is only during very short periods of time, when children engage and concentrate in playing games or reading, that they are able to sit without interruption. Prolonged sitting is present when children watch TV or when they are placed in child seats for transportation—activities which do not reflect the natural behaviour of children.

Thus, it can be questioned why sitting—and especially sitting quietly—is introduced as the predominant posture in schools (and subsequently in universities and workplaces) that needs to be adopted by all those attending a class, listening to a lecture or doing any other kind of concentrated work. From a sociocultural point of view, sitting on a chair (a) during defined periods of time, (b) with a predetermined spatial order of chairs and (c) relatively limited scope for the sitting posture represents some kind of institutional discipline and disciplining [15]. As we get older, we get more and more adapted to this kind of institutional sitting and mostly do not even question it. Certainly, the predominant acceptance without resistance of (institutional) sitting is reinforced by social norms and the omnipresence of chairs and other seats.

Nevertheless, sitting on seats is a relatively new habit when considering the long period of human evolution. Compared to a period of almost 2 million years of human evolution, the history of sitting comprises only the past 5000 years [16]. Prior to the French Revolution (1789–1799), sitting on chairs was primarily a privilege of aristocracy and clergy. People kneeled or crouched on the floor—a posture that is still present in young children and in many indigenous peoples as well as in people living in rural areas of several low- and middle-income countries. It was only since the early nineteenth century that sitting on chairs was secularised in Europe and became a social mass phenomenon which was continuously introduced into various aspects of peoples' lives. Since then, it was discussed how chairs and seats can be designed to be more comfortable and ergonomic. Their general use was no longer questioned.

Nowadays, workplaces (in the office, at home or elsewhere), conference rooms, classrooms, lecture halls, private homes, churches, cinemas, train and bus stations, waiting rooms, public and private transportation and many other areas of public and private use are hard to imagine without seats. Humans can work, talk, play, interact, think and even travel while sitting. According to Eickhoff, modern media and communication technologies allow people to be highly 'mobile' and to overcome sedentariness on a technological level while simultaneously being very sedentary on a physical level [16]. The COVID-19 pandemic serves as a current example that illustrates sociocultural aspects of human sedentary behaviours in a changing environment. Chapter 27 provides more information on the role of sedentary behaviour in public, global and planetary health. Thus, understanding the influence of sociocultural aspects on modern sitting behaviour is crucial for the successful development and implementation of sedentary behaviour recommendations. Changing social and cultural habits that are associated with sitting is essential for effectively reducing sedentary behaviour—for health.

1.2.4 Homo sapiens *or* Homo sedens*?*

Our recent environment has little in common with the environment in which our human species evolved during the course of the past millions of years. Western societies live in an environment that is characterised by urbanisation, passive forms of transportation, sedentary jobs and media and communication technologies that encourage a sedentary lifestyle. Most of us spend a vast majority of our waking hours in a seated position: we go to work by car or public transportation (hoping for a seat); at work we move our fingertips on a keyboard, but our body is still in a seated position; and after going home (by car again) we take a seat on the sofa and relax (Fig. 1.2). During the COVID-19 pandemic, the home setting became the workplace of many people, and new sedentary behaviour patterns emerged. Research data provides an overview of the prevalence of sitting time in several countries. For further details on the descriptive epidemiology of sedentary behaviour, please refer to Chap. 2.

Although the amount of time spent sitting varies across countries and population subgroups, it can be concluded that sitting is an omnipresent behaviour in modern society and that most individuals spend several hours per day in sedentary behaviours.

Fig. 1.2 Different domains of sedentary behaviour

1.2.5 Summary

Although we do not know how much daily time our ancestors spent sedentary, we can assume that it was less than we currently spend in sitting behaviours. From an evolutionary perspective, we can presume that our body is designed to move and to be physically active—it is not designed to sit. However, innovations in technology, transportation and other domains have enabled a more sedentary lifestyle, which is enhanced by sociocultural influences such as institutional sitting in schools and by global health risks such as the COVID-19 pandemic. Even though information on sedentary behaviour is not abundant, data show a high prevalence of sedentary behaviour across all age groups.

1.3 Recommendations on Sedentary Behaviour for Health

1.3.1 Introduction

Compared to the research area of physical activity, research on sedentary behaviour is a relatively new scientific field. However, as this book shows, there is increasing evidence that sedentary behaviour is associated with ill health and that reducing the amount of time an individual spends sedentary reduces the risk for adverse health outcomes. In order to address the existing evidence and to make sedentary behaviour a public health issue, several countries have provided recommendations on sedentary behaviour for health, either by incorporating them into their guidelines for physical activity or by issuing specific sedentary behaviour guidelines. Whereas most countries provide general recommendations to reduce sitting time, only few countries have quantified the maximum daily amount of time individuals should spend sedentary. The Guidelines on Physical Activity and Sedentary Behaviour published by the World Health Organization (WHO) in 2020 for the first time include recommendations on sedentary behaviour [17]. Table 1.2 provides an overview of existing recommendations on sedentary behaviour for health. This section aims at summarising those recommendations, discussing their shortcomings and emphasising the need for additional and more specific guidelines.

1.3.2 Importance of National and International Recommendations on Sedentary Behaviour for Public Health

The main aim of sedentary behaviour recommendations is the primary prevention of health outcomes that are associated with sedentary behaviour. The high prevalence of sedentary behaviour (as described in Chap. 2) and its public health significance

Table 1.2 Existing recommendations on sedentary behaviour for health

Country/region	Age group	Recommendation	Institution and type of document	References	Comments
Australia	0–5	Infants (0–1 year) – Should not be restrained for more than 1 h at a time (such as in a stroller, car seat or high chair) – Should not have any screen time – Should choose educational activities while inactive—like reading, telling a story, singing, painting or doing craft Toddlers (1–2 years) – Should not be restrained for more than 1 h at a time (such as in a stroller, car seat or high chair) – Should limit the time they spend sitting or lying down – Should not be allowed any sedentary screen time – Should choose educational activities while inactive—like reading, telling a story, singing, doing a puzzle, using building blocks, painting or doing craft Preschoolers (3–5 years) – Should not be restrained for more than 1 h at a time (such as in a stroller, car seat or high chair) – Should limit the time they spend sitting or lying down – Should not be allowed any more than 1 h of sedentary screen time per day—less is better	Australian government (Department of Health): 'Physical activity and exercise guidelines for all Australians'	[18]	

		– Should choose educational activities while inactive—like reading, telling a story, singing, doing a puzzle, using building blocks, painting or doing craft			
	5–17	Limit the time spent sitting or lying down—especially in front of screens. Sedentary recreational screen time should be limited to a maximum of 2 h/day. This does not include screen time needed for school It is recommended to break up long periods of sitting as often as possible			
	18–64	Reduce the time spent sitting—for example, by organising walking meetings, using a standing desk or enjoying a walk during your lunch break Break up long periods of sitting—for example, by doing lunges or star jumps or walking around when on the phone			
	Pregnancy	Reduce the time you spend sitting Break up long periods of sitting or standing still			
	≥65	Try to reduce the time you spend sitting down—break that time up as often as you can			

(continued)

Table 1.2 (continued)

Country/region	Age group	Recommendation	Institution and type of document	References	Comments
Austria	All ages	*Break up sedentary periods lasting longer than 60 min* with short bouts of physical activity	Ministry of Health and Gesundheit Österreich GmbH and Fonds Gesundes Österreich: Austrian recommendations for health-enhancing physical activity	[19]	
Canada	0–5	Infants (0–1 year) – Not being restrained for more than 1 h at a time (e.g. in a stroller or high chair) – Screen time is not recommended – When sedentary, engaging in pursuits such as reading and storytelling with a caregiver is encouraged Toddlers (1–2 years) – Not being restrained for more than 1 h at a time (e.g. in a stroller or high chair) or sitting for extended periods – For those younger than 2 years, sedentary screen time is not recommended. For those aged 2 years, sedentary screen time should be no more than 1 h—less is better – When sedentary, engaging in pursuits such as reading and storytelling with a caregiver is encouraged Preschoolers (3–4 years) – Not being restrained for more than 1 h at a time (e.g. in a stroller or car seat) or	Canadian Society for Exercise Physiology (CSEP) 'Canadian 24-Hour Movement Guidelines: An Integration of Physical Activity, Sedentary Behaviour, and Sleep'	[20]	Guidelines include recommendations for physical activity, sedentary behaviour and sleep

		sitting for extended periods – Sedentary screen time should be no more than 1 h—less is better – When sedentary, engaging in pursuits such as reading and storytelling with a caregiver is encouraged			
	5–17	Limit recreational screen time to *no more than 2 h/day* Limited sitting for extended periods			
	18–64	Limiting sedentary time to 8 h or less, which includes limit recreational screen time to *no more than 3 h/day* *Break up long sedentary periods as often as possible*			
	≥65	Limiting sedentary time to 8 h or less, which includes limit recreational screen time to *no more than 3 h/day* *Break up long sedentary periods as often as possible*			
Germany	0–18	Limit the time children and adolescents spend being sedentary (especially during transport and screen time): 0–3 years: *0 min* 4–6 years: *30 min/d* (*maximum*) 6–11 years: *60 min/d* (*maximum*) 12–18 years: *120 min/d* (*maximum*)	National recommendations based on expert consensus: 'Nationale Empfehlungen für Bewegung und Bewegungsförderung'	[21]	Specific and quantified sedentary behaviour guidelines only for children and adolescents
	18–65	Avoid periods of prolonged sitting. Break up sedentary periods with doing some physical activity			
	≥65	Avoid periods of prolonged sitting. Break up sedentary periods with doing some physical activity			

(continued)

Table 1.2 (continued)

Country/region	Age group	Recommendation	Institution and type of document	References	Comments
Hong Kong	Children and students	Spend less time on passive activities such as electronic games, web surfing and karaoke Reduce screen time	Department of Health: 'Healthy Exercise for All Campaign'	[22, 23]	Campaign, no official recommendation
	Women	Do stretching exercise while watching TV			
	Elderly	Do muscle training or balancing exercises when watching TV			
	Adults (at workplace)	When sitting for prolonged periods, do more mobility and stretching exercises. Take the stairs instead of using the escalator	Department of Health: 'Mobility and Stretching in the Workplace'	[24]	
Ireland	0–5	Children should *not be sedentary for more than 1 h at a time* except when sleeping	National Association for Sport and Physical Education: 'Factsheet for childcare providers'	[25]	'The National Guidelines on Physical Activity for Ireland' [26] do not include recommendations on sedentary behaviour
Japan	18–64 and 65 or older	Stay active during TV time Do not keep your body inactive Reduce your sitting time	Ministry of Health, Labour and Welfare: 'Japanese official physical activity guidelines for health promotion'	[27]	

Korea	All age groups	Reduce the amount of time spent sitting Limit the amount of time watching television to *less than 2 h/day*	Ministry of Health and Welfare: 'The Physical Activity Guide for Koreans'	[28]	
	Patients in primary care	Move as much as possible and avoid sedentary activities	Korean Journal of Family Medicine: 'An Overview of Current Physical Activity Recommendations in Primary Care'	[29]	
New Zealand	5–17	Spend less than 2 h/day of recreational screen time Sit less, move more—break up sitting time	Ministry of Health: website recommendations	[30]	'Eating and Activity Guideline Series'
	Adults	Sit less, move more! Break up long periods of sitting *Break up sitting time* throughout the day for *at least a few minutes every hour*, preferably more frequently Limit the time spent sitting in front of a screen gives more time for physical activity	Ministry of Health: 'Eating and Activity Guidelines for New Zealand Adults'	[30, 31]	
	≥65	Limit sedentary behaviour	Ministry of Health: 'Guidelines on Physical Activity for Older People (aged 65 years and over)'	[30, 32]	Explicitly also applies to elderly frail people

(continued)

Table 1.2 (continued)

Country/region	Age group	Recommendation	Institution and type of document	References	Comments
Nordic cooperation (including Denmark, Finland, Iceland, Norway, Sweden and the Faroe Islands, Greenland and Åland	All ages	Reduce sedentary behaviour	Nordic Council of Ministers: 'Nordic Nutrition Recommendations: Integrating nutrition and physical activity'	[33]	
Qatar	0–5	Reduce the total amount of time spent sitting during waking hours and take regular breaks (e.g. every 20–30 min) from sitting Limit long periods of sitting, by moving more and integrating physical activity in the child's everyday routines Limit screen time (electronic games, computer and TV) to less than an hour a day, for 2–4 years. Screen time is not advisable for children under 2	Aspetar Orthopaedic and Sports Medicine Hospital: 'National Physical Activity Guidelines second Edition' 2021	[34]	No sedentary behaviour recommendations for healthy adults
	5–17	Reduce the total amount of time spent sitting during waking hours and take regular breaks (e.g. every 20–30 min) from sitting Reduce sedentary time (sitting or lying down) while awake Limit screen time (electronic games, computer and television) to less than an hour a day, for 5–6 years old, and less than 2 h a day for 7 years old and above Limit long periods of sitting, by moving more and integrating physical activity in the child's everyday routines			

	Adults with medical conditions (obesity, diabetes, hypertension, asthma, heart diseases)	Reduce the total amount of time spent sitting during waking hours and take regular breaks (e.g. every 20–30 min) from sitting Make physical activity a daily habit to reduce your sitting time (using stairs, active commuting, standing meetings and phone calls, parking car further away) Take regular activity breaks from looking at a screen (standing, walking, bodyweight resistance exercises such as lunges, knee raises, squats)			
	Children with medical conditions (obesity, diabetes mellitus type 1, respiratory disorders, mental health disorders, Down syndrome)	Reduce the total amount of time spent sitting during waking hours and to also take regular breaks (e.g. every 20–30 min) from sitting Reduce sedentary time (sitting or lying) while awake Limit screen time (electronic games, computer and TV) to less than an hour a day, for 5–6 years old, and less than 2 h a day for 7 years old and above Limit long periods of sitting, by moving more and integrating physical activity in the child's everyday routines			
	Preconception and pregnant women	Avoid prolonged sitting, laying or motionless standing			

(continued)

Table 1.2 (continued)

Country/region	Age group	Recommendation	Institution and type of document	References	Comments
Singapore	Children and adolescents	Periods of sedentary behaviour and recreational screen time should be kept to a minimum. These periods can be improved by setting boundaries (e.g., duration) or interrupted with regular breaks for physical activity	'Singapore Integrated 24-h activity Guidelines' 01/2021	[35]	
	19–49 and ≥50	*Break up sedentary periods lasting longer than 90 min with 5 to 10 min of standing*, moving around or doing some physical activity Walking to run errands *instead of driving* or riding	Heath Promotion Board (Singapore Government): 'National Physical Activity Guidelines'	[36]	
Spain	0–5	Minimise the amount of time spent being sedentary (sitting) during waking hours to *less than 1 h at a time* Screen time <2 years: *screen time is not recommended* 2–4 years: screen time should be limited to *less than 1 h/day*	Government of Spain: 'Actividad física para la salud y reducción del sedentarismo: recomendaciones para la población'	[37]	Document available only in Spanish language. Recommendations for adults explicitly include pregnant and post-partum women (in the absence of any contraindications)
	5–17	Minimise the amount of time spent being sedentary (sitting) for extended periods Reduce periods of prolonged sitting Encourage active transport and outdoor activities Limit recreational screen time to *no more than 2 h/day*			
	Adults and older adults	Reduce periods of prolonged sitting to *no more than 2 h at a time* Encourage active transport Limit screen time (e.g. TV, tablets)			

Sweden	Adults	Prolonged sitting should be avoided. Regular short breaks with any kind of muscle activity for a few minutes is recommended for those who have sedentary work or spend a lot of time sitting during leisure time. This also applies to those who meet the recommendations for physical activity	Swedish Society of Medicine: 'Recommendations on physical activity for adults'	[38]	Document available only in Swedish language
Switzerland	Children and young people	If possible, avoid long-lasting activities without physical activity and interrupt them after 2 h with active breaks	Bundesamt für Sport: 'Gesundheitswirksame Bewegung bei Kindern und Jugendlichen/ Erwachsenen/älteren Erwachsenen: Empfehlungen für die Schweiz'	[39]	Documents available only in Germany language
	Adults	Prolonged sitting should be interrupted frequently Avoid inactivity.		[40]	
	Older adults	Prolonged sitting should be interrupted frequently Avoid inactivity		[41]	
Turkey	<2	Computer and TV use, etc. are not recommended	Ministry of Health: 'Physical Activity Guidelines for Turkey'	[42]	
	2–5	It is not recommended for children to stay sedentary for a long period of time Screen time (TV viewing, computer use, etc.) of *more than 20 min* (*without interruption*) *or a total of 1 h/day* is not recommended			
	5–18	Recreational screen time should be limited to *no more than 2 h/day*			

(continued)

Table 1.2 (continued)

Country/region	Age group	Recommendation	Institution and type of document	References	Comments
United Kingdom	<5	No explicit recommendations regarding sedentary behaviour	UK Chief Medical Officers' Physical Activity Guidelines 2019	[43]	
	5–18	Children and young people should aim to minimise the amount of time spent being sedentary and when physically possible should break up long periods of not moving with at least light physical activity			
	19–64	Adults should aim to minimise the amount of time spent being sedentary and when physically possible should break up long periods of inactivity with at least light physical activity			
	≥65	Older adults should break up prolonged periods of being sedentary with light activity when physically possible or at least with standing, as this has distinct health benefits for older people			
United States	Children	Limit children's total media time (with entertainment media) to *no more than 1 to 2 h/day* of quality programming	American Academy of Pediatrics: 'Children, Adolescents, and Television'	[44]	Quantified sedentary behaviour time First recommendation that set a time limit on the amount of total media time for children and adolescents
	Children and adolescents	Replace sedentary behaviour with activity whenever possible	US Department of Health and Human	[45]	

	Adults	Adults should move more and sit less throughout the day	Services: 'Physical Activity Guidelines for Americans second edition'		
	At workplace	Stand or move around every 30 min (or as needed) Stand while talking on the phone Hold walking meetings	National Institute for Occupation- al Safety and Health (NIOSH) 2017: 'Workplace Solutions'	[46]	
WHO Western Pacific Region	18–65	Reduce sedentary activities	'Pacific Physical Activity Guidelines for Adults'	[47]	
WHO guidelines for children under 5 years of age	<1 year	Infants should not be restrained for more than 1 h at a time (e.g. in prams/strollers, high chairs or strapped on a caregiver's back). Screen time is not recommended When sedentary, engaging in reading and storytelling with a caregiver is encouraged	WHO 'Guidelines on physical activity and sedentary behaviour for children under 5 years of age'	[48]	
	1–2	Children (1–2 years) should not be restrained for more than 1 h at a time (e.g. in prams/strollers, high chairs or strapped on a caregiver's back) or sit for extended periods of time. For 1 year olds, sedentary screen time (such as watching TV or videos, playing computer games) is not recommended. For those aged 2 years, sedentary screen time should be no more than 1 h; less is better. When sedentary, engaging in reading and storytelling with a caregiver is encouraged			

(continued)

Table 1.2 (continued)

Country/region	Age group	Recommendation	Institution and type of document	References	Comments
	3–4	Children (3–4 years) should not be restrained for more than 1 h at a time (e.g. in prams/strollers) or sit for extended periods of time. Sedentary screen time should be no more than 1 h; less is better. When sedentary, engaging in reading and storytelling with a caregiver is encouraged			
WHO Guidelines 2020	Children and Adolescents (5–17 years)	Children and adolescents should limit the amount of time spent being sedentary, particularly the amount of recreational screen time	WHO 'Guidelines on physical activity and sedentary behaviour'	[17]	
	Adults (18–64 years)	Adults should limit the amount of time spent being sedentary. Replacing sedentary time with physical activity of any intensity (including light intensity) provides health benefits			
	Older adults (≥65 years)	Older adults should limit the amount of time spent being sedentary Replacing sedentary time with physical activity of any intensity (including light intensity) provides health benefits			
	Pregnant and postpartum women	Pregnant and postpartum women should limit the amount of time spent being sedentary. Replacing sedentary time with physical activity of any intensity (including light intensity) provides health benefits			

	Adults and older adults with chronic conditions (≥18 years)	Adults and older adults with chronic conditions should limit the amount of time spent being sedentary. Replacing sedentary time with physical activity of any intensity (including light intensity) provides health benefits			
	Children and adolescents (5–17 years) and adults (≥18 years) living with disability	Children and adolescents living with disability should limit the amount of time spent being sedentary, particularly the amount of recreational screen time Adults and older adults with chronic conditions should limit the amount of time spent being sedentary. Replacing sedentary time with physical activity of any intensity (including light intensity) provides health benefits			
International	Children and youth aged ~5–18 years	Breaking up periods of extended sedentary behaviour with both scheduled and unscheduled movement breaks of varying intensities and durations (at least once every 30 min for ages 5–11 years; at least once every hour for ages 12–18 years) Limiting sedentary homework to no more than 10 min/day, per grade level Limiting school-related screen time Replacing sedentary learning activities with movement-based learning activities (including standing) and replacing screen-based learning activities with non-screen-based learning activities (e.g. outdoor lessons)	International school-related sedentary behaviour recommendations for children and youth	[49]	Specific recommendations regarding school-related sedentary behaviours (i.e. sedentary behaviours performed during the school day, or within the influence of school)

requires a population-based approach to decrease levels of sedentary behaviour. The development, dissemination and implementation of national and international guidelines on sedentary behaviour for health are essential for reducing the amount of time spent sedentary in the population. Goals and aims of sedentary behaviour recommendations are listed in Box 1.1.

Box 1.1 Goals and Aims of Sedentary Behaviour Recommendations
The development, dissemination and implementation of sedentary behaviour recommendations are as follows:

- Provide an evidence-based document with public health relevance
- Increase the proportion of health professionals, policymakers and other relevant stakeholders who are aware of the recommendations
- Inform national policies and other public health interventions targeting sedentary behaviour
- Lead to a strategy for intersectoral collaboration and joint action including all relevant stakeholders (such as policymakers, health professionals, the media, etc.)
- Lead to the development of programmes and interventions targeting sedentary behaviour at the individual level
- Lead to the development of programmes and policies targeting sedentary behaviour at the community level, the social and physical environmental level and the policy level
- Justify the allocation of resources to interventions targeting sedentary behaviour
- Lead to a decreased prevalence of sedentary behaviour
- Provide a standard for (national) surveillance to monitor population levels of sedentary behaviour
- Provide a foundation for future research

1.3.3 Historical Outline: From Screen Time Limits to Recommendations on Sedentary Behaviour

The American Academy of Pediatrics (AAP) in 1984 was one of the first organisations to provide recommendations aimed at reducing childrens' TV time [50]. The Committee on Communications recommended that 'paediatricians should advise parents to limit their children's television viewing to 1–2 h per day'. In 2001, the Committee on Public Education of the AAP provided an update of that recommendation [44]. Paediatricians should advise parents to limit their children's total media time to no more than 1–2 h per day and to avoid TV viewing in children <2 years of age.

These recommendations were made in order to reduce the potential adverse effects of TV such as ‘violent and aggressive behaviour, obesity, poor body concept and self-image, substance use, and early sexual activity’ and not with the primary aim of reducing the adverse health outcomes that are associated with prolonged sitting time—as research in this field was still in its infancy. Since 2000, research on sedentary behaviour increased, and its association with health-related outcomes was investigated in a large number of observational and intervention studies (for more details, please refer to Chap. 2).

Increased knowledge about the high prevalence of sedentary behaviour and its adverse relationship with health outcomes led countries such as Canada and Australia to initiate a guideline development process. In 2009, the Physical Activity Guidelines International Consensus Conference in Kananaskis, Alberta, Canada, decided to develop a guideline for the ‘gap’ area of sedentary behaviour for children and young people [51]. The guideline development process was based on evidence from a systematic review of the association between sedentary behaviour and health indicators in school-aged children and youth [52]. A widely accepted instrument for guideline development, the Appraisal of Guidelines for Research Evaluation (AGREE) II [53], was used as a framework for the development of the Canadian Sedentary Behaviour Guidelines for Children and Youth. Following a guideline development process of 2 years and the involvement of various stakeholders (including scientists, guideline developers and potential guideline users), the guidelines were released in February 2011 [51].

A similar guideline development process was conducted in Australia, which was based on a ‘systematic review to inform the Australian sedentary behaviour guidelines for children and young people’ by a group of researchers that used the AGREE II instrument for the guideline development process, resulting in the release of the Australian sedentary behaviour guidelines [54].

Box 1.2 The Appraisal of Guidelines for Research Evaluation (AGREE) [53, 55]

The AGREE instrument was developed and validated in 2003 by the AGREE collaboration, an international group of scientists, to provide a generic instrument to ‘assess the process of guideline development and how well this process is reported’ [55]. The original AGREE instrument comprised 23 items in the following 6 quality-related domains:

- Domain 1: Scope and purpose (three items)
- Domain 2: Stakeholder involvement (four items)
- Domain 3: Rigour of development (seven items)
- Domain 4: Clarity and presentation (four items)
- Domain 5: Applicability (three items)
- Domain 6: Editorial independence (two items)

1.3.4 Guideline Development Process

For a comprehensive guideline development process, several stages need to be completed (Fig. 1.3). The formulation of clear and targeted research questions is crucial for successful guideline development. The following questions need to be asked: (a) Is the guideline for primary/secondary/tertiary prevention? (b) Who is the target population of the recommendations (children, young people, adults, older adults, etc.)? (c) Will the guidelines include recommendations for specific population subgroups (such as persons with preexisting disease or disability, ethnic minorities or immigrants, etc.)? (d) Who are the target users (policymakers, practitioners, parents, caregivers, etc.)?

A systematic review of the literature on the existing evidence regarding the relationship between sedentary behaviour and health outcomes needs to be conducted by an interdisciplinary team of researchers and guideline developers. Consecutively, findings of existing literature are summarised and interpreted, and an evidence-informed draft of sedentary behaviour recommendations is developed. Furthermore, research gaps identified during the literature review and resulting strengths and limitations of the draft recommendations should be provided. Key stakeholders, including sedentary behaviour researchers, medical practitioners, public health organisations, governments and others, should be consulted to review the recommendations. Finally, guideline finalisation should be based on consensus between all stakeholders involved. Obviously, the final guidelines need to be comprehensible for the target users, and often knowledge needs to be translated into practicable and clear guidelines. Subsequently, guidelines have to be communicated, disseminated and implemented and evaluated. Therefore, well-prepared strategies for communication and dissemination—developed with the collaboration of marketing, media and communication experts—are crucial. Both the guideline

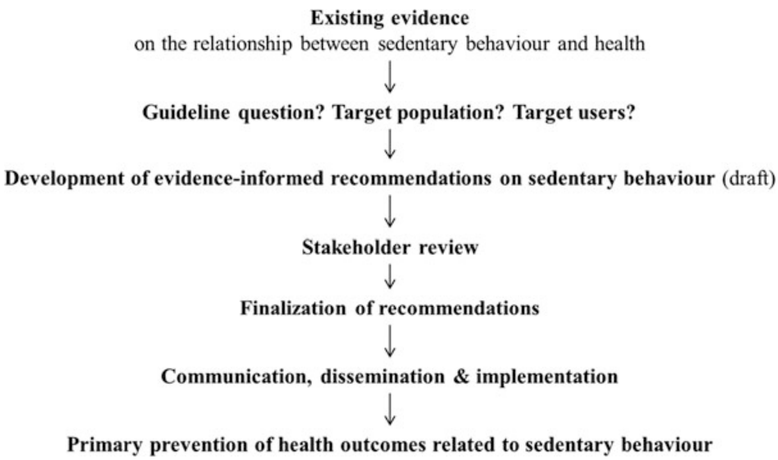

Fig. 1.3 Main steps of the guideline development process

development process and the implementation of guidelines need to be evaluated periodically. The overall guideline development process takes approximately 2 years.

1.3.5 Recommendations on Sedentary Behaviour for Health

The WHO Guidelines on Physical Activity and Sedentary Behaviour

The most recent WHO Guidelines on Physical Activity and Sedentary Behaviour were published in 2020, and they provide evidence-based recommendations regarding sedentary behaviour for all age groups (i.e. children, adolescents, adults and older adults), and for population subgroups, such as pregnant and postpartum women and people living with chronic conditions or disability [17]. The general recommendation to 'limit the amount of time spent being sedentary' is provided for all age groups and all subpopulations. Children and adolescents (including those living with disability) should particularly limit the amount of recreational screen time. Adults and older adults (including those living with disability or with chronic conditions) and pregnant and postpartum women should 'replace sedentary time with physical activity of any intensity (including light intensity)'. Furthermore, adults and older adults (including those living with disability or with chronic conditions) 'should aim to do more than the recommended levels of moderate-to-vigorous physical activity'. Table 1.2 provides more detailed WHO recommendations for all age groups as well as a summary of existing national guidelines on sedentary behaviours. Table 1.3 summarises practical advice on how to reduce sedentary behaviour in different age groups and in different domains such as work or leisure time (Fig. 1.4).

General Recommendations on Sedentary Behaviour

Most countries and organisations that provide recommendations on sedentary behaviour issue nonspecific guidelines. Those countries and institutions include Hong Kong [22, 23], Japan [27], the Nordic cooperation [33], Sweden [38], Switzerland [39, 41, 64], the UK [56], the WHO [17] and the WHO of the Western Pacific Region [47], among others. They recommend reducing or minimising the amount of time spent sedentary or frequently interrupting periods of prolonged sitting. Table 1.3 summarises practical tips that are part of recommendations on sedentary behaviour.

Table 1.3 Practical tips on how to reduce sedentary behaviour

Age group	How to reduce... Sedentary behaviour (sitting time)	Screen time	Sitting during transport
Children and young people	• Limit the use of baby seats, strollers and high chairs during waking hours [18, 56, 57]	• Make mealtimes family times and turn off the TV [58, 59] • Switch off the TV after a programme has finished [59] • Define rules and set limits around screen time [57, 59] • Make the children's room a zone free of TVs and computers [57, 58] • Reward children with outdoor activities instead of screen time [58] • Give presents that can be used for active play (such as skipping ropes, balls) [58] • Set an alarm on the computer as a reminder for regular standing up [60] • Stand up and move during watching TV [60] • Meet friends in person instead of online [60] • Play active family games instead of video games [57] • Choose educational activities while inactive—like reading, telling a story, singing, painting or doing craft [18]	• Interrupt long car trips and take a break at a park or rest area for active play [57, 59] • Let children walk instead of moving them all the way with the pushchair [59] • Let children walk or cycle or use the skateboard or the scooter [59]
	Occupational sitting	Screen time	Sitting during transport
Adults	• Stand up whenever possible [61] • Visit your colleagues to deliver a message instead of emailing and phoning them [23, 62] • Use a standing desk [18] • Stand up for phone conversations [61] • Prefer 'walk and talk' meetings instead of sit down meetings [62] • Enjoy a walk during lunch break [18] • Stand up for reading [63] • Stand up when you drink	• Switch off the TV during the day and get out in the garden [62] • Set an alarm on the computer as a reminder for regular standing up [62] • Meet your friends for a walk instead of sitting to chat [62] • Instead of using the remote control, get up and change the channel on the TV [63] • During TV time, do	• Go by bicycle or walk instead of taking the car or bus—at least for part of the way [23, 27, 56, 62] • Park the car further away [34]

(continued)

Table 1.3 (continued)

	Occupational sitting	Screen time	Sitting during transport
	water [61] • Place your rubbish bin at the other end of the office and get up to go there [63]	muscle training and stretching [27]	
Older adults		Screen time	
		• During TV time, do muscle training or balancing exercises [23]	

Fig. 1.4 Examples of how to reduce sedentary behaviour

Specific Recommendations on Sedentary Behaviour

Several guidelines (including those from the WHO, Australia and Canada) provide specific recommendations on sedentary behaviour by quantifying the amount of time children and young people should spend sedentary, as well as the maximum amount of screen time per day [17, 18, 20, 48]. Parents and caregivers are provided with information on how to reduce sitting time and screen time of their children, such as setting 'no screen time' rules at specific periods of the day or making the children's bedroom a screen-free zone. Tips on active transportation and suggestions on how to reduce sitting time in children and adolescents are given. In addition, the 'international school-related sedentary behaviour recommendations for children and youth' provide setting-specific recommendations for a healthy school day and target all sedentary behaviours performed during the school day, or within the influence of school [49]. For adults, however, recommendations are more general, and it is recommended to reduce sitting time and to interrupt prolonged sitting. Only the Canadian 24-h Movement Guidelines further specify the recommendations for adults and older adults and recommend 'limiting sedentary time to 8 h or less, which includes: limit[ing] recreational screen time to no more than 3 h/day, and break[ing] up long sedentary periods as often as possible' [20].

Other countries and institutions that currently provide quantified recommendations on the maximum amount of screen time and time spent sedentary are Austria [18], Germany [21], New Zealand [30, 31], Qatar [34], Singapore [35], Spain [37], Turkey [42] and the American Academy of Pediatrics [44] as well as the US Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents [45].

In sum, quantified recommendations are largely consistent in recommending that screen time in children and young people should be less than 2 h per day. Furthermore, there is consistency that screen time for children aged <2 years is not recommended at all [37, 57, 59, 65, 66]. However, specific recommendations for adults, older adults and people with disabilities and chronic conditions are still sparse.

Dynamic Sitting and Sit-Stand Dynamic

Certain circumstances require sitting for reasons of safety (e.g. travelling by car or plane), interaction with other people (e.g. during conferences), interior design limitations (e.g. only conventional office equipment available) or physiological constraints (e.g. fatigue). In such instances, sitting should take place in a posture that corresponds to the physiologic curvature of the spine [67]; it should be limited to 20–30 minute bouts, alternated with standing or (light) physical activity [68]; and it should be dynamic. Dynamic sitting is defined as changing your sitting position or posture as frequently as possible. It includes neck rolls (dropping your chin to your chest and rotating your head clockwise several times, then counterclockwise), neck stretches (placing your left hand on the top of your head and gently pulling to the left, then repeating on the right side), shoulder rolls (rolling your shoulders forward several times, then reversing the motion), pelvis rolls (tilting your pelvis to the front and back as well as circling your hips), body weight shifting (shifting the weight of your body from right to left and from front to back), calf raises (raising your heels off the floor until you are on the tips of your toes), ankle rolls (lifting your feet off the ground and rotating your feet at the ankles clockwise, then counterclockwise), toe raises (raising your toes as high as possible while keeping your heels on the floor) and carrying out conscious breathing and relaxation techniques. Even minor movement of the hands or feet such as fidgeting have been shown to reduce the increased risk of mortality associated with prolonged sedentary behaviour [69].

While individually adjusted office chairs with flexible backrest and synchro tilt mechanism that tilts the seat backwards parallel to reclining can facilitate dynamic sitting and provide support, relief and stability, there is no such thing as an ergonomically perfect office chair, and no posture is perfectly appropriate for prolonged sitting [67, 70]. Instead, frequent postural changes (i.e. alternating between dynamic standing and dynamic sitting two to three times per hour) as well as light physical activity (e.g. walking) should be integrated into the daily work routine [71]. Ultimately, the goal for a normal work day is to sit approximately 50% of the time, to stand about 25% of the time and move around about 25% of the time [71]. Some experts recommend further increasing the time spent standing to between 4 h and the entire work day, but that requires a transition period of several weeks [68, 71]. To prevent adverse health outcomes such as low back pain, leg swelling, mental and physical fatigue and varicose veins, prolonged static standing should be avoided as well [72]. By comparison, standing at work that is interrupted by sitting and walking does not cause lower back pain [73].

One useful structural feature to promote a sit-stand dynamic is a height-adjustable desk [72]. An optimal height-adjustable workstation should be adapted to the biomechanics of the individual body. The height of the sit-stand desk should be adjusted such that the forearms held parallel to the floor (at an angle between the upper and lower arm ≥90 degrees) are at the same height as the desk top or keyboard rest. When using a laptop, an external keyboard and an external screen allows the setup to be individualised to a body's individual requirements [68]. If the height-adjustable desk lacks an integrated footrest, a stool footrest should be used because it allows positioning 1 foot higher than the other, thereby reducing the strain on the lumbar spine [74]. A footrest also enables alternating between different standing positions, which should be spaced 2–3 min apart. An elastic mat which allows small movements of the feet but still provides stability (the so-called antifatigue mat) and a backrest to lean against complete the sit-stand workstation [68]. Basic desk attachments or standing desks represent less costly alternatives to height-adjustable sit-stand desks. However, simply making structural changes to office equipment is not sufficient to ensure physiologically correct sitting and needs to be accompanied by, e.g. behavioural interventions, including back exercises, educational materials and counselling sessions [75]. Awareness of the benefits of physiologically correct sitting needs to be established widely across all organisational levels of an institution so that employees may support one another and feel unrestrained to engage in physiologically correct sitting without fear of disapproval from their superiors or colleagues. Until physiologically correct sitting behaviour is internalised, it is helpful to create reminders to stand up via apps, post-it notes or colleagues [68, 75].

If sit-stand desks are not available, there are other options to organise the daily work routine in a physically more active way. Instead of writing an email to a colleague, one can visit them at their office next door. Even small meetings can be easily conducted while standing or taking a short walk [75]. A health-promoting environment can be implemented in the office as well as in the home office.

Specifically, the workplace can be designed such that not all materials can be reached from a sitting position, but instead, that physical movement is needed to access the printer, use the coffee machine or reach the waste paper basket. Certain tasks such as making phone calls can be done standing up without the use of special equipment. The most promising interventions to reduce sitting time in terms of transferability to the home office setting include education materials (e.g. advice on how to reduce sedentary behaviour), role models (e.g. team leaders who exemplify and support the behaviour), incentives (e.g. self-delivered rewards) and recurring prompts (e.g. text messages with reminders to move) [76]. Examples of setting up a healthy home workplace at low cost also include do-it-yourself standing desks (e.g. placing pedestals under the desk, placing platforms on the desk or even using ironing boards) [68, 77].

For relaxation purposes, a seated position is normal as it requires less energy than standing or moving around [67]. Such relaxed sitting, for example, in a reclining chair, requires no muscular action to stabilise the spine [68]. However, an optimal reclining chair should ensure a physiologic body position. This includes a headrest to stabilise the head in a neutral position and a backrest to allow for a natural spinal curvature. While watching TV or videos, sitting in a cross-legged fashion or in a lotus position promotes lower body flexibility, opens the hips and stabilises the spine [68]. As in the workplace, sedentary behaviour during leisure time should be limited and alternated with standing and physical activity. While driving a car, regular breaks provide necessary interruptions from sitting. On trains or planes, light exercises while sitting and regular standing up and moving around prevent uninterrupted sitting bouts. After travelling in passive transportation, one should engage in 10–15 min of light exercise [68].

In summary, both uninterrupted sitting and prolonged static standing are related to adverse health outcomes. There is no such thing as the perfect ergonomic sitting device or the perfectly physiologically correct sitting posture. However, physiologically correct sitting can be supported by ergonomically designed office furniture and a physically dynamic workflow. Notwithstanding, overall sitting should be kept to a minimum and interspersed with standing and movement, with the goal of reducing the proportion of sedentary behaviour and to increase the proportion of physical activity of any intensity.

1.3.6 From Recommendations to Action: Implementing Guidelines into Practice

The goals of sedentary behaviour recommendations—summarised in Box 1.2—are of public health importance. However, in reality, effective dissemination and implementation of guidelines often faces several barriers. After the release of the Canadian physical activity and sedentary behaviour guidelines in 2012 [57], a study was conducted to 'examine the awareness of, agreement with and use of the new [..]

guidelines for children and youth zero to 17 years of age among a sample of Canadian paediatricians' [78]. The study showed that only 5% of 331 paediatricians reported being 'very familiar' with the sedentary behaviour guidelines. Twenty-seven percent and 32% of paediatricians reported being 'somewhat familiar' with the guidelines for the early years (0–4 years) and children/youth (5–17 years), respectively. The majority reported being 'a little familiar' or 'not at all familiar' with the guidelines. When made aware of the guidelines, the vast majority of the study sample reported that they 'strongly agreed' (69%) or 'agreed' (26–28%) with the sedentary behaviour recommendations. Of the paediatricians who performed well-child visits, approximately two-thirds reported providing sedentary behaviour recommendations to parents, caregivers or children 'almost always' or 'often'. The barriers for recommending the guidelines to parents, caregivers or youth during a well-child visit included insufficient motivation; inadequate support from parents, caregivers or youth; and lack of time [78]. This study reflects the importance of increasing the awareness of paediatricians and medical practitioners of other disciplines for (a) the existing evidence on the association between sedentary behaviour and health; (b) the existing guidelines targeting sedentary behaviour; and (c) the consecutive use of the guidelines for counselling and promoting them to individuals of all ages. Practitioners should educate their patients about the potential health risks associated with sedentary behaviour and provide specific strategies on how sedentary behaviour can be limited and interrupted in different settings and in different age groups (Table 1.3). Furthermore, it is crucial to overcome perceived and existing barriers in practitioners. Please refer to Chap. 25 for more detailed information on how sedentary behaviour can effectively be targeted at the policy level.

1.3.7 Progress Regarding Sedentary Behaviour Guidelines

The Global Recommendations on Physical Activity for Health published by the WHO in 2010 [3] provided age-specific recommendations for the duration, intensity and frequency of physical activity, but did not include recommendations on reducing sedentary behaviour. That limitation was overcome by the publication of the WHO Guidelines on Physical Activity and Sedentary Behaviour in 2020 [17]. For the first time, the WHO Guidelines include recommendations on the associations between sedentary behaviour and health outcomes. This is an important step for acknowledging the global relevance of sedentary behaviour. The current WHO Guidelines may thus inform policymakers in low-, middle- and high-income countries. Furthermore, the WHO Guidelines provide recommendations for people of all age groups, as well as for population subgroups, such as pregnant and postpartum women and people living with chronic conditions or disability.

1.3.8 Limitations of Existing Guidelines and Future Needs

Despite progress regarding the development and publication of sedentary behaviour guidelines, there are a number of limitations concerning the guideline development process, the guidelines themselves and their implementation. The guideline development process is often not fully transparent and comprehensible. Whereas some sedentary behaviour recommendations were developed relying on existing systematic reviews, others have followed recent best-practice recommendations and have applied validated tools to assess the quality of the guideline development process.

Several limitations of sedentary behaviour guidelines are worth mentioning. First, not all recommendations target sedentary behaviour specifically. Some recommend avoiding physical inactivity, which can be misinterpreted as reflecting the opposite of physical activity and does not represent the equivalent of sedentary behaviour. Furthermore, only few recommendations provide integrated 24-h movement guidelines (e.g. Canada [20]) with recommendations on physical activity, sedentary behaviour and sleep).

Second, current guidelines do not provide details regarding a quantified threshold for sedentary time (i.e. whether there is a specific time-based threshold of sedentary behaviour that is associated with increased health risks). Third, upcoming guidelines need to integrate recommendations on how to break up sedentary behaviour. Fourth, most recommendations target 'traditional' forms of TV viewing or recommend not having a TV in the bedroom. However, advances in media and IT technology have led to the opportunity to 'watch TV' on tablets, smartphones or PCs. These changes need to be taken into account when formulating new recommendations. Fifth, future recommendations will need to deal with sedentary behaviour in times of challenging conditions such as the COVID-19 pandemic with altered work and movement patterns (e.g. working at home). Sixth, there is a need for sedentary behaviour recommendations for low- and middle-income countries because they are facing a high burden of noncommunicable diseases resulting from the epidemiologic transition [79] (Chap. 27). Furthermore, other countries, such as Spain, Sweden and Switzerland, publish their recommendations in their respective language only, which makes them difficult to locate. Therefore, the list of recommendations provided in Table 1.2 may not be comprehensive, and guidelines that are currently under development were not accessible.

1.3.9 Summary

This section shows that several countries and organisations have developed recommendations on sedentary behaviour for health to address the public health relevance of sedentary behaviour across all age groups. Many countries provide national guidelines on sedentary behaviour. In addition, the current WHO Guidelines on Physical Activity and Sedentary Behaviour include recommendations on sedentary behaviour for all age groups and population subgroups such as pregnant women and people living with chronic conditions. For guidelines to be successfully implemented, an emphasis on public health and prevention policies is required.

References

1. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary Behavior Research Network (SBRN) - Terminology consensus project process and outcome. Int J Behav Nutr Phys Act. 2017;14(1):75.
2. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc. 2000;32(9 Suppl):S498–504.
3. World Health Organization. Global recommendations on physical activity for health. Geneva: WHO; 2010.
4. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32.
5. Ekelund U, Tarp J, Steene-Johannessen J, Hansen BH, Jefferis B, Fagerland MW, et al. Dose-response associations between accelerometery measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. BMJ. 2019;366: l4570.
6. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than one million men and women. Lancet. 2016;388(10051):1302–10.
7. Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ, et al. Objectively measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Diabetes Care. 2008;31(2):369–71.
8. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105–13.
9. Leatherdale ST, Wong SL. Modifiable characteristics associated with sedentary behaviours among youth. Int J Pediatr Obes. 2008;3(2):93–101.
10. Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary". Exerc Sport Sci Rev. 2008;36(4):173–8.
11. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. Am J Prev Med. 2011;41(2):189–96.
12. Biddle S, Gorely T. Sitting psychology: towards a psychology of sedentary behaviour. In: Papaioannou AG, Hackford D, editors. Routledge companion to sport and exercise psychology: global perspectives and fundamental concepts. East Sussex, UK: Routledge; 2014.
13. Maslin MA, Shultz S, Trauth MH. A synthesis of the theories and concepts of early human evolution. Philos Trans R Soc Lond B Biol Sci. 2015;370(1663):20140064.
14. Lieberman DE, Bramble DM. The evolution of marathon running: capabilities in humans. Sports Med. 2007;37(4–5):288–90.
15. Der NH. Körper, der auf dem Sessel sitzt. In: Böhler A, Herzog C, Pechriggle A, editors. Korporale Performanz: Zur bedeutungsgenerierenden Dimension des Leibes. Bielefeld, Germany: Transcript Verlag; 2013.
16. Eickhoff H. Himmelsthron und Schaukelstuhl: Die Geschichte des Sitzens. Munich: Carl Hanser Verlag; 1993.
17. World Health Organization. WHO guidelines on physical activity and sedentary behaviour. Geneva: WHO; 2020.

18. Australian Government - Department of Health. Physical activity and exercise guidelines for all Australians. 2021.
19. Fonds Gesundes Österreich. Österreichische Bewegungsempfehlungen (Wissensband 17). Wien: Gesundheit Österreich GmbH; 2020.
20. The Canadian Society for Exercise Physiology (CSEP). Canadian 24-hour movement guidelines: An integration of physical activity, sedentary behaviour, and sleep. 24-Hour Movement Guidelines; 2021.
21. Bundeszentrale für gesundheitliche Aufklärung. Menschen in Bewegung bringen - Nationale Empfehlungen für Bewegung und Bewegungsförderung. Cologne: BZgA; 2019.
22. Department of Health. Healthy exercise for all campaign - Body weight management of children. Hong Kong, 2016.
23. Department of Health PA, Health Improvement and Protection. Healthy exercise for all campaign. Hong Kong; 2015.
24. Department of Health. Healthy exercise for all - mobility and stretching exercises in the workplace. Hong Kong. 2020;
25. National Association for Sport and Physical Education. Fact sheet for Childcare Providers. Ireland; 2006.
26. Department of Health. The national guidelines on physical activity for Ireland. Ireland: Department of Health and Children & Health Service Executive; 2009.
27. Ministry of Health Labour and Welfare. Active guide – Japanese official physical activity guidelines for health promotion, Japan; 2013.
28. Ministry of Health and Welfare. The physical activity guide for Koreans. Korea: Ministry of Health; 2013.
29. Yang YJ. An overview of current physical activity recommendations in primary care. Korean J Fam Med. 2019;40(3):135–42.
30. Ministry of Health. Eating and activity guidelines for New Zealand adults: updated 2020. Wellington: Ministry of Health; 2020.
31. Ministry of Health. Eating and Activity Guidelines for New Zealand Adults. Wellington, New Zealand: Ministry of Health; 2015.
32. Ministry of Health (New Zealand Government). Guidelines on physical activity for older people (aged 65 years and over). Wellington, New Zealand: Ministry of Health; 2013.
33. Nordic Council of Ministers. Nordic Nutrition Recommendations 2012: integrating nutrition and physical activity. Copenhagen: Nordic Council of Ministers; 2012.
34. Al-Mohannadi AS, et al. Qatar national physical activity guidelines. 2nd ed. Doha: Aspetar Orthopaedic and Sports Medicine Hospital; 2021.
35. College of Paediatrics & Child Health. Singapore integrated 24-hour activity guidelines for children and adolescents. Singapore: College of Paediatrics & Child Health; 2021.
36. Health Promotion Board. National Physical Activity Guidelines: Professional Guide. Singapore; 2011.
37. Gobierno de España MdS, Servicios Sociales e Igualdad. Actividad Física para la Salud y Reducción del Sedentarismo. Recomendaciones para la población. Madrid: Estrategia de Promoción de la Salud y Prevención en el SNS; 2015.
38. Svenska Läkaresällskapet (Swedish Society of Medicine). Rekommendationer om fysisk aktivitet för vuxna; 2011.
39. Bundesamt für Sport BASPO. Gesundheitswirksame Bewegung bei Kindern und Jugendlichen Empfehlungen für die Schweiz. Bundesamt für Sport BASPO, Magglingen, Switzerland; 2013.
40. Bundesamt für Sport BASPO. Gesundheitswirksame Bewegung bei Erwachsenen Empfehlungen für die Schweiz. In: BASPO BfS, editor. Bundesamt für Sport BASPO, Magglingen, Switzerland; 2013.
41. Bundesamt für Sport BASPO. Gesundheitswirksame Bewegung bei älteren Erwachsenen Empfehlungen für die Schweiz. Bundesamt für Sport BASPO, Magglingen, Switzerland; 2013.
42. Ministry of Health - Public Health Institution. Physical activity guidelines for Turkey. Ankara, Turkey: Ministry of Health - Public Health Institution; 2014.

43. Department of Health and Social Care LCWG, Department of Health Northern Ireland and the Scottish Government. UK Chief Medical Officers' physical activity guidelines; 2019.
44. American Academy of Pediatrics. Committee on Public Education. American Academy of Pediatrics: children, adolescents, and television. Pediatrics. 2001;107(2):423–6.
45. U.S. Department of Health and Human Services. Physical activity guidelines for Americans. 2nd ed. Washington, DC: U.S. Department of Health and Human Services; 2018.
46. National Institute for Occupational Safety and Health. Workplace solutions; 2017.
47. World Health Organization - Western Pacific Region. Pacific physical activity guidelines for adults: framework for accelerating the communication of physical activity guidelines; 2008.
48. World Health Organization. Guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age. Geneva; 2019.
49. Saunders TJ, Rollo S, Kuzik N, Demchenko I, Belanger S, Brisson-Boivin K, et al. International school-related sedentary behaviour recommendations for children and youth. Int J Behav Nutr Phys Act. 2022;19(1):39.
50. American Academy of Pediatrics Committee on Communications. Children, adolescents, and television. Pediatrics. 1990;85(6):1119–20.
51. Tremblay MS, Leblanc AG, Janssen I, Kho ME, Hicks A, Murumets K, et al. Canadian sedentary behaviour guidelines for children and youth. Appl Physiol Nutr Metab. 2011;36(1): 59–64.
52. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Act. 2011;8:98.
53. Brouwers MC, Kho ME, Browman GP, Burgers JS, Cluzeau F, Feder G, et al. AGREE II: advancing guideline development, reporting, and evaluation in health care. Prev Med. 2010;51 (5):421–4.
54. Okely AD, Salmon J, Vella S, Cliff D, Timperio A, Tremblay M, Trost S, Shilton T, Hinkley T, Ridgers N, Phillipson L, Hesketh K, Parrish A, Janssen X, Brown M, Emmel J, Marino N. A systematic review to inform the australian sedentary behaviour guidelines for children and young people. Report prepared for the Australian Government Department of Health. Commonwealth of Australia; 2013.
55. The AGREE Collaboration. Development and validation of an international appraisal instrument for assessing the quality of clinical practice guidelines: the AGREE project. Qual Saf Health Care. 2003;12(1):18–23.
56. Department of Health. Start active, stay active: a report on physical activity for health from the four home countries' Chief Medical Officers. London, UK: Department of Health, Physical Activity, Health Improvement and Protection; 2011.
57. Canadian Society for Exercise Physiology. Canadian physical activity guidelines, Canadian Sedentary behaviour guidelines. Ottawa, Canada: Canadian Society for Exercise Physiology; 2012.
58. Australian Government - Department of Health. Make your move - sit less. Become active for life! Australia's physical activity and sedentary behavior guidelines: 5–12 years; 2014.
59. Australian Government - Department of Health. Move and play every day - National physical activity recommendations for children 0–5 years; 2014.
60. Australian Government - Department of Health. Make your move - Sit less. Become active for life! Australia's Physical Activity and Sedentary Behavior Guidelines: 13–17 years; 2014.
61. American College of Sports Medicine. Reducing sedentary behaviors: sitting less and moving more. Indianapolis, IN: ACSM; 2011.
62. Australian Government - Department of Health. Make your move - sit less. Become active for life! Australia's physical activity and sedentary behavior guidelines: adults; 2014.
63. Australian Government - Department of Health. Australia's physical activity and sedentary behavior guidelines: tips and ideas for adults (18–64 years); 2014.
64. Bundesamt für Sport BASPO. Gesundheitswirksame Bewegung bei Erwachsenen Empfehlungen für die Schweiz. Bundesamt für Sport BASPO, Magglingen, Switzerland; 2013.

65. Ruetten A, Pfeifer K. Nationale Empfehlungen für Bewegung und Bewegungsförderung: Friedrich-Alexander-Universität Erlangen-Nürnberg; 2016. http://www.in-form.de/fileadmin/redaktion/Profi/Aktuelles/Nationale-Empfehlungen-fuer-Bewegung-und-Bewegungsfoerderung-2016.pdf
66. Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents. Expert panel on integrated guidelines for cardiovascular health and risk reduction in children and adolescents: summary report. Pediatrics. 2011;128(Supplement 5):S213–56.
67. Szczygieł E, Zielonka K, Mętel S, Golec J. Musculo-skeletal and pulmonary effects of sitting position - a systematic review. Ann Agric Environ Med. 2017;24(1):8–12.
68. Starrett K, Starrett J, Cordoza G. Deskbound: standing up to a sitting world. Las Vegas: Victory Belt Publishing; 2016.
69. Hagger-Johnson G, Gow AJ, Burley V, Greenwood D, Cade JE. Sitting time, fidgeting, and all-cause mortality in the UK women's Cohort study. Am J Prev Med. 2016;50(2):154–60.
70. Lengsfeld M, Frank A, van Deursen DL, Griss P. Lumbar spine curvature during office chair sitting. Med Eng Phys. 2000;22(9):665–9.
71. Buckley JP, Hedge A, Yates T, Copeland RJ, Loosemore M, Hamer M, et al. The sedentary office: an expert statement on the growing case for change towards better health and productivity. Br J Sports Med. 2015;49(21):1357–62.
72. Waters TR, Dick RB. Evidence of health risks associated with prolonged standing at work and intervention effectiveness. Rehabil Nurs. 2015;40(3):148–65.
73. Roffey DM, Wai EK, Bishop P, Kwon BK, Dagenais S. Causal assessment of occupational standing or walking and low back pain: results of a systematic review. Spine J. 2010;10(3):262–72.
74. Rücken GJ. Beschwerden wirksam begegnen: Ursachen - Therapie – Training. Herausgeber: W. Zuckschwerdt Verlag; 2020.
75. Nguyen P, Le LK, Nguyen D, Gao L, Dunstan DW, Moodie M. The effectiveness of sedentary behaviour interventions on sitting time and screen time in children and adults: an umbrella review of systematic reviews. Int J Behav Nutr Phys Act. 2020;17(1):117.
76. Morton S, Fitzsimons C, Jepson R, Saunders DH, Sivaramakrishnan D, Niven A. What works to reduce sedentary behavior in the office, and could these intervention components transfer to the home working environment?: A rapid review and transferability appraisal. Front Sports Act Living. 2022;4:954639.
77. Gerding T, Syck M, Daniel D, Naylor J, Kotowski SE, Gillespie GL, et al. An assessment of ergonomic issues in the home offices of university employees sent home due to the COVID-19 pandemic. Work. 2021;68(4):981–92.
78. Carson V, Leblanc CM, Moreau E, Tremblay MS. Paediatricians' awareness of, agreement with and use of the new Canadian Physical Activity and Sedentary Behaviour Guidelines for children and youth zero to 17 years of age. Paediatr Child Health. 2013;18(10):538–42.
79. World Health Organization. Global status report on noncommunicable diseases 2014. Geneva: WHO; 2014.

Chapter 2
The Descriptive Epidemiology of Sedentary Behaviour

Hannah Ahrensberg, Christina Bjørk Petersen, Jane Nereah Wesonga Jacobsen, Mette Toftager, and Adrian Ernest Bauman

Abstract There is an interest in monitoring increases in sedentary time globally, although recent European data does not show such a trend. New norms due to the COVID-19 pandemic may influence both total sitting time and domain-specific sitting time. Also, recent evidence on the interplay between sedentary behaviour and physical activity has identified the joint association of 'high sitting-low active' as a risk indicator and not just high sitting time. This chapter summarises recent evidence on the prevalence of sedentary behaviour among different age groups, comprising 50 large and population-representative studies for adults, 7 studies for older adults and 26 studies for children and adolescents, published between 2012 and 2021. Furthermore, this chapter describes the correlates of sedentary behaviour for adults, older adults and children and adolescents derived from large population-based cross-sectional studies. Among adults the median total sitting time was 6.4 h/day. Self-reported sedentary time was 5.6 h/day which was more than 2½ h/day less than that observed from device-based measured sitting time (median 8.3 h/day). Reported television (TV) watching time showed a median of 2.2 h/day. The median prevalence of sedentary behaviours among older adults (6.7 h/day) was higher than among adults (6.4 h/day), especially measured TV time (3.2 h/day vs. 2.3 h/day). For children and adolescents, the total median sedentary time was 7.5 h/day and increased from early childhood through adolescence. The median screen time was

H. Ahrensberg · C. Bjørk Petersen (✉)
National Institute of Public Health, University of Southern Denmark, Copenhagen, Denmark
e-mail: hana@sdu.dk; chrb@sdu.dk

J. N. W. Jacobsen
University of Southern Denmark, Esbjerg, Denmark

M. Toftager
Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark
e-mail: mtoftager@health.sdu.dk

A. Ernest Bauman
School of Public Health, Sydney University, Sydney, NSW, Australia
e-mail: adrian.bauman@sydney.edu.au

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_2

2.9 h/day. Overall, no differences in the prevalence estimates were observed in studies from 2016 and onwards compared to previous studies.

What Is New?

- Updated surveillance prevalence estimates for sedentary behaviour in population studies of children and adolescents, adults and older adults.
- New perspectives on monitoring and surveillance of sedentary behaviour including domain-specific considerations and cut-points for high sitting volumes.
- Estimates and considerations of the combined prevalence and correlates of 'high sitting time and low physical activity'.

2.1 Introduction

There has been a growing interest in describing the patterns of sedentary behaviour due to the association between sedentary behaviour and risk of development of chronic diseases such as hypertension, type 2 diabetes, cardiovascular diseases, cancers and premature mortality [1–6]. Sedentary time may have increased in recent decades, especially in the industrialised world [7–9], although European data does not show such a trend [8, 9]. More recently, the COVID-19 pandemic may have induced an acute increase in sedentary time due to a large part of the population working or studying from home and adhering to restrictions on time spent outside the home.

Since 2008, there has been a substantial increase in publications on sedentary behaviour, especially from 2008 to 2014, after which the numbers seemed to plateau (see Fig. 2.1). In fact, misclassification is likely in the early 2000s, as 'sedentary behaviour' was a term then also used to describe 'low physical activity levels not meeting recommendations or guidelines', but in recent years it has mainly described sitting time (<1.5 metabolic equivalent (METs) activity of sitting or lying/reclining (not sleeping)). In particular, epidemiological and physiological studies have proliferated, which examined the health consequences of prolonged and uninterrupted sitting, and in addition, many papers have provided policy commentaries on sedentary behaviour. Also, the number of published reviews on sedentary behaviour has increased over the past decade. More than 80% of the population-based studies reporting prevalence measures for sedentary behaviour are systematic reviews or meta-analyses, and thus only a small proportion has been in the form of original surveillance studies.

In the past decade, researchers have explored the potential interplay between levels of physical activity and levels of sedentary behaviour, as this constitutes a group of people ('high sitting-least active') with combined and synergistic risk of developing chronic diseases. Large observational meta-analyses have reported that

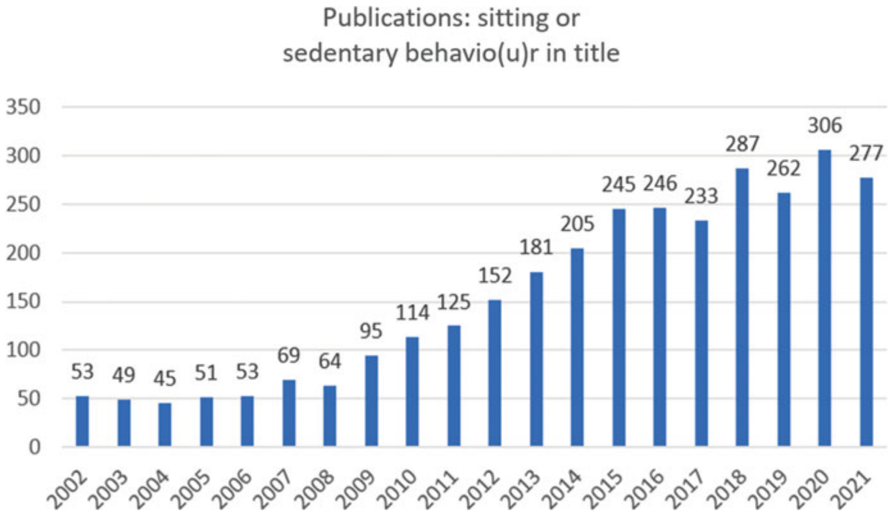

Fig. 2.1 Trends in populations on sitting and sedentary behavio(u)r (Title, Pubmed database) from January 1, 2002, until October 11, 2021

the highest levels of moderate-intensity physical activity (about 60–75 min/day) have the potential to eliminate the mortality risks associated with sedentary behaviour [2, 10]. Even though this interplay does not directly influence surveillance of sedentary behaviour, monitoring the combined 'high sitting-least active' group may be useful for characterising risk in population surveys.

This chapter summarises recent estimates of sedentary behaviour prevalence (studies published between 2012 and 2021) for adults, older adults and children and adolescents and explores factors typically associated with sedentary behaviour in large and population-representative studies. Identifying prevalence and correlates of sedentary behaviour are also important for population health planning, as they identify the characteristics of population sub-groups that report high volumes of sedentary behaviour. The chapter is an updated version of the chapter in the first edition [11].

2.2 Surveillance and Prevalence of Sedentary Behaviour

2.2.1 Surveillance and Population Measurement

Sedentary behaviour is a measure of low-energy expenditure (below 1.5 METs) in a sedentary behaviour-relevant posture/position (sitting or lying/reclining) [12]. Prevalence data on sedentary behaviour often contain information on the duration of sedentary behaviours and possibly also frequency of interruptions to sedentary time.

Sedentary behaviour is usually expressed as total sitting time throughout the day; alternatively, domain (setting)-specific sitting time can be estimated for sitting at work or school, at home or in travelling from place to place. In addition, some studies use TV time or screen time as proxy measures for discretionary domestic sitting time. The choice of measurement method depends on the aim of the study, target group (e.g. different age groups) and resources available (e.g. practical and financial resources).

2.2.2 Measuring Sedentary Behaviours in Populations of Adults, Older Adults, Children and Adolescents

The aim of population surveillance is to provide valid estimates of sedentary behaviours in representative samples. Self-report remains the most practical method for most national surveillance systems, but a growing number of studies are using device-based measures of sedentary time. In general, self-reported methods are suitable for measuring type and context of specific sedentary activities, whereas device-based, formerly described as ‘objective’, methods are suitable to measure total sedentary time and the distribution of sedentary behaviour during the day [13, 14].

Self-report measures include questionnaires and online surveys, diaries or logs, direct observations and proxy reporting. Questionnaires can either be self-completed or interview-administered and are, together with online surveys, designed to collect information on total sitting time and domain-specific sitting by a single item or multiple items about several aspects of sedentary behaviour [14, 15]. For children under 11 or 12 years of age, proxy reporting of their sedentary behaviour by their parent or teacher is necessary [16]. Self-reported measurements are scalable and affordable measures across regions or countries as part of routine surveillance systems [14].

Device-based measures include motion-sensing devices and can capture time-varying changes in movement behaviour. For example, by using accelerometers, pre-established cut-points (e.g. <100 counts-per-minute) can classify sedentary time based on energy expenditure [14]. Accelerometers can quantify the duration of total daily sitting, the number of breaks in sitting time, identify sit-stand transitions and differentiate time spent sitting down from time spent standing still [17]. Wearable technologies are rapidly evolving, including wrist worn devices and smart watches, and provide access to data from large numbers of people [18, 19]. For further details on subjective and device-based measurements of sedentary behaviour, please refer to Chap. 3.

2.2.3 Compiling the Prevalence Estimates

In order to estimate prevalence of sedentary behaviours across studies, PubMed, Embase and Scopus were searched for articles published in English from January

1, 2012, to October 11, 2021. These were used as the most recent years, during which 76% of sedentary behaviour papers to date were published (Fig. 2.1).

The syntax used for searching in PubMed was as follows:

((sitting(Title) OR sedentary(Title)) AND (Prevalence(Title/Abstract) OR population(Title/Abstract) AND ("2012"(Date - Publication): "2021"(Date - Publication))).*

This resulted in 4008 publications. The publications were reviewed to identify studies that provided prevalence estimates. Population-based studies with at least 1500 participants for cross-sectional studies were included. Some studies cover a wide age range and present estimates for, e.g. both adults and older adults. These are presented as subsamples where study participant numbers do not necessarily exceed 1500. Further, we excluded studies that did not report an appropriate and comparable estimate of sedentary behaviour, defined as providing means and standard deviation (SD) or medians and interquartile range (IQR) for total sitting time or selected domains of sedentary behaviour. Studies not reporting prevalence measures on the total population (e.g. estimates for men and women separately or in clinical populations) were excluded. Furthermore, we used a threshold of at least 6 h/day for 'high volumes of sitting' according to evidence from large epidemiological studies [10, 20–22].

Prevalence data from the selected studies were examined to produce an overall mean range and median estimate of sedentary behaviour. The studies among adults ($n = 50$ studies) and older adults ($n = 7$) are shown in Table 2.1, and among children and adolescents in Table 2.2 ($n = 26$). For each paper, the lead author and year of publication are reported as well as the country and year of study, age group and sample size. Information on sedentary behaviour was extracted as follows: for *adults* and *older adults*: total sitting time, TV-viewing/screen time, sitting time at work and computer use and for *children and adolescents*: total sitting time, TV-viewing, computer use and screen time. The prevalence of sedentary behaviour is expressed as total sitting time (hours per day) or as time spent on specific sitting activities (hours per day).

2.2.4 The Prevalence of Total Sitting Time Among Adults

The purpose of the descriptive epidemiology of sedentary behaviour is to estimate the prevalence of sitting time. As can be seen from Table 2.1, estimates were mostly from high-income countries. Across included studies, the median of the estimates of *total daily sitting time* was 6.4 h/day ranging from 2.5 to 11.9 h of sitting per day. From studies measuring sitting time using device-based methods, the median was 8.3 h/day (mean range 6.9 to 11.9 h/day). This is 2.7 h more than the median self-reported sitting time, where the median was 5.6 h/day (mean range 2.5–10.4). In studies reporting sitting for more than 6–8 h/day, the median prevalence of 'high sitting time' was approximately one third of the samples (32%).

Table 2.1 Descriptive estimates of the prevalence of sedentary behaviour 2012–2021, adults and older adults

Study	Country	Year	Age group	Sample size (*N*)	Context of sitting time Mean hours per day (h/day) ± SD if nothing else is stated			
					Total sitting time	TV viewing/ screen-time	Work	Computer
Self-reported								
Aadahl et al. (2013) [23]	Denmark	2010	25–79	77,517			4.60 ± 2.79 h/day	
Aguilar-Farias et al. (2017) (subsample) [24]	Chile	2009–2010	18–69	Not stated (whole population: $n = 5031$)	2.5 h/day			
Aguilar-Farias et al. (2017) (subsample) [24]	Chile	2009–2010	70–79	Not stated (whole population: $n = 5031$)	2.7 h/day			
Asztalos et al. (2015) [25]	Belgium	Not stated	25–64	4344[a]	4.7 ± 2.3 h/day			
Bennie et al. (2013) [26]	32 countries	2005	15–98	27637[b]	5.2 ± 3.1 h/day *5 (3–7) h/day*			
Bjork Petersen et al. (2014) [27]	Denmark	2007–2008	18–99	71363[c]	*6.9 (4.5–8.7) h/day*			
Borodulin et al. (2015) [28]	Finland	2002	25–74	4516[d]	6.4 ± 3.2 *6.0 (4.0–9.0) h/day*			
Celis-Morales et al. (sub-sample) (2015) [29]	Chile	2009–2010	18–64	4157	3.4 h/day			
Celis-Morales et al. (sub-sample) (2015) [29]	Chile	2009–2010	64+		6.1 h/day	≥2 h/day: *84.1%*		≥1 h/day: *53.4%*
Chau et al. (2015) [30]	Norway	2006–2008		50817[e]		4+ h/day: *13.3%*		

					7+: h/day: 32.0% 10 + h/day: 13.3%			
Chau et al. (2012) [31]	Australia	2007–2008	15–69	10,785 working adults[f]		3.8 ± 3.0 h/day		
Clemes et al. (2016) [32]	UK	2012	18+	4436	10.4 ± 2.8 h/day	1.5 ± 1.2 h/day	6.3 ± 1.8 h/day	
Guallar-Castillon et al. (2014) [33]	Spain	2008–2012	18+	4271		2.2 ± 1.47		
Hadgraft et al. (2015) [34]	Australia	2011–2012	Mean: 53	1235 working[g]		*1.4 (0.7–2.1) h/day*	*6.0 (3.0–7.6) h/day*	
Hamer et al. (2014) [35]	England	2008	16–95	11,658	4.9 ± 1.5 h/day	2.8 ± 1.6		
Herman et al. (2016) [36]	Canada	2011–2012	20–75+	92,918		≥2 h/day: 31%		≥5 h/day: 44%
Horta et al. (2015) [37]	Brazil	2012–2013	30	1241[h]	Highest quartile: 12.3–15.9 h/day			
Lin et al. (2015) [38]	USA	2002	38–45	5285 working[i]			3.0 ± 1.1 h/day	
Matthews et al. (2012) [39]	USA	1995–1996	50–71	240,819[j]	7+ h/day: 23% 9+ h/day: 8.3%	3+ h/day: 62.7% 5+ h/day: 18.9%		
Matthews et al. (2014) [40]	USA	2002–2009	40–79	63,308[k]	Highest quartile: >12.0 h/day			
Matthews et al. (2021) (subsample) [41]	USA	2019	20–69	2509	9.5 h/day	2.3 h/day	1.9 h/day	1.0 h/day
Medina et al. (2021) [42]	Mexico	2018–2019	20–69	38,033				

(continued)

Table 2.1 (continued)

Study	Country	Year	Age group	Sample size (*N*)	Context of sitting time Mean hours per day (h/day) ± SD if nothing else is stated			
					Total sitting time	TV viewing/ screen-time	Work	Computer
					3.6 h/day: ≥7 h/day: 11.3%			
Mielke et al. (2014) [43] and Munir et al. (2015) [44]	Brazil	2012	>20	2927[l]	5.8 ± 4.5 h/day *4.5 (2.5–8.0) h/day*			
Milton et al. (2014) [45]	27 European countries	2013	>15	27,919[m]	4.9 ± 2.3 *5.0 (3.0–7.0) h/day* 8.5 + h/day: 11.3%			
Mitáš et al. (2014) [46]	Czech Republic	2007	15–69	4097	*5.9 (4.0–8.0)*			
Munir et al. (2015) [44]	Northern Ireland	2012	Median age 35–44 years	4436			6.4 ± 1.9 h/day	
Pinto Pereira and Power (2013) [47]	UK	2003	44–45	6562 working[n]		3+ h/day: 19.9%	3–4 h/day: 6.8% 4+ h/day: 35.0%	
Ryu et al. (2015) [48]	Korea	2011–2013	Mean: 39.9	139,056[o]	7.6 ± 3.8 h/day			
Saidj et al. (2015) [49]	France	2009	>18	35,444 working[p]		2.19 ± 1.62 h/day	4.2 ± 3.1 h/day	

Saidj et al. (2013) [50]	Denmark	2006	18–69	3544 working[q]	7.2 ± 2.8 h/day		4.1 ± 2.7 h/day	
Sharkas et al. (2015) [51]	Jordan	2007	>18	3654	9.8 h/day			
Shih et al. (2014) [52]	Taiwan	2011	>40	10940[r]	7+ h/day: 31.7%			
Sloan et al. (2013) [53]	Singapore	2010	18–79	4337[s]	*5 (3–8) h/day* Highest tertile: 10 (8–11) h/day			
Sodergren et al. (2012) [54]	Australia	2010	55–65	3644[t]	5.8 ± 2.9 h/day *5.1 (5.0–5.3)*			
Staiano et al. (2014) [55]	USA	2007	20+	4560[u]	*5.7 (5.5–5.8) h/day*			
Stamatakis et al. (2012a) [56]	Australia	2010	>47	26,366 working[v]	5.5 ± 3.1 h/day	2.4 ± 1.4 h		
Stamatakis et al. (2012b) [57]	UK	2008	16–65	5948[w]	Highest tertile: >7.8 h/day			
Tcymbal et al. (2020) [58]	Armenia	2016	18–69	2249	3.8 ± (3.6–4.1) h/day *3.0 (2.0–5.5) h/day* >8 h/day: 13.2%			
Ussery et al. (2021) [21]	US	2017–2018	>18	5856	5.9 h/day ≥6 h/day: 19.7%			
van der Ploeg et al. (2012) [59]	Australia	2006–2010	>45	22,2497[x]	8+ h/day: 25.1% 11+ h/day: 6.4%			
Wallmann-Sperlich et al. (2013) [60]	Germany	2010	Mean: 49.3	2000	5.3 ± 3.1 h/day *5.0 h/day* >6 h/day: 30.1%			
Win et al. (2015) [61]	Singapore	2012	Mean: 43	2319[y]	*6 (3–8) h/day* 8+ h/day: 37%			

(continued)

Table 2.1 (continued)

Study	Country	Year	Age group	Sample size (N)	Context of sitting time Mean hours per day (h/day) ± SD if nothing else is stated			
					Total sitting time	TV viewing/ screen-time	Work	Computer
Yang et al. (2019) (sub-sample) [62]	USA	2003–2016	20–64	31,898	6.5 h/day	≥ 2 h/day: 61.5%		≥ 2 h/day: 49.9%
Yang et al. (2019) (sub-sample) [62]	USA	2003–2016	>64		6.1 h/day	≥2 h/day: 84.1%		≥1 h/day: 53.4%
Device-based*								
Barone Gibbs et al. (2015) [63]	USA	2005–2006	38–50	2027[z]	8.1 ± 1.7 h/day			
Carson et al. (2014) [64]	Canada	2009/2011	20–79	4935	10.8 ± 2.0 h/day			
Chen et al. (2017) (subsample) [65]	Japan	2009	40–64	899[aa]	6.9 h/day			
Chen et al. (2017) (subsample) [65]	Japan	2009	≥65	841[aa]	7.3 h/day			
Hagströmer et al. (2015) [66]	Sweden	2001	18–75	1172	8.21 ± 1.5 h/day			
Husu et al. (2016) [67]	Finland	2011–2012	18–85	1587	8.3 h/day			
Johansson et al. (2019) (subsample) [68]	Denmark	2011–2015	20–65	968[ab]	*9.5 h/day*			
Johansson et al. (2019) (subsample) [68]	Denmark	2011–2015	>65	702[ab]	9.9 h/day			
Kim et al. (2015) [69]	USA	2003–2006	>18	5917[ac]	8.1 ± 4.5 h/day			
Qi et al. (2015) [70]	USA	2008–2011	18–74	12,083 Hispanic and Latinos[ad]	11.9 h/day			

Stamatakis et al. (2012b) [57]	UK	2008	16–65	1772[ae]	Highest tertile: >10.2 h/day			
Van Dyck (2015) [71]	10 countries	2002–2011	18–65	5712[af]	8.55 ± 1.75 h/day			
Yatsugi et al. (2021) [72]	Japan	2009, 2011, 2017	65+	3998	7.5 h/day ± 2.0 h/day			

When the paper includes multiple years of survey, only the most recent years and estimates are included
Italics indicate that the estimates are median values and the interquartile range
[a]Belgian Health Interview Survey (B-HIS), [b]Eurobarometer study, [c]DANHES cohort, [d]FINRISK 2002, HUNT3 Study, [f]Australian National Health, Survey, [g]AusDiab Study, [h]1982 Pelotas (Brazil) Birth Cohort, [i]National Longitudinal Survey of Youth 1979 (NLSY79), [j]NIH-AARP Diet and Health Study, [k]Southern Community Cohort Study, [l]This study is part of a multipurpose health survey conducted in the city of Pelotas, Southern Brazil in 2012, [m]Eurobarometer study—population size is the total number of people in all included countries (27 countries), [n]1958 British birth cohort, [o]Kangbuk, Samsung Health Study, [p]NutriNet-Sante Study, [q]Health 2006 Study, [r]National Health Interview Survey (NHIS), [s]Singapore Ministry of Health's 2010 National Health Survey, [t]Wellbeing, Eating and Exercise for a Long Life (WELL) study, [u]NHANES 2010, [v]Social, Economic, and Environmental Factor Study, [w]Health Survey for England (HSE) 2008, [x]45 and Up Study, [y]Singapore Health 2012 Study, [z]Coronary Artery Risk Development in Young Adults (CARDIA) study, [aa]The Hisayama study, [b]The Copenhagen City Heart Study, [c]NHANES 2006–2008, [ad]Hispanic Community Health, Study/Study of Latinos (HCHS/SOL), [ae]Health Survey for England (HSE) 2008, [af]IPEN adult study
[*]Sedentary behaviour defined as <100 counts per minute

Table 2.2 Descriptive estimates of the prevalence of sedentary behaviour, studies published 2012–2021, children and adolescents

Study	Country	Year	Age group	Sample size (*N*)	Context of sitting time Mean hours per day (h/day) ± SD if nothing else is stated			
					Total sitting time	TV viewing	computer	Screen time
Self-reported								
Babey et al. (2013) [73]	USA	2005	12–17	4029		2.3 ± 0.04 h/day	1.4 ± 0.04 h/day	
Baygi et al. (2015) [74]	Iran	2009–2010	10–18	2618		3.5 ± 1.2 h/day	2.0 ± 1.2 h/day	5.56 ± 1.8 h/day
Carson et al. (2015) [75]	USA	2007–2012	12–19	3556	7.5 ± 6.5 h/day			
Chen et al. (2014) [76]	Taiwan	2012	9–12	1933	4.7 ± 2.4 h/day			2.9 ± 2.5 h/day
Chen et al. (2014) [77]	China	2011	11–18	9901		>4 h/day: 1.2%	> 4 h/day: 1.7%	
Dadvand et al. (2014) [78]	Spain	2006	9–12	3178				> 1 h/workday and > 2 h/weekend day: 28.4%
Duan et al. (2015) [79]	China	2013	12–15	1793		≥2 h/day: 8.3%	≥2 h/day: 22.7%	≥2 h/day: 42.9%
Iannotti and Wang (2013) [80]	USA	2009–2010	11–15	10,848		2.4 ± 0.05 h/day	1.5 ± 0.05 h/day	
Kiefte-de Jong et al. (2013) [81]	The Netherlands	2002–2006	2	2420				

						≥2 h/ day: 9.0%		
Kim et al. (2016) [82]	USA	2012–2013	14–17	12,081		≥3 h/ day: 31.8%	≥3 h/ day: 41.0%	
Kong et al. (2015) [83]	Korea	2013	12–18	53,769	9.3 h/day			
Leatherdale et al. (2015) [84]	Canada	2012–2013	14–17	23,031	8.2 ± 5.2 h/day[a]	1.95 ± 1.4 h/ day	1.4 ± 1.8 h/ day	
Lee (2014) [85]	USA	2001–2002	11–21	3717		1.8 ± 1.8 h/ day	0.7 ± 1.2 h/ day	3.2 ± 3.4 h/day
Loprinzi (2015) [86]	USA	2011–2012	6–17	40,446				2.0 ± 0.02 h/day
van Rossem et al. (2012) [87]	The Netherlands	2002–2006	3	4688		≥2 h/ day: 7.8%		
Wijtzes et al. (2014) [88]	The Netherlands	2002–2006	6	5913		≥2 h/ day: 19.9%	≥1 h/d: 7.6%	
Yang et al. (2019) (subsample) [62]	USA	2001–2016	5–11	10,359		≥2 h/ day: 62.2%	≥2 h/ day: 55.9%	
Yang et al. (2019) (subsample) [62]	USA	2003–2016	12–19	9639	8.2 h/day	≥2 h/ day: 59.4%	≥2 h/ day: 12.9%	
Zhang et al. (2012) [89]	China	2004	6–18	5497		>2 h/ day: 23.1%		

(continued)

Table 2.2 (continued)

Study	Country	Year	Age group	Sample size (*N*)	Context of sitting time Mean hours per day (h/day) ± SD if nothing else is stated			
					Total sitting time	TV viewing	computer	Screen time
Device-based[*]								
Atkin et al. (2013) [90]	U.K	2011	9–14	2064	5.8 ± 0.7 h/day			2.2 (1.2–3.7) h/day
Herrmann et al. (2015) [91]	Europe[b]	2007–2008 and 2009–2010	2–5 and 6–0	1512 and 2953	2–5 years: 4.4 ± 1.5 h/day 6–10 years: 5.7 ± 1.5 h/day			
Hildebrand et al. (2015) [92]	Europe[c]	1997–2007	6–18	10,793	6.2 ± 1.5 h/day[d]			
Katzmarzyk et al. (2015) [93]	ISCOLE Study[d]	2011–2013	9–11	6539	8.55 ± 1.15 h/day[d]			
Loprinzi et al. (2015) [94]	USA	2003–2006	6–17 Children:6–11 Adolescents: 12–17	Children: 1036 Adolescents: 1608	Children: 5.9 (5.8–6.0) h/day[d] Adolescents: 8 (7.8–8.2) h/day[d]			
Santos et al. (2014) [95]	Portugal	2008	10–18	2506	9.0 ± 0.03 h/day[d]			
Sherar et al. (2016) [96]	ICAD[e]	1997–2009	10–18	12,770	6.4 ± 1.6 h/day[d]			

When the paper included multiple years of survey, only the most recent years and estimates were included

[a]Total sedentary behaviour time is based on the sum of lowest values for each of the five different recreational sedentary behaviours reported ('watching/streaming TV shows or movies'; 'playing video/computer games'; 'talking on the phone'; 'surfing the Internet' and 'texting, messaging, emailing')

[b]IDEFICS, identification and prevention of dietary- and lifestyle-induced health effects in children and infants

[c]ALSPAC, Avon Longitudinal Study of Parents and Children; EYHS, European Youth Heart Study; KISS, Kinder Sport study; SPEEDY, Sport, Physical Activity and Eating Behaviour: Environmental Determinants in Young People

[d]ISCOLE, The International Study of Childhood Obesity, Lifestyle and the Environment. Study sites located in Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, the UK and the USA

[e]ICAD data were collected in Australia ($N = 2$: 2001/2004/2006; 2002–2003/2006), Brazil (2006–2007), Denmark (1997–1998 and 2003–2004), Estonia (1998–1999), Portugal (1999–2000), Switzerland (2005–2006), the UK ($N = 2$: 2003–2007; 2006–2009) and the USA (2002–2006). Baseline data are used in this study

[*]Sedentary behaviour defined as <100 counts per minute

Recent World Health Organization (WHO) recommendations on physical activity suggest that sedentary behaviour needs to be considered in combination with physical activity. In the literature search, only one large population-based study was identified reporting on the combined prevalence of high sedentary time and low physical activity. The study by Ussery et al. (2021) found that the prevalence of 'high sitting-least active' group was 8.2% in 2007/2008 and 8.7% in 2017/2008 among American adults based on self-reported data from the National Health and Nutrition Surveys [21]. This prevalence is similar to a multi-country showing estimates of 'high sitting-least active' group ranging from 7% to 10% across national population samples [9].

For many adults, three key domains contribute to total sitting time: work, leisure time and transportation [97, 98]. For working adults, occupational sitting is the largest contributor to the total amount of sitting time accumulated during the day [99, 100]. Today, many adults have sedentary jobs with continuous screen time and the use of labour-saving devices [98, 101, 102]. Based on the estimates in Table 2.1, the overall median *occupational sitting time* was 4.2 h/day (range 1.9–6.4 h/day). Thus, most working adults spent more than half of their working day sitting down. In addition to sitting at work, adults also engage in sedentary activities outside work. Both TV time and screen time have been used as proxy measures of sedentary behaviour in the domestic setting. In studies where *TV time or screen time* was reported, the median of the TV time estimates was 2.3 h/day (range 1.5–3.5 h/day), and overall, 41.2% reported watching TV for more than 3–4 h/day. Only a few studies have estimated the prevalence of sitting for transportation. The amount of time spent sitting for *transportation* depends on urban and transport planning as well as the transport culture [98]. Studies on European working adults have reported a mean sitting time for transportation between 0.5 and 1.0 h/day. Also, the distance to work influences the prevalence of sitting for transportation. In 2019, before the COVID-19 pandemic, four in five (79%) employed people in the European countries mainly worked at their employer's or own premises, and the average time spent commuting was 25 minutes each way, which means 50 minutes per day for those driving or taking public transportation [103].

In addition to the individual sample studies in Table 2.1, several multi-country studies have compared sedentary prevalence. Jelsma et al. [9] analysed the prevalence of sedentary behaviour over time between 2002 and 2017 among European adults (15+ years) over four surveys from the Eurobarometer. The sample included 28 European Member States with >15,000 respondents at each of the four time points. Sitting time were measured with The International Physical Activity Questionnaire (IPAQ), and high sitting was defined as >7.5 h/day. Results showed that trends in high sitting time were relatively stable over the 15-year period although the time trend was limited by a change in the sitting question between 2005 and 2013. Across years, 22.5% of the adult population (18+ years) was considered 'high sitting' in 2002, 21.1% in 2005, 17.5% in 2013 and 19.2% in 2017 [9].

2.2.5 Sedentary Behaviour in Older Adults

Although sedentary behaviour research suggests that older adults (aged ≥65 years) are the most sedentary, this age group has only had limited research. Table 2.1 shows seven studies reporting on the prevalence of sedentary behaviour among older adults. Across studies, there is a slight increase in the prevalence of sedentary time from younger older adults (e.g. 65–70 years) to the oldest adults (e.g. ≥85 years). The median daily siting time was 6.7 h ranging from 2.7 to 10.9, which indicates a wide variation in sedentary behaviour. This is partly due to differences in measurement methods and differences in countries. As seen in Fig. 2.2, the median was 7.4 h/day (mean range 7.3 to 7.5 h/day) among studies using device-based measures, while the median was 5.0 h/day (mean range 2.7 to 10.9 h/day) in studies using self-reported methods. Sedentary behaviour seems to be more prevalent among wealthier and urban countries [104]. The lowest median estimates of sedentary behaviour are seen among studies in Chile (2.7 h/day [24] and 4.0 h/day [29]), whereas Denmark and the USA have some of the highest sedentary behaviour estimates (9.9 h/day [68] and 10.9 h/day [41]). The increase in sedentary time with age is largely due to an increase in TV viewing. The median TV time among older adults was 3.2 h/day, while it was 1.8 h/among children/adolescents and 2.3 h/day among adults [41]. Furthermore, Yang et al. (2019) reported that 84.1% of older people aged ≥65 years watching TV for 2 h/day or more, while it was 61.5% among adults aged 20–64 years [62]. These population-based estimates are similar to findings in pooled analyses and systematic reviews. The most recent systematic review of sedentary behaviour among elderly was conducted by Wullems et al. (2016). They reviewed 48 studies and found older adults to be the most sedentary group (>60 years), with an accelerometer-derived median daily sitting time of 8.5–9.6 h/day, representing 65–80% of their waking time [105]. Another systematic review by Harvey et al. (2013) found that approximately 60% of older adults (>60 years) reported sitting for more than 4 h/day; around a quarter reported more than 7 h sitting per day; and more than 54% reported TV viewing for more than 3 h/day [106].

Across years, prevalence estimates remained rather stable. The trend study by Jelsma et al. [9] shows a prevalence of 'high sitting' (>7.5 h/day) among the older age groups (65+ years) from 2002 to 2017, ranging from 16.9% to 22.6% of the study population [9].

2.2.6 Sedentary Behaviour Prevalence Estimates in Children and Adolescents

Table 2.2 shows the prevalence of sedentary behaviour among children and adolescents aged 2–21 years. The median total daily sitting time was 7.5 h (Fig. 2.2) and ranged from 4.4 for the youngest children, age 2–5 [91], to 9.3 h/day for adolescents, age 12–18 years [83].

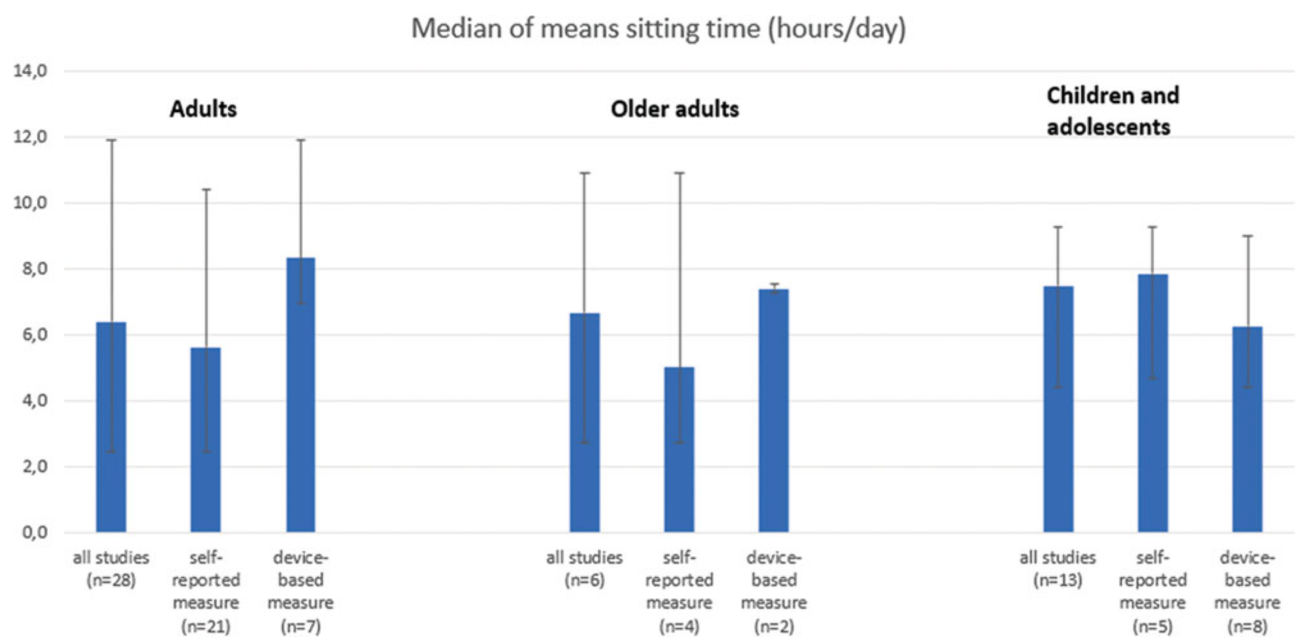

Fig. 2.2 Pooled prevalence of the distribution of mean sitting times in studies using self-reported and device-based methods to estimate sitting time. The estimates present the median of the mean values presented in Tables 4.1 and 4.2, showing the range of mean estimates obtained from the reported studies

According to the WHO recommendations on physical activity and sedentary behaviour, there is sufficient evidence to support recommendations on limiting sedentary behaviours among children and adolescents. However, there is insufficient evidence available to fully describe the dose-response relationships between sedentary behaviour and health outcomes, and whether the associations vary by type or domain of sedentary behaviour [107]. For the individual studies reviewed in Table 2.2, the reported mean hours of TV viewing ranged from 1.8 h/day [74] to 3.5 h/day [85]. One study reported that 31.8% of youth age 14–17 years reported more than 3 h/day on TV time [82], and another study reported that 62.2% of children, age 5–11, spent more than 2 h/day on TV viewing [62]. The overall screen time prevalence varied from 2 h to 5.6 h/day.

Two large international school-based surveys, the Health Behaviour in School-aged Children (HBSC) study and the Global School-Based Student Health Survey, present data on time spent sedentary. In the Global School-Based Student Health Survey across 97 countries, 25% of boys and 24% of girls aged 13–15 years reported sitting for longer than 3 h/day in their leisure time. In the HBSC study, the prevalence of 11–15 year olds who watch TV for 2 h or longer in weekdays was 60% for boys and 56% for girls, and the prevalence of playing computer and video games for 2 h or longer on weekdays was 51% for boys and 33% for girls [108].

2.2.7 Discussion of Sedentary Behaviour Prevalence Estimates

This review examined sedentary behaviour in studies published between 2012 and 2021 and showed that sedentary behaviour comprises a substantial part of the total day for adults, older adults, children and adolescents. Since 2016, the median sedentary time among adults, older adults and children and adolescents has not changed significantly. For example, median self-report estimates for adults were 5.6 h/day in the period 2012–2021, while studies from the period 2012–2016 showed a median time of 5.5 h/day. However, there seems to be an increase in the number of studies using device-based measurements.

For children and adolescents, prevalence data were higher using self-reported measures compared to device-based measures, whereas self-report estimates were lower than estimates obtained by device-based measures among adults and older adults (the data are summarised in Fig. 2.2). Although samples were not directly comparable, it suggests that adult self-report substantially underestimates total sitting time due to response bias (e.g. imprecise recall or influence of social desirability) [29]. In a validation study, Gupta et al. (2017) reported a mean difference of 204 min per day (~3.5 h/day) for total sitting time for self-reported versus accelerometer-based measures [109]. Also, a recent review of 132 studies comparing the data from 55,199 adults shows that the average mean difference was 1.7 h/day lower when self-reported compared to device measures [14]. Among children, no large difference in estimates was observed between studies using self-reported and device-based measures. However, it should be noted that among children device-based measures tend to be the most frequent mode of surveillance, due to challenges in obtaining accurate self-reported information from children.

Large national surveys of adults used brief questionnaires to report on either total or domain- specific sedentary behaviour. Self-reported questionnaires are less sensitive and include risk of recall bias in relation to changes in sedentary time. However, self-reported time spent sitting at work seems to be better recalled compared to leisure time sedentary behaviour and the total sitting time during the day [14, 110]. For this reason, days of the week that are recalled or assessed by devices need to be considered in estimating total weekly sitting [111]. For example, among working adults, greater sitting time is reported on workdays resulting in variation in sitting time by weekend and weekday.

Estimating the prevalence of high sitting in populations is complicated by a lack of consensus on the dose response relations and no clear threshold for too much sitting. Guidelines for sedentary behaviour only refer to reducing sitting time and, for children and adolescents, to reduce recreational screen time.

In general, most studies show that for adults, mortality risk seems to increase for sitting times greater than 6–8 h/day [10, 20–22]. Thus, it may be inappropriate for studies to define high sitting as a total sitting time less than 6–8 h/day (≥5 h/day) and similarly missing substantial risk where studies define high sitting above the range of 6–8 h/day (≥10 h/day). Further, it is not known whether cut-points for sedentary behaviour differ by domain or differ according to continuous versus interrupted sitting time. However, prolonged bouts of sitting are only reported in a few studies, making it difficult to compare estimates.

Additional challenges for estimating sitting time include survey and sample differences, as some were estimates from population-representative data and others from more selected but large samples. For children and adolescents, screen time measures currently are limited to video games, television and computer time and summed to a measure of total sedentary behaviour. New sedentary technologies, including time on smart phones, games, tablets and other new screen-based devices, may contribute to additional, and currently unmeasured, sedentary time. However, it is still unclear whether screen time is a useful proxy measurement for sedentary time, as screen time does not necessarily take place while sitting or lying due to an increase in portable devices.

2.3 Correlates of Sedentary Behaviour and Sitting

During recent years, it has become apparent that both individual (e.g. age and gender), social (e.g. marital status and socioeconomic status) and environmental factors (e.g. physical environment) influence sedentary behaviours. Factors that influence sedentariness need to be identified in order to develop successfully interventions to address sedentary behaviour. In this section, correlates of sedentary behaviour among adults, older adults and children and adolescents will be described.

2.3.1 Correlates of Sitting in Adults

Numerous studies have examined factors associated with sitting time among working age adults. The contexts and types of sitting vary, as do the factors associated with them, but broadly, studies have examined the correlates of sitting at work and TV time and the correlates of total sitting time [112]. The largest study of sitting correlates was carried out in serial multi-country studies of European adults [9, 26, 113]. Consistent correlates of high sitting time across countries were being a white-collar worker, self-employed, having higher educational attainment, being a student or being retired [9, 112, 113]. Other correlates were low life satisfaction (depression) and both financial insecurity and unemployment [113]. In relation to age and gender differences, there is some variation by domains of sitting. Some studies have reported higher domestic sitting among women while men have higher occupational sitting and sitting for transportation.

Among environmental correlates, those living in urban areas are more likely to have high sitting time [114]. Jelsma et al. [9] showed a threefold variation in high sitting by geographic residence across European countries in 2017 [9]. There is some evidence of higher total sitting time in Northern European countries such as in Denmark and the Netherlands compared to those in the southern parts of Europe [9, 26].

In most research, a strong and consistent positive association is noted between sitting and education attainment, income or measures of social position or socioeconomic status [112, 115]. Those with higher education or socioeconomic position report sitting for longer, especially at work [112]. Full-time employment is a consistent correlate of prolonged sitting [115, 116]. Thus, both sitting time during work and traveling to and from work is higher for full-time workers than for part-time workers. However, some studies have also shown that high sitting at work may result in less sedentary time outside of work [112]. On the other hand, unemployment is positively correlated with more TV and screen time [112]. Thus, the association between workplace sitting time and higher education is reversed for domestic sitting as measured by television time.

There are consistent associations between high domestic sitting time (TV and screen time) and increased body mass index (BMI) [115, 117], and a few studies have also shown positive correlations between occupational sitting time and BMI [112]. One possible explanation of the domain-specific correlations is that leisure sitting time and TV time correlated with food cravings and snacking [112].

The presence of comorbidity and chronic health conditions is consistently associated with increased sitting time [116]. Also, research suggest that sedentary behaviour may be linked (bidirectionally) to mental health outcomes such as depression and anxiety health [118–121], but the evidence for an association between various types of sedentary behaviour and stress is limited [122]. Again, the associations may be influenced by other co-existing factors in which smoking correlates with sedentary behaviour, while alcohol consumption is unrelated [111].

Regarding physical activity, there appears to be an inverse association with sitting time [34]. Survey data from 2017 show some indication of more active people being less likely to be 'high sitters' [9]. However, several other studies have not found that lack of physical activity is associated with high total sitting time [112]. The combination of high volumes of sedentary behaviour combined with low physical activity level may constitute a group most at risk of cardiometabolic disease, but correlates of this 'high sitting/low physical activity' combination need further exploration. In contrast to high sedentary behaviour which is dominated by individuals with higher educational attainment, the combination of high sedentary time and low physical activity is characterised by individuals with lower education [9]. Also, a study has shown that the concomitant pattern of both 'high sitting and low physical activity' is more strongly associated with obesity in young adults and may be a better marker of obesity risk [123].

2.3.2 Correlates of Sitting in Older Adults

Older age groups usually refer to adults approaching or beyond retirement age, typically aged 65 years and older. One consistent factor through older adulthood is increased time spent watching television, partly as a consequence of increased free time, and partly contributed to by decreased mobility or increased comorbidity [124].

Chastin and colleagues (2015) carried out a systematic review of 25 studies of sedentary behaviours among older adults and identified that sitting time increased with age, and with low neighbourhood safety. In addition, those who were retired or had substantial comorbidity (including obesity) were more likely to spend time in prolonged sitting [125]. The trend study by Jelsma et al. [9] found that retired people consistently were more likely to be in the high sitting category compared to manual workers across years from 2002 to 2017 [9]. Furthermore, a national health survey of Canadians showed that older adults sat more if they lived in apartments (compared with living in houses or separated dwellings) or if they felt disconnected from their community. Increased rates of high volumes of sedentary behaviour were also seen among widowed or divorced older adults but showed no clear associations with income or education in older age [9, 126]. Comorbidity was repeatedly associated with prolonged sitting, especially chronic cardiac or pulmonary disease, obesity, low physical activity or poor self-rated health [127]. Similar associations were seen in a large sample of older adults in southern Brazil, where comorbidity and low physical activity were correlates of prolonged sitting time [128], as well as in studies of colon cancer patients [129] and older Canadians [130]. Thus, poorer level of functioning and chronic diseases explain why sedentary time increases with age (cf. Sect. 2.3.2) [131].

A study of older Canadians showed significant correlates included poor self-rated health status, obesity, smoking and low physical activity [132]. Another study of older Canadians suggested that total sitting was correlated with obesity and with home Internet availability [133]. By contrast, an Australian population study failed to find specific correlates of sitting in the elderly, except for social supports and friends who discouraged sitting [134].

Kesse-Guyot et al. (2012) examined the relationship between sedentary time and cognitive function in a large French cohort aged over 65 years and followed between 2001 and 2007 [135]. Increased computer use was associated with improvements in cognitive performance, but increased TV time showed the opposite association. This longitudinal study showed the different health relationships of different contexts and types of sitting. Changes in sitting time in longitudinal studies may better characterise epidemiological exposure and are more useful in understanding correlates/determinants than simple associations from cross-sectional studies [136].

2.3.3 Correlates of Sitting and Sedentary Behaviours Among Children and Adolescents

The majority of children and adolescents attend school, and hence measurement of their sedentary behaviour focuses on their discretionary (outside of school) time. It has been estimated that children spent between 41% and 51% of the after-school period sedentary and that adolescents are more sedentary than children. Sedentary activities include TV viewing and other screen-based behaviours as well as non-screen-based sedentary behaviours such as social sedentary behaviours, motorised transport, homework and reading [137]. Information on the correlates of sedentary behaviour in children and adolescents and screen time in particular can inform intervention efforts for children at greatest risk of sitting for longer periods of time that may impact on their health [108].

Correlate studies among children and adolescents are limited by the differences in the measurement across surveys including variable inclusion of new screen devices. Although better measures of sedentary behaviour are required, there have been several reviews of sedentary behaviour correlates in children and adolescents which consistently show sociodemographic and environmental factors influence sedentary behaviour. The review by Temmel and Rhodes (2013) based on 181 studies published between 2001 and 2011 shows that age, gender and (family) socioeconomic status are consistently associated with children and adolescents' sedentary behaviour [138]. Also, a European study conclude that television viewing and computer use were positively associated with accelerometer-derived sedentary time [139].

Age has been the most consistent correlate with most studies indicating that sedentary behaviour increases as children move into adolescence [138]. There are, however, gender differences in sedentary behaviour, with boys more likely to have higher screen time compared with girls and girls more likely to spend time in non-screen time sedentary behaviour activities such as reading, compared with boys [138, 140].

High socioeconomic status or high parental education was associated with lower levels of some aspects of sedentary behaviour, including children and adolescent's television and video watching time [73, 141]. Some of these aspects of sedentary behaviour were more common among boys than girls [73]. Even within categories of screen time, cultural differences occur, with more television time reported by African-American adolescents from low socioeconomic backgrounds, and more screen and computer time reported by Asian-Americans from higher income backgrounds who also reported less physical activity [73].

Globally, social and economic correlates are less clear, with some evidence of increased sedentary behaviour in urban environments, compared with rural children in low-middle-income countries [142]. There are added seasonal differences in some countries, with increased sedentary behaviour in the coldest or warmest months [143]. Higher screen time has been reported among migrant children in developed countries, compared with nonmigrant children although this may be due to low socioeconomic circumstances, a lack of access to other leisure time facilities and urban crowding [138].

Psychosocial correlates have been examined in several studies. Self-esteem has been shown to be inversely related to screen time [144], and overall measures of sedentary behaviour are associated with reduced quality of life, and measures of emotional health and wellbeing [145]. Regarding behavioural correlates of sedentary behaviour, overall, studies show an inverse association between healthy diet, measured through indicators of fruit and vegetable consumption and sedentary behaviours [138]. Also, sleep is consistently and inversely associated with sedentary behaviour, as there is a displacement effect of more sedentary time encroaching on sleep time; this was demonstrated in a substitution modelling paper using accelerometer data on American adolescents [146]. For children and adolescents, there are clear and inverse associations between physical activity and sedentary behaviour [138, 147, 148] where sedentary behaviour has been shown to be associated with lesser participation in physical education classes [149]. The association between sedentary behaviour and obesity may be stronger for TV time compared to other settings for sedentary behaviours and is partly a consequence of food advertising to children on television, and the displacement of time that could be spent in physical activity [150].

Environmental and social factors influence sedentary behaviours and sitting time and may be moderated by cultural and economic influences. Outdoor environmental factors, such as accessible play spaces and playground density, may be associated with decreased sedentary behaviours and concomitant increases in physical activity [151]. By contrast, low neighbourhood safety is associated with increased sedentary behaviour [138]. Dog ownership and a walkable environment were associated with increased walking but made no difference to sedentary behaviour or screen time [152].

A longitudinal study of Vietnamese adolescents followed from age 11 to age 16 years showed marked increases in screen time through adolescence, especially those from more affluent families, showing a different pattern to developed countries [153]. More important contributions come from indoor and family environments, which influence and regulate sedentary behaviour among adolescents through the presence of a television in the child's bedroom, through parental modelling of sedentary behaviours and physical activity and through behaviours such as being allowed to eat meals in front of television [154, 155]. Studies to 2011 were remarkably consistent in this area, with all of 19 studies showing associations between TV in the bedroom and increased sedentary behaviour [138].

Information on the prevalence and correlates of sedentary behaviour among preschool age children is limited. In this age group, sedentary behaviour is reported by parents who can only report on their child's behaviour while in their care. There is some information on screen time in this age group, and a review estimated that preschoolers screen time ranges from 37 minutes up to almost 6 h a day [156]. Further, sedentary behaviour among preschool-age children differs from sedentary behaviour in older children. For example, no studies have examined time spent in strollers/prams and other child restraint devices (e.g. play pens, car seats). Accelerometers have been used in this age group, but these devices provide no contextual information on the child's sedentary behaviour and the information that is collected is hampered by the lack of consensus on cut points for sedentary behaviour.

2.4 Implications of Current Prevalence and Correlates of Sedentary Behaviour

When monitoring sedentary behaviour in the general population, it is often desirable to use the most low-cost and feasible but also the most accurate and robust methods. Different measures assess sedentary behaviours in different contexts, and for population surveillance, and provide different and complementary information (Chap. 3). Self-report measures provide a measure of perceived behaviour and can provide more contextual information such as the type of sedentary behaviour being performed (e.g. television watching, passive transport, screen time), whereas device measures continuously capture bodily movement at specific thresholds or in specific postures (i.e. sitting/lying), but often lack contextual information [157]. The variability has great consequences for the interpretation of the prevalence of total sitting time in the population. In this chapter, we have reported on the prevalence in large sample and population studies measured by either self-reported or device-based measured sitting time. Among adults, the self-reported estimate was 2.7 h less than that measured by device-based assessment. Surveillance data on sedentary behaviour rely on cross-sectional prevalence studies and is influenced by methods used for collection and assessment of data. Thus, the proportional increase in the number of device-based studies compared to self-reported studies may explain the apparent increase in the overall median sitting time.

Device-based methods may better characterise sedentary behaviour and should be applied in prevalence studies. Rapid changes in future technologies may provide new methods for assessing sedentary time. Nonetheless, the respondent burden, costs and feasibility should be considered when assessing sedentary behaviour in large population samples. Further, besides measuring duration, information on both total and domain-specific sedentary behaviour are needed to better characterise risks associated with sedentary behaviour. Furthermore, there is a fundamental need to monitor the prevalence of sedentary behaviours over time, using identical measures and methods to identify population trends. Few trend studies have investigated changes in sedentary behaviour over the past years; however, sedentary behaviour is defined by different cut-point and some studies look at 'high sitting time' based on epidemiological evidence (≥6–8 h/day). Using device-based measures is desirable, but would need to be future-proof, to prevent technical advances creating noncomparable population measurements [158].

Based on the concept of 'tracking', prevalence across the lifespan can contribute important policy-relevant information. In a longitudinal perspective, sedentary behaviour among children today 'tracks' into adulthood, as some sedentary behaviours such as screen time may have strong habitual elements [159, 160]. Therefore, childhood may be a critical period in the development of healthy sedentary behaviour habits as it reduces the longer-term health consequences of high volumes of sedentary behaviour later in life. A pooled analysis estimated that total sedentary time increases by 21 min/day per year on average in youth, suggesting that young people with high levels of sedentary time are likely to retain high sedentary time as they grow older [161].

A diverse set of sedentary behaviours increase throughout childhood and adolescence, as active play time is replaced by sedentary screen time, a sociocultural trend that may further increase sedentary time in many countries. Increases in sedentary behaviours also reduce time for physical activity in children and adolescents but also in adults and older adults, and efforts to maintain physical activity levels remain paramount.

For older adults, high rates of sedentary behaviour are attributable to the domestic setting, television watching and comorbidity. Device-based assessment is again substantially higher than self-report sitting, with estimates from Denmark and the USA ranging from 9.9 to 10.9 h/day of sitting time.

During recent years it seems that rates of sedentary behaviour remain stable in high-income countries. However, specifically during 2020 and 2021, the COVID-19 epidemic was associated with reduced overall physical activity in the population, particularly among already inactive populations, and likely increased sedentary behaviour time for both adults and children [162, 163]. Even though people were allowed out for an hour per day in some countries during lockdown periods of COVID-19 epidemic cases, commuting was reduced due to changed working conditions, and total and much incidental physical activity were reduced and replaced by housebound increased sitting time [164]. Despite the recognised mental and physical health benefits of being active during the pandemic, and to reduce COVID-19 infection severity [165], we still have little knowledge of the consequences of increased sedentary behaviour due to the COVID-19 pandemic.

Many of risk factors correlates with sedentary behaviour in some domains only (such as TV time) and may be simply associations, as the true relationships may be bidirectional [119, 166]. Also, the aspect of the 'sitting-obesity' relationship is challenged by research predominantly from cross-sectional studies [117]. An interesting observation was seen in a longitudinal study regarding prolonged sitting in cars in which daily car commuters had an increase in weight gain of around 0.2 kg per year compared to those not engaged in lengthy car commutes or not travelling to work [167]. Also, the co-existence of risk factors underlines the complexity and synergistic clustering risk in some sedentary segments which need to be further explored in future surveillance studies.

In terms of epidemiologic risk, the synergistic combination of 'high sitting and low physical activity' may be of particular concern. In recent years, the epidemiologic evidence has started to change, suggesting that much of the risk of sedentary time can be offset by high levels of physical activity, both for all-cause mortality and for cardiovascular and cancer risk [2, 10]. Few surveillance system assess this, but in a study of over 30 European countries monitored over time through the Eurobarometer surveys, rates of 'high sitting-low activity' did not change between 2005 and 2017 [9]; in 91 estimates from European countries across 3 time points, the median prevalence of 'high sitting-low active' group was 8.4% (interquartile range 7.1, 10.6); that is a small population segment but is at substantial risk, and it may worthwhile to monitor this combined attribute in ongoing surveillance systems.

The factors associated with sedentary behaviours are somewhat different to those associated with physical activity. In particular, high education and full-time employment are associated with higher work-related sedentary behaviour, and in these groups, physical activity shows the inverse pattern. Nonetheless, some sedentary behaviour settings, such as TV time at home, are inversely related to socioeconomic characteristics for both adults and adolescents. For children, gender, socioeconomic position and environmental correlates are different across sub-groups. Some correlates are modifiable and therefore of policy relevance, such as parental rules about screen time and having TVs and other screen-based devices in the child's bedroom. Overall, the research that has produced many correlate studies that are limited by cross-sectional research designs and longitudinal research will better clarify which factors are more likely to show a causal relationship to sedentary behaviour in adults and children.

In conclusion, sedentary behaviours are pervasive, especially in the most affluent countries, and need careful measurement and monitoring and better understanding and sub-group identification in the population. The published prevalence studies primarily focus on duration of sedentary behaviour, while knowledge about different domains and prolonged bouts of sedentary behaviour is needed. Given the high proportions of the waking day that is spent in different domains of sedentary behaviour, this area merits greater research attention.

References

1. Ku P-W, Steptoe A, Liao Y, Hsueh M-C, Chen L-J. A cut-off of daily sedentary time and all-cause mortality in adults: a meta-regression analysis involving more than 1 million participants. BMC Med. 2018;16(1):1–9.
2. Ekelund U, Brown WJ, Steene-Johannessen J, Fagerland MW, Owen N, Powell KE, et al. Do the associations of sedentary behaviour with cardiovascular disease mortality and cancer mortality differ by physical activity level? A systematic review and harmonised meta-analysis of data from 850 060 participants. Br J Sports Med. 2019;53(14):886–94.
3. Bailey DP, Hewson DJ, Champion RB, Sayegh SM. Sitting time and risk of cardiovascular disease and diabetes: a systematic review and meta-analysis. Am J Prev Med. 2019;57(3): 408–16.
4. Berger FF, Leitzmann MF, Hillreiner A, Sedlmeier AM, Prokopidi-Danisch ME, Burger M, et al. Sedentary behavior and prostate cancer: a systematic review and meta-analysis of prospective cohort studies. Cancer Prev Res. 2019;12(10):675–88.
5. Wang J, Huang L, Gao Y, Wang Y, Chen S, Huang J, et al. Physically active individuals have a 23% lower risk of any colorectal neoplasia and a 27% lower risk of advanced colorectal neoplasia than their non-active counterparts: systematic review and meta-analysis of observational studies. Br J Sports Med. 2020;54(10):582–91.
6. Patterson R, McNamara E, Tainio M, de Sá TH, Smith AD, Sharp SJ, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. Eur J Epidemiol. 2018;33 (9):811–29.
7. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32.
8. Milton K, Gale J, Stamatakis E, Bauman A. Trends in prolonged sitting time among European adults: 27 country analysis. Prev Med. 2015;77:11–6.
9. Jelsma JG, Gale J, Loyen A, van Nassau F, Bauman A, van der Ploeg HP. Time trends between 2002 and 2017 in correlates of self-reported sitting time in European adults. PLoS One. 2019;14(11):e0225228.
10. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet. 2016;388(10051):1302–10.
11. Bauman AE, Petersen CB, Blond K, Rangul V, Hardy LL. The descriptive epidemiology of sedentary behaviour. In: Sedentary behaviour epidemiology. Springer; 2018. p. 73–106.
12. Panahi S, Tremblay A. Sedentariness and health: is sedentary behavior more than just physical inactivity? Front Public Health. 2018;6:258.
13. Healy GN, Clark BK, Winkler EA, Gardiner PA, Brown WJ, Matthews CE. Measurement of adults' sedentary time in population-based studies. Am J Prev Med. 2011;41(2):216–27.
14. Prince SA, Cardilli L, Reed JL, Saunders TJ, Kite C, Douillette K, et al. A comparison of self-reported and device measured sedentary behaviour in adults: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2020;17(1):1–17.
15. Dall P, Coulter EH, Fitzsimons C, Skelton D, Chastin SF. TAxonomy of Self-reported Sedentary behaviour Tools (TASST) framework for development, comparison and evaluation of self-report tools: content analysis and systematic review. BMJ Open. 2017;7(4):e013844.
16. Pate RR, O'Neill JR, Mitchell J. Measurement of physical activity in preschool children. Med Sci Sports Exerc. 2010;42(3):508–12.
17. van Nassau F, Chau JY, Lakerveld J, Bauman AE, van der Ploeg HP. Validity and responsiveness of four measures of occupational sitting and standing. Int J Behav Nutr Phys Act. 2015;12(1):1–9.

18. Strain T, Wijndaele K, Dempsey PC, Sharp SJ, Pearce M, Jeon J, et al. Wearable-device-measured physical activity and future health risk. Nat Med. 2020;26(9):1385–91.
19. Bauman A, Pedišić Ž, Bragg K. Objective measurement in physical activity surveillance: Present role and future potential. In: The objective monitoring of physical activity: contributions of accelerometry to epidemiology, exercise science and rehabilitation. New York: Springer; 2016. p. 347–67.
20. Stamatakis E, Gale J, Bauman A, Ekelund U, Hamer M, Ding D. Sitting time, physical activity, and risk of mortality in adults. J Am Coll Cardiol. 2019;73(16):2062–72.
21. Ussery EN, Whitfield GP, Fulton JE, Galuska DA, Matthews CE, Katzmarzyk PT, et al. Trends in self-reported sitting time by physical activity levels among US adults, NHANES 2007/2008–2017/2018. J Phys Act Health. 2021;18(S1):S74–83.
22. Ussery EN, Fulton JE, Galuska DA, Katzmarzyk PT, Carlson SA. Joint prevalence of sitting time and leisure-time physical activity among US adults, 2015-2016. JAMA. 2018;320(19): 2036–8.
23. Aadahl M, Andreasen AH, Hammer-Helmich L, Buhelt L, Jørgensen T, Glümer C. Recent temporal trends in sleep duration, domain-specific sedentary behaviour and physical activity. A survey among 25–79-year-old Danish adults. Scand J Public Health. 2013;41(7):706–11.
24. Aguilar-Farias N, Martino-Fuentealba P, Cortinez-O'Ryan A, Chandia-Poblete D, Celis-Morales CA, Bahamondes P, et al. The descriptive epidemiology of sitting in Chilean adults: results from the National Health Survey 2009–2010. J Sport Health Sci. 2019;8(1):32–8.
25. Asztalos M, Cardon G, De Bourdeaudhuij I, De Cocker K. Cross-sectional associations between sitting time and several aspects of mental health in Belgian adults. J Phys Act Health. 2015;12(8):1112–8.
26. Bennie JA, Chau JY, van der Ploeg HP, Stamatakis E, Do A, Bauman A. The prevalence and correlates of sitting in European adults: a comparison of 32 Eurobarometer-participating countries. Int J Behav Nutr Phys Act. 2013;10(1):1–13.
27. Petersen CB, Bauman A, Grønbæk M, Helge JW, Thygesen LC, Tolstrup JS. Total sitting time and risk of myocardial infarction, coronary heart disease and all-cause mortality in a prospective cohort of Danish adults. Int J Behav Nutr Phys Act. 2014;11(1):1–11.
28. Borodulin K, Kärki A, Laatikainen T, Peltonen M, Luoto R. Daily sedentary time and risk of cardiovascular disease: the national FINRISK 2002 study. J Phys Act Health. 2015;12(7): 904–8.
29. Celis-Morales C, Salas C, Alduhishy A, Sanzana R, Martínez MA, Leiva A, et al. Socio-demographic patterns of physical activity and sedentary behaviour in Chile: results from the National Health Survey 2009–2010. J Public Health. 2016;38(2):e98–e105.
30. Chau JY, Grunseit A, Midthjell K, Holmen J, Holmen TL, Bauman AE, et al. Sedentary behaviour and risk of mortality from all-causes and cardiometabolic diseases in adults: evidence from the HUNT3 population cohort. Br J Sports Med. 2015;49(11):737–42.
31. Chau JY, van der Ploeg HP, Merom D, Chey T, Bauman AE. Cross-sectional associations between occupational and leisure-time sitting, physical activity and obesity in working adults. Prev Med. 2012;54(3–4):195–200.
32. Clemes SA, Houdmont J, Munir F, Wilson K, Kerr R, Addley K. Descriptive epidemiology of domain-specific sitting in working adults: the Stormont Study. J Public Health. 2016;38(1): 53–60.
33. Guallar-Castillón P, Bayán-Bravo A, León-Muñoz LM, Balboa-Castillo T, López-García E, Gutierrez-Fisac JL, et al. The association of major patterns of physical activity, sedentary behavior and sleep with health-related quality of life: a cohort study. Prev Med. 2014;67:248–54.
34. Hadgraft NT, Lynch BM, Clark BK, Healy GN, Owen N, Dunstan DW. Excessive sitting at work and at home: correlates of occupational sitting and TV viewing time in working adults. BMC Public Health. 2015;15(1):1–13.
35. Hamer M, Chida Y. Walking and primary prevention: a meta-analysis of prospective cohort studies. Br J Sports Med. 2008;42(4):238–43.

36. Herman KM, Saunders TJ. Sedentary behaviours among adults across Canada. Can J Public Health. 2016;107(4):e438–e46.
37. Horta BL, Schaan BD, Bielemann RM, Vianna CÁ, Gigante DP, Barros FC, et al. Objectively measured physical activity and sedentary-time are associated with arterial stiffness in Brazilian young adults. Atherosclerosis. 2015;243(1):148–54.
38. Lin T-C, Courtney TK, Lombardi DA, Verma SK. Association between sedentary work and BMI in a US national longitudinal survey. Am J Prev Med. 2015;49(6):e117–23.
39. Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. Am J Clin Nutr. 2012;95(2):437–45.
40. Matthews CE, Cohen SS, Fowke JH, Han X, Xiao Q, Buchowski MS, et al. Physical activity, sedentary behavior, and cause-specific mortality in black and white adults in the Southern Community Cohort Study. Am J Epidemiol. 2014;180(4):394–405.
41. Matthews CE, Carlson SA, Saint-Maurice PF, Patel S, Salerno E, Loftfield E, et al. Sedentary behavior in United States adults: Fall 2019. Med Sci Sports Exerc. 2021;53:2512.
42. Medina C, Jáuregui A, Hernández C, Shamah T, Barquera S. Physical inactivity and sitting time prevalence and trends in Mexican adults. Results from three national surveys. PLoS One. 2021;16(7):e0253137.
43. Mielke GI, da Silva IC, Owen N, Hallal PC. Brazilian adults' sedentary behaviors by life domain: population-based study. PLoS One. 2014;9(3):e91614.
44. Munir F, Houdmont J, Clemes S, Wilson K, Kerr R, Addley K. Work engagement and its association with occupational sitting time: results from the Stormont study. BMC Public Health. 2015;15(1):1–12.
45. Milton K, Macniven R, Bauman A. Review of the epidemiological evidence for physical activity and health from low-and middle-income countries. Glob Public Health. 2014;9(4): 369–81.
46. Mitáš J, Ding D, Frömel K, Kerr J. Physical activity, sedentary behavior, and body mass index in the Czech Republic: a nationally representative survey. J Phys Act Health. 2014;11(5): 903–7.
47. Pinto Pereira SM, Power C. Sedentary behaviours in mid-adulthood and subsequent body mass index. PLoS One. 2013;8(6):e65791.
48. Ryu S, Chang Y, Jung H-S, Yun KE, Kwon M-J, Choi Y, et al. Relationship of sitting time and physical activity with non-alcoholic fatty liver disease. J Hepatol. 2015;63(5):1229–37.
49. Saidj M, Menai M, Charreire H, Weber C, Enaux C, Aadahl M, et al. Descriptive study of sedentary behaviours in 35,444 French working adults: cross-sectional findings from the ACTI-Cités study. BMC Public Health. 2015;15(1):1–10.
50. Saidj M, Jørgensen T, Jacobsen RK, Linneberg A, Aadahl M. The influence of housing characteristics on leisure-time sitting. A prospective cohort study in Danish adults. Prev Med. 2015;81:58–62.
51. Sharkas GF, Saheb T, Arqoub K, Haddadin R. Sedentary lifestyle among adults in Jordan, 2007. Fam Med Community Health. 2016;4(3):4–8.
52. Shih Y-H, Chang H-Y, Lu M-I, Hurng B-S. Time trend of prevalence of self-reported cataract and its association with prolonged sitting in Taiwan from 2001 and 2013. BMC Ophthalmol. 2014;14(1):1–9.
53. Sloan RA, Sawada SS, Girdano D, Liu YT, Biddle SJ, Blair SN. Associations of sedentary behavior and physical activity with psychological distress: a cross-sectional study from Singapore. BMC Public Health. 2013;13(1):1–8.
54. Södergren M, McNaughton SA, Salmon J, Ball K, Crawford DA. Associations between fruit and vegetable intake, leisure-time physical activity, sitting time and self-rated health among older adults: cross-sectional data from the WELL study. BMC Public Health. 2012;12(1):1–9.
55. Staiano A, Harrington D, Barreira T, Katzmarzyk P. Sitting time and cardiometabolic risk in US adults: associations by sex, race, socioeconomic status and activity level. Br J Sports Med. 2014;48(3):213–9.

56. Stamatakis E, Davis M, Stathi A, Hamer M. Associations between multiple indicators of objectively-measured and self-reported sedentary behaviour and cardiometabolic risk in older adults. Prev Med. 2012;54(1):82–7.
57. Stamatakis E, Hamer M, Tilling K, Lawlor DA. Sedentary time in relation to cardio-metabolic risk factors: differential associations for self-report vs accelerometry in working age adults. Int J Epidemiol. 2012;41(5):1328–37.
58. Tcymbal A, Andreasyan D, Whiting S, Mikkelsen B, Rakovac I, Breda J. Prevalence of physical inactivity and sedentary behavior among adults in Armenia. Front Public Health. 2020;8:157.
59. Van der Ploeg HP, Chey T, Korda RJ, Banks E, Bauman A. Sitting time and all-cause mortality risk in 222 497 Australian adults. Arch Intern Med. 2012;172(6):494–500.
60. Wallmann-Sperlich B, Bucksch J, Hansen S, Schantz P, Froboese I. Sitting time in Germany: an analysis of socio-demographic and environmental correlates. BMC Public Health. 2013;13 (1):1–10.
61. Win AM, Yen LW, Tan KH, Lim RBT, Chia KS, Mueller-Riemenschneider F. Patterns of physical activity and sedentary behavior in a representative sample of a multi-ethnic South-East Asian population: a cross-sectional study. BMC Public Health. 2015;15(1):1–11.
62. Yang L, Cao C, Kantor ED, Nguyen LH, Zheng X, Park Y, et al. Trends in sedentary behavior among the US population, 2001-2016. JAMA. 2019;321(16):1587–97.
63. Gibbs BB, Gabriel KP, Reis JP, Jakicic JM, Carnethon MR, Sternfeld B. Cross-sectional and longitudinal associations between objectively measured sedentary time and metabolic disease: the Coronary Artery Risk Development in Young Adults (CARDIA) study. Diabetes Care. 2015;38(10):1835–43.
64. Carson V, Wong SL, Winkler E, Healy GN, Colley RC, Tremblay MS. Patterns of sedentary time and cardiometabolic risk among Canadian adults. Prev Med. 2014;65:23–7.
65. Chen T, Kishimoto H, Honda T, Hata J, Yoshida D, Mukai N, et al. Patterns and levels of sedentary behavior and physical activity in a general Japanese population: the Hisayama study. J Epidemiol. 2017;2017:JE20170012.
66. Hagströmer M, Kwak L, Oja P, Sjöström M. A 6 year longitudinal study of accelerometer-measured physical activity and sedentary time in Swedish adults. J Sci Med Sport. 2015;18(5): 553–7.
67. Husu P, Suni J, Vähä-Ypyä H, Sievänen H, Tokola K, Valkeinen H, et al. Objectively measured sedentary behavior and physical activity in a sample of Finnish adults: a cross-sectional study. BMC Public Health. 2016;16(1):1–11.
68. Johansson MS, Korshøj M, Schnohr P, Marott JL, Prescott EIB, Søgaard K, et al. Time spent cycling, walking, running, standing and sedentary: a cross-sectional analysis of accelerometer-data from 1670 adults in the Copenhagen City Heart Study. BMC Public Health. 2019;19(1): 1–13.
69. Kim Y, Welk GJ, Braun SI, Kang M. Extracting objective estimates of sedentary behavior from accelerometer data: measurement considerations for surveillance and research applications. PLoS One. 2015;10(2):e0118078.
70. Qi Q, Strizich G, Merchant G, Sotres-Alvarez D, Buelna C, Castañeda SF, et al. Objectively measured sedentary time and cardiometabolic biomarkers in US Hispanic/Latino adults: the Hispanic Community Health Study/Study of Latinos (HCHS/SOL). Circulation. 2015;132 (16):1560–9.
71. Van Dyck D, Cerin E, De Bourdeaudhuij I, Hinckson E, Reis RS, Davey R, et al. International study of objectively measured physical activity and sedentary time with body mass index and obesity: IPEN adult study. Int J Obes. 2015;39(2):199–207.
72. Yatsugi H, Chen T, Chen S, Narazaki K, Nagayoshi S, Kumagai S, et al. Normative data of objectively measured physical activity and sedentary time in community—dwelling older Japanese. Int J Environ Res Public Health. 2021;18(7):3577.
73. Babey SH, Hastert TA, Wolstein J. Adolescent sedentary behaviors: correlates differ for television viewing and computer use. J Adolesc Health. 2013;52(1):70–6.

74. Baygi F, Heshmat R, Kelishadi R, Mohammadi F, Motlagh ME, Ardalan G, et al. Regional disparities in sedentary behaviors and meal frequency in Iranian adolescents: the CASPIAN-III study. Iran J Pediatr. 2015;25(2):e182.
75. Carson V, Staiano AE, Katzmarzyk PT. Physical activity, screen time, and sitting among US adolescents. Pediatr Exerc Sci. 2015;27(1):151–9.
76. Chen Y-C, Tu Y-K, Huang K-C, Chen P-C, Chu D-C, Lee YL. Pathway from central obesity to childhood asthma. Physical fitness and sedentary time are leading factors. Am J Respir Crit Care Med. 2014;189(10):1194–203.
77. Chen Y, Zheng Z, Yi J, Yao S. Associations between physical inactivity and sedentary behaviors among adolescents in 10 cities in China. BMC Public Health. 2014;14(1):1–9.
78. Dadvand P, Villanueva CM, Font-Ribera L, Martinez D, Basagaña X, Belmonte J, et al. Risks and benefits of green spaces for children: a cross-sectional study of associations with sedentary behavior, obesity, asthma, and allergy. Environ Health Perspect. 2014;122(12):1329–35.
79. Duan J, Hu H, Wang G, Arao T. Study on current levels of physical activity and sedentary behavior among middle school students in Beijing, China. PLoS One. 2015;10(7):e0133544.
80. Iannotti RJ, Wang J. Trends in physical activity, sedentary behavior, diet, and BMI among US adolescents, 2001–2009. Pediatrics. 2013;132(4):606–14.
81. Kiefte-de Jong JC, de Vries JH, Escher JC, Jaddoe VW, Hofman A, Raat H, et al. Role of dietary patterns, sedentary behaviour and overweight on the longitudinal development of childhood constipation: the Generation R study. Matern Child Nutr. 2013;9(4):511–23.
82. Kim Y, Barreira TV, Kang M. Concurrent associations of physical activity and screen-based sedentary behavior on obesity among US adolescents: a latent class analysis. J Epidemiol. 2016;26(3):137–44.
83. Kong IG, Lee H-J, Kim SY, Sim S, Choi HG. Physical activity, study sitting time, leisure sitting time, and sleep time are differently associated with obesity in Korean adolescents: a population-based study. Medicine. 2015;94(44):e1965.
84. Leatherdale ST, Harvey A. Examining communication-and media-based recreational sedentary behaviors among Canadian youth: results from the COMPASS study. Prev Med. 2015;74:74–80.
85. Lee PH. Association between adolescents' physical activity and sedentary behaviors with change in BMI and risk of type 2 diabetes. PLoS One. 2014;9(10):e110732.
86. Loprinzi PD. Association of family functioning on youth physical activity and sedentary behavior. J Phys Act Health. 2015;12(5):642–8.
87. van Rossem L, Vogel I, Moll HA, Jaddoe VW, Hofman A, Mackenbach JP, et al. An observational study on socio-economic and ethnic differences in indicators of sedentary behavior and physical activity in preschool children. Prev Med. 2012;54(1):55–60.
88. Wijtzes AI, Bouthoorn SH, Jansen W, Franco OH, Hofman A, Jaddoe VW, et al. Sedentary behaviors, physical activity behaviors, and body fat in 6-year-old children: the generation R study. Int J Behav Nutr Phys Act. 2014;11(1):1–10.
89. Zhang J, Seo D-C, Kolbe L, Middlestadt S, Zhao W. Associated trends in sedentary behavior and BMI among Chinese school children and adolescents in seven diverse Chinese provinces. Int J Behav Med. 2012;19(3):342–50.
90. Atkin AJ, Corder K, van Sluijs EM. Bedroom media, sedentary time and screen-time in children: a longitudinal analysis. Int J Behav Nutr Phys Act. 2013;10(1):1–10.
91. Herrmann D, Buck C, Sioen I, Kouride Y, Marild S, Molnár D, et al. Impact of physical activity, sedentary behaviour and muscle strength on bone stiffness in 2–10-year-old children-cross-sectional results from the IDEFICS study. Int J Behav Nutr Phys Act. 2015;12(1):1–12.
92. Hildebrand M, Kolle E, Hansen BH, Collings PJ, Wijndaele K, Kordas K, et al. Association between birth weight and objectively measured sedentary time is mediated by central adiposity: data in 10,793 youth from the International Children's Accelerometry Database. Am J Clin Nutr. 2015;101(5):983–90.

93. Katzmarzyk PT, Barreira TV, Broyles ST, Champagne CM, Chaput JP, Fogelholm M, et al. Physical activity, sedentary time, and obesity in an international sample of children. Med Sci Sports Exerc. 2015;47(10):2062–9.
94. Loprinzi PD, Cardinal BJ, Lee H, Tudor-Locke C. Markers of adiposity among children and adolescents: implications of the isotemporal substitution paradigm with sedentary behavior and physical activity patterns. J Diabetes Metab Disord. 2015;14(1):1–14.
95. Santos R, Mota J, Okely AD, Pratt M, Moreira C, Coelho-e-Silva MJ, et al. The independent associations of sedentary behaviour and physical activity on cardiorespiratory fitness. Br J Sports Med. 2014;48(20):1508–12.
96. Sherar LB, Griffin TP, Ekelund U, Cooper AR, Esliger DW, van Sluijs EM, et al. Association between maternal education and objectively measured physical activity and sedentary time in adolescents. J Epidemiol Community Health. 2016;70(6):541–8.
97. Brown WJ, Bauman AE, Owen N. Stand up, sit down, keep moving: turning circles in physical activity research? Br J Sports Med. 2009;43(2):86–8.
98. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior: determinants and interventions. Am J Prev Med. 2011;41(2):189–96.
99. Ryan CG, Dall PM, Granat MH, Grant PM. Sitting patterns at work: objective measurement of adherence to current recommendations. Ergonomics. 2011;54(6):531–8.
100. Thorp AA, Healy GN, Winkler E, Clark BK, Gardiner PA, Owen N, et al. Prolonged sedentary time and physical activity in workplace and non-work contexts: a cross-sectional study of office, customer service and call centre employees. Int J Behav Nutr Phys Act. 2012;9(1):1–9.
101. Church TS, Thomas DM, Tudor-Locke C, Katzmarzyk PT, Earnest CP, Rodarte RQ, et al. Trends over 5 decades in US occupation-related physical activity and their associations with obesity. PLoS One. 2011;6(5):e19657.
102. Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. Obes Rev. 2012;13(8):659–80.
103. Eurostat. Majority commuted less than 30 minutes in 2019. 2020. Available from https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20201021-2
104. Guthold R, Stevens GA, Riley LM, Bull FC. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants. Lancet Glob Health. 2018;6(10):e1077–e86.
105. Wullems JA, Verschueren SM, Degens H, Morse CI, Onambélé GL. A review of the assessment and prevalence of sedentarism in older adults, its physiology/health impact and non-exercise mobility counter-measures. Biogerontology. 2016;17(3):547–65.
106. Harvey JA, Chastin SF, Skelton DA. Prevalence of sedentary behavior in older adults: a systematic review. Int J Environ Res Public Health. 2013;10(12):6645–61.
107. World Health Organization. WHO guidelines on physical activity and sedentary behaviour. 2020.
108. van Sluijs EM, Ekelund U, Crochemore-Silva I, Guthold R, Ha A, Lubans D, et al. Physical activity behaviours in adolescence: current evidence and opportunities for intervention. Lancet. 2021;398:429.
109. Gupta N, Christiansen CS, Hanisch C, Bay H, Burr H, Holtermann A. Is questionnaire-based sitting time inaccurate and can it be improved? A cross-sectional investigation using accelerometer-based sitting time. BMJ Open. 2017;7(1):e013251.
110. Pedersen ESL, Danquah I, Petersen C, Tolstrup J. Intra-individual variability in day-to-day and month-to-month measurements of physical activity and sedentary behaviour at work and in leisure-time among Danish adults. BMC Public Health. 2016;16(1):1–9.
111. Van Uffelen JG, Heesch KC, Brown W. Correlates of sitting time in working age Australian women: who should be targeted with interventions to decrease sitting time? J Phys Act Health. 2012;9(2):270–87.
112. O'Donoghue G, Perchoux C, Mensah K, Lakerveld J, Van Der Ploeg H, Bernaards C, et al. A systematic review of correlates of sedentary behaviour in adults aged 18–65 years: a socio-ecological approach. BMC Public Health. 2016;16(1):1–25.

113. Loyen A, van der Ploeg HP, Bauman A, Brug J, Lakerveld J. European sitting championship: prevalence and correlates of self-reported sitting time in the 28 European Union member states. PLoS One. 2016;11(3):e0149320.
114. Lakerveld J, Loyen A, Schotman N, Peeters CF, Cardon G, van der Ploeg HP, et al. Sitting too much: a hierarchy of socio-demographic correlates. Prev Med. 2017;101:77–83.
115. Loyen A, Chau JY, Jelsma JG, Van Nassau F, Van Der Ploeg HP. Prevalence and correlates of domain-specific sedentary time of adults in The Netherlands: findings from the 2006 Dutch time use survey. BMC Public Health. 2019;19(2):1–12.
116. Plotnikoff RC, Costigan SA, Short C, Grunseit A, James E, Johnson N, et al. Factors associated with higher sitting time in general, chronic disease, and psychologically-distressed, adult populations: findings from the 45 & up study. PLoS One. 2015;10(6):e0127689.
117. Ahmad S, Shanmugasegaram S, Walker K, Prince S. Examining sedentary time as a risk factor for cardiometabolic diseases and their markers in South Asian adults: a systematic review. Int J Public Health. 2017;62(4):503–15.
118. Hamer M, Stamatakis E, Mishra GD. Television-and screen-based activity and mental well-being in adults. Am J Prev Med. 2010;38(4):375–80.
119. Rebar AL, Vandelanotte C, Van Uffelen J, Short C, Duncan MJ. Associations of overall sitting time and sitting time in different contexts with depression, anxiety, and stress symptoms. Ment Health Phys Act. 2014;7(2):105–10.
120. Puig-Ribera A, Martínez-Lemos I, Giné-Garriga M, González-Suárez ÁM, Bort-Roig J, Fortuño J, et al. Self-reported sitting time and physical activity: interactive associations with mental well-being and productivity in office employees. BMC Public Health. 2015;15(1): 1–10.
121. Teychenne M, Costigan SA, Parker K. The association between sedentary behaviour and risk of anxiety: a systematic review. BMC Public Health. 2015;15(1):1–8.
122. Teychenne M, Stephens LD, Costigan SA, Olstad DL, Stubbs B, Turner AI. The association between sedentary behaviour and indicators of stress: a systematic review. BMC Public Health. 2019;19(1):1–15.
123. Cleland V, Schmidt M, Salmon J, Dywer T, Venn A. Combined associations of sitting time and physical activity with obesity in young adults. J Phys Act Health. 2014;11(1):136–44.
124. Gardiner PA, Healy GN, Eakin EG, Clark BK, Dunstan DW, Shaw JE, et al. Associations between television viewing time and overall sitting time with the metabolic syndrome in older men and women: the Australian diabetes obesity and lifestyle study. J Am Geriatr Soc. 2011;59(5):788–96.
125. Chastin SF, Buck C, Freiberger E, Murphy M, Brug J, Cardon G, et al. Systematic literature review of determinants of sedentary behaviour in older adults: a DEDIPAC study. Int J Behav Nutr Phys Act. 2015;12:127.
126. Dogra S, Stathokostas L. Correlates of extended sitting time in older adults: an exploratory cross-sectional analysis of the Canadian Community Health Survey Healthy Aging Cycle. Int J Public Health. 2014;59(6):983–91.
127. Biaani L-GB, Palència L, Puig-Ribera A, Bartoll X, Pérez K. Does adult recreational screen-time sedentary behavior have an effect on self-perceived health? Public Health in Practice. 2020;1:100055.
128. Meneguci J, Sasaki JE, da Silva SÁ, Scatena LM, Damião R. Socio-demographic, clinical and health behavior correlates of sitting time in older adults. BMC Public Health. 2015;15(1): 1–10.
129. Lynch BM, Boyle T, Winkler E, Occleston J, Courneya KS, Vallance JK. Patterns and correlates of accelerometer-assessed physical activity and sedentary time among colon cancer survivors. Cancer Causes Control. 2016;27(1):59–68.
130. Brazeau A-S, Hajna S, Joseph L, Dasgupta K. Correlates of sitting time in adults with type 2 diabetes. BMC Public Health. 2015;15(1):1–7.

131. Koltyn KF, Crombie KM, Brellenthin AG, Leitzelar B, Ellingson LD, Renken J, et al. Intervening to reduce sedentary behavior in older adults–pilot results. Health Promot Perspect. 2019;9(1):71.
132. Copeland JL, Clarke J, Dogra S. Objectively measured and self-reported sedentary time in older Canadians. Prev Med Rep. 2015;2:90–5.
133. Vallance JK, Buman MP, Stevinson C, Lynch BM. Associations of overall sedentary time and screen time with sleep outcomes. Am J Health Behav. 2015;39(1):62–7.
134. Van Holle V, McNaughton SA, Teychenne M, Timperio A, Van Dyck D, De Bourdeaudhuij I, et al. Social and physical environmental correlates of adults' weekend sitting time and moderating effects of retirement status and physical health. Int J Environ Res Public Health. 2014;11(9):9790–810.
135. Kesse-Guyot E, Charreire H, Andreeva VA, Touvier M, Hercberg S, Galan P, et al. Cross-sectional and longitudinal associations of different sedentary behaviors with cognitive performance in older adults. PLoS One. 2012;7(10):e47831.
136. Leon-Munoz LM, Martinez-Gomez D, Balboa-Castillo T, Lopez-Garcia E, Guallar-Castillon-P, Rodriguez-Artalejo F. Continued sedentariness, change in sitting time, and mortality in older adults. Med Sci Sports Exerc. 2013;45(8):1501–7.
137. Arundell L, Fletcher E, Salmon J, Veitch J, Hinkley T. A systematic review of the prevalence of sedentary behavior during the after-school period among children aged 5-18 years. Int J Behav Nutr Phys Act. 2016;13(1):1–9.
138. Temmel CS, Rhodes R. Correlates of sedentary behaviour in children and adolescents aged 7-18: a systematic review. Health Fitness J Canada. 2013;6(1):119–99.
139. Verbestel V, De Henauw S, Bammann K, Barba G, Hadjigeorgiou C, Eiben G, et al. Are context-specific measures of parental-reported physical activity and sedentary behaviour associated with accelerometer data in 2–9-year-old European children? Public Health Nutr. 2015;18(5):860–8.
140. Klitsie T, Corder K, Visscher TL, Atkin AJ, Jones AP, van Sluijs EM. Children's sedentary behaviour: descriptive epidemiology and associations with objectively-measured sedentary time. BMC Public Health. 2013;13(1):1–8.
141. Coombs N, Shelton N, Rowlands A, Stamatakis E. Children's and adolescents' sedentary behaviour in relation to socioeconomic position. J Epidemiol Community Health. 2013;67 (10):868–74.
142. Muthuri SK, Wachira L-JM, Leblanc AG, Francis CE, Sampson M, Onywera VO, et al. Temporal trends and correlates of physical activity, sedentary behaviour, and physical fitness among school-aged children in Sub-Saharan Africa: a systematic review. Int J Environ Res Public Health. 2014;11(3):3327–59.
143. Janssen X, Basterfield L, Parkinson K, Pearce M, Reilly J, Adamson A, et al. Determinants of changes in sedentary time and breaks in sedentary time among 9 and 12 year old children. Prev Med Rep. 2015;2:880–5.
144. Suchert V, Hanewinkel R, Isensee B. Sedentary behavior and indicators of mental health in school-aged children and adolescents: a systematic review. Prev Med. 2015;76:48–57.
145. Gopinath B, Hardy LL, Baur LA, Burlutsky G, Mitchell P. Physical activity and sedentary behaviors and health-related quality of life in adolescents. Pediatrics. 2012;130(1):e167–74.
146. Buman MP, Winkler EA, Kurka JM, Hekler EB, Baldwin CM, Owen N, et al. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. Am J Epidemiol. 2014;179(3):323–34.
147. LeBlanc AG, Katzmarzyk PT, Barreira TV, Broyles ST, Chaput J-P, Church TS, et al. Correlates of total sedentary time and screen time in 9–11 year-old children around the world: the international study of childhood obesity, lifestyle and the environment. PLoS One. 2015;10(6):e0129622.
148. Bringolf-Isler B, Mäder U, Dössegger A, Hofmann H, Puder JJ, Braun-Fahrländer C, et al. Regional differences of physical activity and sedentary behaviour in Swiss children are not

explained by socio-demographics or the built environment. Int J Public Health. 2015;60(3): 291–300.
149. Herman KM, Sabiston CM, Mathieu M-E, Tremblay A, Paradis G. Correlates of sedentary behaviour in 8- to 10-year-old children at elevated risk for obesity. Appl Physiol Nutr Metab. 2015;40(1):10–9.
150. Chaput J-P. Screen time associated with adolescent obesity and obesity risk factors. J Pediatr. 2017;186:209–12.
151. Stierlin AS, De Lepeleere S, Cardon G, Dargent-Molina P, Hoffmann B, Murphy MH, et al. A systematic review of determinants of sedentary behaviour in youth: a DEDIPAC-study. Int J Behav Nutr Phys Act. 2015;12(1):1–19.
152. Christian H, Trapp G. Understanding the relationship between dog ownership and children's physical activity and sedentary behaviour. J Sci Med Sport. 2012;15:S275.
153. Trang NH, Hong TK, van der Ploeg HP, Hardy LL, Kelly PJ, Dibley MJ. Longitudinal sedentary behavior changes in adolescents in Ho Chi Minh City. Am J Prev Med. 2013;44 (3):223–30.
154. Gebremariam M, Altenburg T, Lakerveld J, Andersen L, Stronks K, Chinapaw M, et al. Associations between socioeconomic position and correlates of sedentary behaviour among youth: a systematic review. Obes Rev. 2015;16(11):988–1000.
155. Cameron A, Van Stralen M, Brug J, Salmon J, Bere E, ChinAPaw M, et al. Television in the bedroom and increased body weight: potential explanations for their relationship among European school children. Pediatr Obes. 2013;8(2):130–41.
156. Downing KL, Hnatiuk J, Hesketh KD. Prevalence of sedentary behavior in children under 2 years: a systematic review. Prev Med. 2015;78:105–14.
157. Colley RC, Butler G, Garriguet D, Prince SA, Roberts KC. Comparison of self-reported and accelerometer-measured physical activity in Canadian adults. Health Rep. 2018;29(12):3–15.
158. Pedišić Ž, Bauman A. Accelerometer-based measures in physical activity surveillance: current practices and issues. Br J Sports Med. 2015;49(4):219–23.
159. Janssen X, Mann KD, Basterfield L, Parkinson KN, Pearce MS, Reilly JK, et al. Development of sedentary behavior across childhood and adolescence: longitudinal analysis of the Gateshead Millennium Study. Int J Behav Nutr Phys Act. 2016;13(1):1–10.
160. Biddle SJ, Pearson N, Ross GM, Braithwaite R. Tracking of sedentary behaviours of young people: a systematic review. Prev Med. 2010;51(5):345–51.
161. Van Ekris E, Wijndaele K, Altenburg TM, Atkin AJ, Twisk J, Andersen LB, et al. Tracking of total sedentary time and sedentary patterns in youth: a pooled analysis using the International Children's Accelerometry Database (ICAD). Int J Behav Nutr Phys Act. 2020;17:1–10.
162. Ammar A, Brach M, Trabelsi K, Chtourou H, Boukhris O, Masmoudi L, et al. Effects of COVID-19 home confinement on eating behaviour and physical activity: results of the ECLB-COVID19 international online survey. Nutrients. 2020;12(6):1583.
163. Dunton GF, Do B, Wang SD. Early effects of the COVID-19 pandemic on physical activity and sedentary behavior in children living in the US. BMC Public Health. 2020;20(1):1–13.
164. Stockwell S, Trott M, Tully M, Shin J, Barnett Y, Butler L, et al. Changes in physical activity and sedentary behaviours from before to during the COVID-19 pandemic lockdown: a systematic review. BMJ Open Sport Exerc Med. 2021;7(1):e000960.
165. Sallis R, Young DR, Tartof SY, Sallis JF, Sall J, Li Q, et al. Physical inactivity is associated with a higher risk for severe COVID-19 outcomes: a study in 48 440 adult patients. Br J Sports Med. 2021;55:1099.
166. Pedisic Z, Grunseit A, Ding D, Chau JY, Banks E, Stamatakis E, et al. High sitting time or obesity: which came first? Bidirectional association in a longitudinal study of 31,787 Australian adults. Obesity (Silver Spring). 2014;22(10):2126–30.
167. Sugiyama T, Ding D, Owen N. Commuting by car: weight gain among physically active adults. Am J Prev Med. 2013;44(2):169–73.

Chapter 3
Measurement of Sedentary Behaviour in Population Studies

Barbara Ainsworth, Fabien Rivière, and Alberto Florez-Pregonero

Abstract Measurement of sedentary behaviours in surveillance systems and in population studies involves the use of subjective and objective methods. Subjective methods have traditionally included questionnaires to provide a snapshot of sedentary behaviours and to quantify the time spent in sedentary behaviours as categorised by energy expenditure and posture. New horizons for subjective methodologies include smartphone applications that allow measurement of the facets and subcategories of the Consensus Taxonomy of Sedentary Behaviours. Objective methods have used pedometers to determine the proportion of the populations with <5000 steps/day as defined by the step-defined Sedentary Behaviour Index and accelerometers to determine the time spent in sedentary behaviours defined as <100 acceleration counts per minute. New horizons for objective methodologies include integrated motion and posture sensors to assess time spent in metabolic intensities ≤1.5 metabolic equivalents (METs) and sitting or reclining postures. Innovative ways to score accelerometer outputs to allow pattern recognition of types of sedentary behaviours also are on the horizon. Selection of a sedentary measurement method should include considerations of the validity, reliability and responsiveness of a method to reduce measurement error. Methods also should be selected that allow evaluation of Hill's Criteria for Causality to advance the understanding of the effects of sedentary behaviours on health outcomes.

B. Ainsworth (✉)
College of Health Promotion, Arizona State University, Phoenix, AZ, USA

School of Exercise and Health, Shanghai Universit of Sport, Shanghai, China
e-mail: barbara.ainsworth@asu.edu

F. Rivière
ONG Essentiel, Nice, France

A. Florez-Pregonero
Pontificia Universidad Javeriana, Bogotá, Colombia

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_3

What Is New?

- Several systematic reviews and meta-analyses have summarised the validity and reliability of sedentary behaviour assessment [1–3].
- For valid and reliable assessment of self-reported sedentary behaviours in adults, logs, diaries and ecological momentary assessment methods are recommended. In large-scale population health studies, simple one-item questionnaires focusing on a specific domain of sedentary behaviours may be preferable to elaborate questionnaires [1].
- If the use of multi-item questionnaires is feasible in population health studies, the different modes of sedentary behaviours should be considered [2].
- Device-based assessment of sedentary behaviours should include information on the total wear time, total sedentary time and number and length of bouts [4, 5].

3.1 Relevance of Accurate Exposure Assessment

When measuring sedentary behaviours as an exposure in epidemiologic studies, investigators must consider which assessment method is best able to assess the frequency, duration and volume of the exposure while minimising bias. Epidemiologic studies have traditionally relied on subjective methods to measure sedentary behaviours (e.g. job classification and questionnaires), whereas more recent studies have used questionnaires and objective methods (e.g. motion sensors). The rationale for using objective measures to measure sedentary behaviours is to reduce the potential for bias due to measurement error in the exposure.

Measurement errors may be systematic (differential) or random (non-differential). Systematic or differential errors are often related to questionnaires or monitors used to measure sedentary behaviours, whereas non-differential errors are often related to other factors. Questionnaires are prone to systematic errors through an incorrect classification of sedentary behaviours or an inability of respondents to estimate their frequency and duration of sedentary behaviours performed. These errors are often referred to as information or misclassification bias and may cause an overestimate or an underestimate of true associations between exposures and outcomes. On the other hand, random or non-differential error may occur if all respondents are subject to the same source of error. This error could arise if pedometers vary in their ability to record steps or if an interviewer transposes values when recording data. Non-differential errors can result in an underestimate of the true strength of an association between the exposure and the outcome; however, statistical procedures often can adjust for the errors. Sources of error can be minimised by standardising testing conditions to avoid participant fatigue, enhance motivation to recall information and by using a questionnaire administration style that fits the respondent.

To advance the understanding of causality between sedentary behaviours and health outcomes, the ideal measurement method would have the capacity to aid in satisfying Sir Bradford Hill's criteria for causality [6]. For example, to identify dose response, a sedentary behaviour measure should be able to identify three or more levels of some indicator of sedentariness (e.g. watching television <2 h/day, 2–4 h/day, >4 h/day). For a basic description of the Bradford Hill criteria, please refer to Chap. 4. The measure also should have sufficient psychometric properties of validity, reliability and responsiveness to compute the strength of the association between the sedentary behaviours measure and the outcome. Further, measures should reflect the construct of sedentary behaviours to enhance comparison of studies when evaluating consistency of results.

3.1.1 Psychometric Properties

Knowing the psychometric properties of a questionnaire is essential to know how to use it and to interpret the results. Psychometric properties of a questionnaire refer to the validity, reliability and the responsiveness of the questionnaire [7].

Validity

A questionnaire is valid if it measures what it purports to measure. Validity has several forms that relate to questionnaires and objective monitors. Logical or face validity refers to types of information one seeks to identify in a straightforward manner, such as asking a respondent if they mostly sit, stand or walk at work. Cognitive interviews are commonly performed to ensure the face validity. Content validity is the degree to which the content of the questionnaire is relevant to the measurement of the construct it is supposed to measure. It is determined by the amount and quality of information supplied to assess a behavioural domain of interest. If one is interested in identifying the frequency and duration of total sitting during a day with a questionnaire, items would need to address sitting during transportation, work, during leisure time and in other relevant areas. Otherwise, a single-item question may be suited to assess time spent in a single activity domain [1]. To address the content validity, the questionnaire is usually reviewed by a group of experts, which agree that the questionnaire includes all the relevant questions required to measure the construct of interest. On the other hand, construct validity relates to how well an assessment methods fits into a construct of interest. Ideally, for sedentary behaviours, construct validity would be obtained by comparing sedentary behaviours questionnaires with a gold standard. As there is no such gold standard for sedentary behaviours, direct observation or objective monitors are considered to be good options. Assuming the construct of sedentary behaviours is defined as waking behaviours characterised by an energy expenditure of $\leq$1.5 metabolic equivalents (METs) while in a sitting or reclining posture, then an objective assessment method would need to capture all movements $\leq$1.5 METs, including all reclining and sitting activities [8]. Similarly, a questionnaire would need to have a sufficient number of items to reflect relevant behaviours ≤1.5 METs within the construct of sedentary behaviours. Most often, investigators are examining criterion validity when they want to know if an assessment method is measuring what it is supposed to measure or if the sedentary behaviours assessment can predict desired outcomes. Concurrent validity is a type of criterion validity that compares scores from one assessment method with another. It is common for investigators to compare questionnaires with objective monitors and other validated questionnaires. Predictive validity often is used in epidemiologic studies to identify the ability of an assessment method to classify dose-response relations in a health outcome or determine relative risks. A good example of predictive validity is in the Nurses' Health Study where a questionnaire assessment of sedentary behaviours showed that for each 2 h per day increment in television watching, the risk for obesity increased by 17% to 30%, and the risk for diabetes increased by 5% to 23% [9].

Reliability
Reliability refers to the capacity of a questionnaire to obtain consistent results for repeated measurements. It ensures that the questionnaire is free from measurement errors. A common way to measure reliability is to administer a questionnaire or have individuals wear an objective measure 1 week or 1 month apart. Correlations between the two measures with $r > 0.70$ are deemed to have high reliability. Referred to also as consistency, reliability is important for use in multi-year cohort studies to determine the influence of sedentary behaviours on health outcomes. Clinical studies also rely on having reliable sedentary behaviour assessment methods to determine the effects of an intervention on behavioural and health outcomes. Failure to establish high reliability of an assessment method produces systematic errors that negate the validity of the method.

Responsiveness
Responsiveness is the capacity of a questionnaire to detect change over time in the scores of respondents. It is of prime interest in intervention studies where the aim is to modify sedentary behaviours. Responsiveness can be assessed by comparing the change in a sedentary behaviours score obtained from the questionnaire with direct observation or objective monitors. Responsiveness studies usually are performed prior to a questionnaire or objective monitor being used in surveillance system or population studies.

3.1.2 Conforming to a Consensus Taxonomy of Sedentary Behaviours

In 2013, Chastin et al. presented a taxonomy of sedentary behaviours that was developed in collaboration with others and named the Sedentary behaviour International Taxonomy (SIT) project [10]. The taxonomy was developed to establish a system to classify categories, facets and sub-domains of sedentary behaviours for use in surveillance and research settings. Under the construct of sedentary behaviours, facets (and sub-domains of the facets) of the taxonomy include purpose of the behaviour (e.g. work, education, transport, etc.), environment (e.g. location, physical and social factors), posture (i.e. sitting, reclining), social setting (i.e. behaviours performed alone or with others), type of measurement (i.e. subjective or objective measurement method), associated behaviours (e.g. concurrent behaviours such as snacking, smoking or drinking), state (e.g. one's functional or psychological state), time (i.e. time of day or year) and type (i.e. screen-based or not screen-based). The taxonomy is useful in evaluating the ability of subjective and objective measurement tools to provide a comprehensive assessment of sedentary behaviours. As an established taxonomy, instruments used to assess sedentary behaviours may reflect one or more of the facets, but it is unlikely that a single instrument measures all facets.

3.2 Subjective Methods of Sedentary Behaviour Measurement

Subjective methods that exist to measure sedentary behaviours include questionnaires, ecological momentary assessment (EMA) and sedentary behaviour logs. Most surveillance systems and population research studies historically have used questionnaires. Questionnaires are a subjective assessment method composed of a number of selected items intended to standardise the collection of specific information about facts or opinions of a person. Due to their low cost and ease of use, questionnaires are the most frequently used instruments to measure sedentary behaviours. Two types of questionnaires exist that can be differentiated and used for different purposes: global questionnaires and quantitative recall questionnaires. Questionnaires often are tailored for use by settings (e.g. surveillance, population studies and intervention studies) and by the types of information obtained (e.g. global impressions of sedentary behaviours and quantification of sedentary behaviours in specific behaviours). Logs are checklists of behaviours or characteristics of behaviours (e.g. intensity of an activity) that can be recorded throughout specific periods of the day to provide an estimate of the time spent in sedentary behaviours and an energy expenditure of daily physical activities [11]. With advancements in smartphone technology, EMA methods have become more feasible in population settings. EMA involves repeated sampling of a person's behaviour to include many of the facets of the Consensus Taxonomy of Sedentary Behaviours: purpose, environment, posture, social setting, associated behaviours and types of sedentary behaviours performed throughout a period of time [12]. Since EMA and logs are not feasible for use in surveillance settings and population studies at the current time, the focus of this section will be on questionnaires.

3.2.1 Types of Questionnaires

Global Questionnaires

Global questionnaires aim to provide a general categorisation of an individual's sedentary behaviour level. They are short (1–3 items) and designed for use in population health surveys or studies where questions are limited by space constraints. Many countries have a module measuring sedentary behaviour in their national surveillance surveys to support the development of policies promoting physical activity and preventing sedentary lifestyles. Responses can require a respondent to select a category, such as the hours spent watching television per week (0, 1–3, or > 3 h/week); provide a binary response to a question such as 'Do you sit at work for more than 5 h per day?' (yes, no); or give an estimate of the hours one performs a behaviour (How many hours do you watch television per day?). An example of a global questionnaire is in the 2014 Eurobarometer survey. Here a single-item question assessed sitting time in 27,919 respondents from the 28 European Member States [11]. Respondents were asked about the time they spent sitting on a usual day, including time spent at a desk, visiting friends, studying or watching television. On a usual day, about two-thirds (69%) of respondents spent between 2.5 and 8.5 h sitting (an increase of 5% as compared with 2002), while 11% sat for more than 8.5 h and 17% for 2.5 h or less [12]. Various epidemiologic cohort studies also have used global questionnaires to assess sedentary behaviours as an exposure for health outcomes. In the European Prospective Investigation into Cancer and Nutrition (EPIC)-Potsdam Study on television viewing time and incident diabetes, sitting time was measured by the average hours per day watching television during the past 12 months. Among the 23,855 participants, those who watched television >4 h per day had a 1.63 (95% CI, 1.17–2.27) increased risk of developing diabetes as compared with participants who watched television <1.0 h per day [13]. The advantages of using global questionnaires to assess sedentary behaviours are that they are short, simple and easy for respondents to answer. A disadvantage is that they provide only limited information about a behaviour that may increase chances for misclassification.

Quantitative Recall Questionnaires

Quantitative recall questionnaires are designed to obtain the frequency, duration, mode and types of sedentary behaviours. The questionnaires purport to characterise the patterns of sedentary behaviours during specific periods of the day or week. They range in length from as few as 5 items that capture details about a specific behaviour to a detailed list with 68 items that capture detailed information about many sedentary behaviours. Examples of two popular questionnaires are the Sedentary Behaviour Questionnaire (SBQ) and the Last 7-Day Sedentary Time Questionnaire (SIT-Q-7d). The SBQ is a relatively short, self-administered instrument, with nine items designed to assess time spent sitting at home and at work (television, computer games, sitting activities, office/paper work, reading, playing musical instruments, arts and crafts, driving a car). It has been used in randomised controlled trials and a prospective study [14] investigating change in weight and health behaviours during the transition from high school to college/university in 291 students. The prospective study found a decrease in some sedentary behaviours (television (TV)/digital video disk (DVD) viewing, playing computer games) and an increase in other sedentary behaviours (Internet use, time spent studying). The SIT-Q-7d is a comprehensive recall of 68 items designed to measure the time spent in different sedentary activities for work, transportation, domestic, education, social eating and caregiving behaviours, during both a weekday and a weekend day. The SIT-Q-7d has been used in a recent 1-year follow-up study with 301 adults to examine the relationships of intrapersonal, social-cognitive and physical environmental variables with context-specific sitting time [15]. The study revealed different correlates of the variables studied depending on the sedentary behaviours, highlighting the interest of using such a questionnaire.

3.2.2 Characteristics of Sedentary Behaviour Questionnaires

A growing number of sedentary behaviour questionnaires with acceptable validity and reliability are currently available (see Tables 3.1 and 3.2). The questionnaires differ in their mode of administration, content (including facets of the sedentary behaviour taxonomy) and psychometric properties as described below. These characteristics should be considered when selecting a questionnaire to assess sedentary behaviours.

Mode of Administration

The administration style for sedentary behaviour questionnaires may differ for self-administered (paper or computer forms) and for interviewer-administered (face-to-face or telephone interview) modes. In adults, most sedentary behaviour questionnaires used in epidemiologic studies are self-reported. This differs from surveillance system questionnaires which are often interviewer-administered [28]. Proxy-reported responses may be used for children and for persons with intellectual disabilities due to their limited cognitive capacity. While proxy responses may restrain the accuracy of the recall, proxy reports from parents, relatives or professional healthcare workers are likely to provide the most accurate responses [29]. The mode of administration also may impact the cost of the study and the responses provided by respondents [30].

Content of Sedentary Behaviour Questionnaires

Depending on the population and purpose of the study, questionnaires focus on the characteristics of sedentary behaviours of interest and the types of information sought, such as the frequency and duration of selected behaviours and interruptions in sedentary behaviours. The desired recall frame for sedentary behaviours also must fit the study needs. The reader is referred to Ainsworth et al. [31] for a discussion of the factors to consider when selecting a questionnaire for use in physical activity and sedentary behaviour research.

Table 3.1 Characteristics of a sample of sedentary behaviour questionnaires

Name	Purpose	Items	Admin style	Recall frame	Frequency	Duration	Summary score
International Physical Activity Questionnaire Short Form [16, 17]	Time sitting in general	1	Interview and self	Typical weekday	1 weekday	Open ended h and min	h/day
Workplace Sitting Time Questionnaire [18]	Time sitting and number of breaks at work	2	Interview and self	Past week	1 week	Open ended h and min sitting Categorical number of breaks	h/day
Self-Reported Sedentary Time Questionnaire [19]	Time sitting or reclining during leisure	7	Self	Past week	1 week recall	Open ended h and min	h/day
Past-day Adults Sedentary Time Questionnaire [20]	Time sitting and reclining in various domains	7	Self	Past day	1 week day	Open ended h	h/day
Sedentary Behavior Questionnaire [21]	Time sitting at home and work	9	Self	Typical weekday Typical weekend day	1 day 1 weekend day	Categorical h and min	h/wk
Sedentary Time and Activity Reporting Questionnaire [22]	Total 24-h physical activity, sedentary behaviours and sleep	~ 60	Self	Past 4 weeks	4-week recall	Open ended h and min	Total EE Activity EE MET-h/day PAL
Multicontext Sitting Time Questionnaire [23]	Time sitting in various activities and sleep	14	Self	Average work day and nonwork day during a usual wk	Work day and non-work day	Open ended h and min	h/day
		~50	Self				

Recent Physical Activity Questionnaire [24, 25]	Physical and sedentary activities in four domains (domestic life, recreation, work and transport)			Average workday and weekend day last 4 weeks	Frequency of four travel modes (always, never, rarely)	Open ended h and min Categorical	MET-time; h/day
Last 7-Day Sedentary Time Questionnaire [26]	Sedentary time for meals, transportation, occupation, leisure screen time and other activities and sleep	~68	Self	Average week day and weekend day during the last 7 days	Number of breaks/day during sitting, occupation, watching TV	Categorical h or min	Number of breaks; h/day
Older adults' reporting of specific sedentary behaviours [27]	Time spent sitting in 11 activities	21	Interview	Usual day during the last 7 days	Number of day during the last 7 days	Open ended h and min	Number of days; h/day

h hours; *min* minutes; *EE* energy expenditure; *MET* metabolic equivalent; *PAL* physical activity level

Table 3.2 Measurement qualities of a sample of sedentary behaviour questionnaires

	Validity		Reliability	
Name	Criterion measure	Coefficient	Test-retest recall frame	Coefficient
International Physical Activity Questionnaire Short Form [16, 17]	ActiGraph CSA 7164 worn for 7 days	Spearman's $r = 0.34^a$	3 to 7 days	Spearman's $r = 0.81^a$
Workplace Sitting Time Questionnaire [18]	ActiGraph GT1M worn for 7 days	Total sitting time Spearman's $r = 0.29$ 95% CI (0.22, 0.53) Breaks in sitting Pearson's $r = 0.26$ 95% CI (0.11, 0.44)	Not measured	Not measured
Self-Reported Sedentary Time Questionnaire [19]	ActiGraph GT1M worn for 7 days	Total sitting time Spearman's $r = 0.30$ 95% CI (0.02, 0.54)	1 week	Spearman's $r = 0.56$ 95% CI[b] (0.33, 0.73)
Past-Day Adults Sedentary Time Questionnaire [20]	activPAL® version 3 and ActiGraph GT3X+ worn for 7 days, counts <100	activPAL® total Pearson's $r = 0.58$ 95% CI (0.40, 0.72) ActiGraph <100 cts Pearson' $r = 0.51$ 95% CI (0.29, 0.68)	6 months	ICC = 0.50 95% CI (0.32, 0.64)
Sedentary Behavior Questionnaire [21]	ActiGraph 7164 worn for 7 days, counts <100 IPAQ total sitting time	ActiGraph <100 cts Males, $r = -0.01$ ($p = 0.81$) Females, $r = 0.10$ ($p = 0.07$) IPAQ total sitting Males, $r = 0.31$ ($p = 0.00$) Females, $r = 0.28$ ($p = 0.00$)	2 weeks	Weekday Spearman's $r = 0.79$ 95% CI (0.58, 0.85) Weekend day Spearman's $r = 0.74$ 95% CI (0.65, 0.78)
Sedentary Time and Activity Reporting Questionnaire [22]	Not reported	Not reported	3 months	Sedentary time ICC = 0.53 95% CI (0.37, 0.66)
Multicontext Sitting Time Questionnaire [23]	ActiGraph GT1M worn on a workday and a non-workday	Pearson's $r = 0.61$, $p = 0.01$ on non-workdays and $r = 0.34$, $p = 0.13$ on workdays	1 week	Total sitting on non-workdays and workdays ICC = 0.72 and 0.76
Recent Physical Activity Questionnaire [24, 25]	Actiheart, CamNtech Ltd, Cambridge, UK, worn a minimum of 4 days	Spearman's correlation $r = 0.21$ and $r = 0.18$ in women	2 weeks	Sedentary time ICC = 0.76, $p < 0.001$

(continued)

Table 3.2 (continued)

	Validity		Reliability	
Name	Criterion measure	Coefficient	Test-retest recall frame	Coefficient
		and men (both $p < 0.001$)		
Last 7-Day Sedentary Time Questionnaire [26]	ActivPAL worn on 7 days (Dutch-speaking population-DsP) or Actiheart for 6 days and nights (English-speaking population-EsP)	Spearman's correlation $r = 0.52$ (DsP) and $r = 0.22$ (EsP) ($p < 0.001$)	3 weeks	Total sedentary time ICC = 0.68 95% CI (0.50, 0.81) (DsP) and ICC = 0.53 95% CI (0.44, 0.62) (EsP)
Older adults' reporting of specific sedentary behaviours [27]	ActiGraph GT3X+ worn 7 consecutive days	Spearman's correlation $r = 0.30$ ($p < 0.001$)	10 days	Total sitting time ICC = 0.77 95% CI (0.57, 0.89)

[a] Standard deviation or confidence interval not reported
[b] CI = confidence interval

Characteristics or Domains of Sedentary Behaviours

Considering which characteristics or types of sedentary behaviours to be measured is a first step in the process of selecting a questionnaire. Most sedentary behaviour questionnaires measure sitting time spent watching television during a day. Others also assess sedentary modes of transport, time spent being sedentary at work and engagement in sedentary leisure-time pursuits. Very few questionnaires measure sedentary behaviours related to cooking, household chores or the associated sedentary behaviours such as snacking while doing a sedentary behaviour [32]. Table 3.3 presents the types of data available for subjective measurement methods as they conform to the Consensus Taxonomy of Sedentary Behaviours.

Recall Frame

The recall frame relates to the number of hours, days or weeks one recalls a behaviour in the past. Most quantitative recall questionnaires ask respondents to recall 1 week or 1 or more days in the past. Relatively short recall frames are used to enhance the recall of details about sedentary behaviours. More accurate recall increases the reliability and validity of the questionnaire. Alternatively, long recall frames (1 month, 1 year) are often used with a questionnaire that is designed to measure usual patterns of sedentary behaviours. Because long recall frames have high cognitive demands and specific details about one's behaviour are difficult to recall, questionnaires that query sedentary behaviours during the past year or over a lifetime have a high potential for information bias [31].

Table 3.3 MET values for sedentary behaviours classified by posture from the 2011 Compendium of Physical Activities [33]

Category	Posture			
	Reclining	METs	Sitting	METs
Inactivity	Lying quietly and watching television	1.0	Sitting quietly and watching television	1.3
	Writing	1.3	Sitting quietly, general	1.3
	Lying quietly, doing nothing, lying in bed awake, listening to music (not talking/reading)	1.3	Sitting quietly, fidgeting, fidgeting hands	1.5
	Talking or talking on the phone	1.3	Sitting smoking	1.3
	Reading	1.3	Sitting at a desk, resting head in hands	1.5
	Meditating	1.0	Meditating	1.0
			Sitting, listening to music (not talking or reading) or watching a movie in a theatre	1.3
Conditioning			Whirlpool	1.3
Home activity	Reclining with baby	1.5		
			Knitting, sewing, wrapping presents, sitting	1.3
Miscellaneous			Card playing, chess game, board games, traditional video game, computer game	1.5
			Reading book or newspaper, etc.	1.3
			Writing, desk work, typing	1.3
			Talking in person, on the phone, computer, or text messaging	1.5
			Studying, including reading and/or writing	1.5
			Spectator at a sporting event	1.5
Occupation			Police, riding in a squad car	1.3
			Light office work, general	1.5
			Meetings, talking, eating	1.5
			Typing, computer, electric, manual	1.3
Self-care			Eating	1.5
			Bathing	1.5
			Taking medication	1.5
			Having hair or nails done by someone else	1.3
Sexual activity	Kissing and hugging	1.3	Kissing and hugging	1.3

(continued)

Table 3.3 (continued)

Category	Posture			
	Reclining	METs	Sitting	METs
Transport			Riding in car, truck, on a bus, train or plane	1.3
Religious			Kneeling in church or at home, praying	1.3
Water activities			Boating, power, passenger	1.3

Frequency of a Behaviour

Frequency refers to the number of times one performs a behaviour over a specific period (e.g. days/week, weeks/month and months/year). The most common frequency is the number of days per week the respondent engages in sedentary behaviours.

Duration of a Behaviour

Duration refers to the hours or minutes spent in a sedentary behaviour. Most questionnaires ask about the duration per day spent in sedentary behaviours. Depending on the questionnaire, the duration may be recalled as a continuous variable that queries hours and minutes or as a discrete variable that has respondents select from a 1–5 numbered responses to represent different periods of time.

Interruption

Interruption refers to the number of breaks in sedentary time during a prolonged sedentary bout. This might be the number of times one gets up from his or her desk while working or standing breaks taken while travelling distances in a car or train.

Scoring Sedentary Behaviour Questionnaires

Recall questionnaires require calculation of a summary score to reflect time spent in sedentary behaviours. The summary units usually include hours and minutes per day, hours and minutes per week or a combination of the time spent in sedentary behaviours and the intensity score in METs. A MET refers to the metabolic equivalent of an activity and is defined as the ratio of the activity metabolic rate in millilitres per kilogram body weight per minute ($ml \cdot kg^{-1} \cdot min^{-1}$) divided by the resting metabolic rate in $ml \cdot kg^{-1} \cdot min^{-1}$. For simplicity, the standard MET uses a resting metabolic rate of 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ to compute MET values. Sedentary behaviours range from 1.0 to 1.5 METs and differ by posture and types of activities performed. Multiplication of a MET intensity by the time spent in sedentary behaviours can be expressed as MET-minutes or MET-hours. Because the range of MET values for sedentary behaviours is so narrow, few sedentary behaviour questionnaires have summary scores expressed as MET-minutes or MET-hours; instead most questionnaires sum the frequency and duration of sedentary behaviours as minutes and hours per day or as minutes and hours per week. Table 3.3 provides an example of the MET values for selected sedentary behaviours [16].

Overall, questionnaires are easy to use and give useful information to characterise sedentary behaviours. It should be noted, however, that for most questionnaires available, the psychometric properties and quality of the validation studies are limited. While the perfect questionnaire will never exist, investigators are encouraged not to develop a new questionnaire for every new setting as existing questionnaires are available to measure sedentary behaviours. That said, one should take care to use a questionnaire that fits best the purpose of the study with the characteristics mentioned above taken into consideration.

3.3 Objective Methods of Sedentary Behaviour Measurement

Objective methods used to assess sedentary behaviours include pedometers, accelerometers/inclinometers (for motion and posture), physiological sensors, direct observation and context awareness (using cameras and GPS). This discussion will focus on pedometers and accelerometers/inclinometers as they are suitable for use in surveillance and population studies. Collectively, pedometers and accelerometers are referred to as activity monitors. Monitors are small portable electronic devices that measure and record specific physiological or physical signals that are used to estimate physical activity and sedentary behaviour parameters. Older generations of monitors included spring-loaded pedometers and accelerometers without the capacity to download data. Modern generations now have sophisticated electronic sensors that can assess movement in multiple planes, assess physiologic and environmental parameters and store data for months with easy downloading to a computer. These newer features allow investigators to integrate motion, physiological and contextual information in the study of sedentary behaviours [34]. Table 3.4 presents the types of data available for objective measurement methods as they conform to the Consensus Taxonomy of Sedentary Behaviours. Monitors are being used with greater frequency in surveillance [35–37] and epidemiologic [38–41] settings to quantify physical activity and sedentary behaviours. Two approaches (single-unit and multi-unit) to using activity monitors can be used to estimate time spent in sedentary behaviours. With single-unit approaches, individuals wear only one monitor at some location on their body. Pedometers and accelerometers are the most common monitors used for single-unit estimates of sedentary behaviours. Data from a single-unit approach includes steps, hours or minutes per day spent in sedentary behaviours. Most surveillance and epidemiologic studies use a single-unit approach because it is easy for study participants to wear only one monitor and the scoring methods used to determine the sedentary behaviour score are relatively easy to compute.

Multi-unit approaches are used in settings that aim to identify patterns of behaviour (behavioural recognition) to assess multiple types of information (e.g. body position, physiologic data and context of the behaviour) [42]. For example, the activPAL has demonstrated high accuracy for estimating sitting, standing and

Table 3.4 Overview of recommended instruments in epidemiologic studies to measure facets of the Consensus of the sedentary behaviour taxonomy [10]

Measurement	Purpose[a]	Environment[b]	Posture[c]	Social[d]	Associated behaviour[e]	State[f]	Time[g]	Type[h]
Objective methods								
Motion sensors (accelerometer-based)	+	+	+	+	+	+	+++	+
Posture sensors (accelerometer-based)	+	+	+++	+	+	+	+++	+
Physiological/combined sensors	+	+	+	+	+	+	+++	+
Pedometers	+	+	+	+	+	+	+	+
Direct observation	+++	+++	+++	+++	+++	+	+++	+++
Context awareness	+++	+++	++	+++	+++	+	+++	++
Subjective methods								
Global questionnaires	+	+	+	+	+	+	+	+
Quantitative recall questionnaires	++	++	+	++	++	+	+	++
EMA	+++	+++	+++	+++	+++	+	+	+++
Log	++	++	+	+	+	+	+	++

+ (poor), ++ (fair), +++ (good)
EMA ecological momentary assessment
[a]Purpose: ability to distinguish domain (work, education, care, transport, eating, rest, relaxation, leisure)
[b]Environment: location (indoor/outdoor, built environment), physical variables (visibility, temperature), social variables
[c]Posture: sitting or reclining
[d]Social: alone or with others (friends, family, strangers)
[e]Associated behaviour: concurrent behaviours (snacking, smoking, drinking)
[f]State: functional status (limitations/none), psychological state (depression, self-efficacy, emotion)
[g]Time: time of day, time of year
[h]Type: screen-based/not screen-based

stepping time; however, it does not discriminate between sitting and lying postures because its location on the thigh is horizontal in both postures. New approaches have placed a second activPAL on the torso allowing accurate detection of seated versus lying postures [43]. Another example of a multi-unit approach is pairing the activPAL with a time lapse camera (Vicon Revue™ formerly known as SenseCam) used to obtain information about sedentary behaviour and the context where the activity is performed [44]. This latter approach may be useful for surveillance settings if information about the location and purpose of behaviours are desirable [45]. Since most surveillance and epidemiologic studies use accelerometers and/or pedometers, this discussion will focus on single-unit approaches.

3.3.1 Pedometers

Pedometers are low-cost, battery-operated digital step counters that have gained popularity in surveillance and population study settings [46–50]. Pedometers generally are worn at the waist or wrist; however, some models can be worn in the pocket or on a chain around the neck. In pedometers manufactured prior to 2000 (e.g. Yamax Digiwalker SW2000), step counts were triggered by vertical accelerations that cause a horizontal spring-suspended level arm circuit. Later models included a horizontal cantilevered beam with a weight on the end which compresses a piezo-electric crystal when subjected to acceleration. Several studies have shown variation in accuracy of these older models in counting steps in free-living populations and in older adults [51–54]. A major drawback of most of the early pedometer models is that they lacked the ability to store data nor did they have the capacity for downloading steps into a computer database. Such features limited their use in population settings. Most of the newer model pedometers are sold commercially (e.g. Fitbit, Omron, Striiv, Garmin, Jawbone, Polar, Nike and integration in smart phones) and have varied features that increase their utility for use in population studies. Newer pedometers use microelectromechanical system (MEMS) inertial sensors that can detect acceleration in 1-, 2- or 3-axes. This permits more accurate detection of steps and fewer false positives than older models. Depending on the model, pedometers now use sophisticated, proprietary software that allows users to store steps for nearly 30 days and download data using Bluetooth® technology to sync with computers and smartphones. In an evaluation of newer model commercial pedometers worn on the hip (Realalt 3DTriSport, Omron HJ-720 ITC) and the wrist (Apple Watch SE, Fitbit Versa 3, Fitbit Inspire 3), Nelson et al. [55] observed that all pedometers estimated energy expenditure during sedentary behaviours within 8% of measured oxygen uptake. All waist-worn pedometers recorded zero steps during sedentary behaviours, and wrist-worn pedometers recorded a small number of steps associated with moving the arms. While waist-worn pedometers may provide a more accurate assessment of sedentary behaviours, the trade-off of small errors associated with wrist-worn pedometers should be considered in relation to compliance for wearing the monitor during daily activities.

In a series of publications, Tudor-Locke identified step cut-points that are associated with meeting physical activity recommendations [56–58], adverse health outcomes [59] and overweight and obesity [60, 61]. In 2013, Tudor-Locke and colleagues [62] identified a Step-Defined Sedentary Lifestyle Index of <5000 steps/day. This is characteristic of one who moves very little and spends more accumulated time in sedentary behaviours. Readers are referred to Tudor-Locke et al. [62] for a detailed explanation of the research leading to the recommendation of the Step-Defined Sedentary Lifestyle Index.

Benefits of using pedometers for surveillance and population studies of sedentary behaviours are that the instruments are relatively inexpensive depending on the features included in the pedometer and that they are easy for participants to wear and for staff to interpret. However, if the step-count data can be viewed by the participant, merely wearing the monitor may serve as a motivational device to increase steps taken.

3.3.2 Accelerometers/Inclinometers

Accelerometers are small, battery-operated electronic motion sensors that measure the rate and magnitude of displacement of the body's centre of mass during movement [58]. The placement of accelerometers varies with the brand and model. Most are worn on the waist, wrist or upper arm. Types of accelerometers include uniaxial models that detect movement in the vertical plane and tri-axial models that detect movement in the vertical and horizontal planes. The value of tri-axial models is that movements in a vertical plane (standing, slow walking) and horizontal plane (moving up an incline) can be assessed, whereas uniaxial accelerometers are unable to detect the added energy cost of such activities. The most common type of accelerometers used to assess movement and sedentary behaviours in population-based settings is the ActiGraph (ActiGraph LLC, Pensacola, FL, USA). As an example, the ActiGraph accelerometer was first marketed in the 1990s under the name Computer Science Applications (CSA). This early uniaxial accelerometer detected movement intensity, duration and steps taken but had limited battery life and memory to store data. With advances in technology, the ActiGraph in use today uses a microelectromechanical system tri-axial accelerometer (wGT3X-BT and ActiGraph GT9X Link) with a 14–25-day battery life and memory capable of storing raw movement data for 240 days. The ambulatory data are sampled at a user-specified rate up to 100 Hertz that can be aggregated and stored in epochs (sampling intervals) as frequent as 1 s or longer. Objective measures include raw acceleration of movement (G's), sedentary and activity bouts, body position, steps taken, activity counts, energy expenditure, sleep metrics and heart rate R-R intervals that can be used to assess heart rate. Output data are downloaded using Bluetooth® Smart technology, scored using proprietary software and stored in a computer database. The ActiGraph uses counts to express movement intensity, with higher counts reflecting higher intensities. Examples of count cut-points for sedentary behaviours

Table 3.5 Accelerometer cut-points for sedentary behaviours in adults

Cut-point value for sedentary behaviours	Epoch length	Activity monitor used	Number of axis	Placement site	Precision/ accuracy
Counts = 50 [63]	1 minute	ActiGraph	One axis (vertical)	Hip	Not reported
Counts = 8 [64]	10 seconds	ActiGraph	One axis (vertical)	Hip	Not reported
Counts = 77 [65]	1 minute	GENEActiv	Three axes	Hip	AUC[a] (95% CI) = 0.97 (0.96–0.98)
Counts = 217 [65]	1 minute	GENEActiv	Three axes	Left wrist	AUC[a] (95% CI) = 0.98 (0.98–0.99)
Counts = 386 [65]	1 minute	GENEActiv	Three axes	Right wrist	AUC[a] (95% CI) = 0.98 (0.97–0.99)
Counts = 100 [66]	1 minute	ActiGraph	One axis (vertical)		Not reported
Counts = 150 [67]	1 minute	ActiGraph	One axis (vertical)	Hip	Bias[b] = − 0.9 min SE[c] = 7.7 min
Counts = 500 [68]	1 minute	ActiGraph	One axis (vertical)	Hip	Not reported

[a]Area under a ROC curve (AUC) quantifies the overall ability of the monitor to discriminate between activities that are sedentary behaviours and those that are not. An AUC value of 1 represents a perfect test; an area of 0.5 represents a worthless test
[b]Bias refers to the extent that each monitor overestimated or underestimated sedentary time
[c]SE is the random error that indicates how far the estimate of sedentary minutes randomly fluctuates above and below its average value for each person on each day

are presented in Table 3.5. Adult population-based studies utilising accelerometer-based activity monitors typically use a 1-min epoch [69] and 100 counts per minute as the threshold for sedentary behaviours [66].

In addition to the selection of cut-points, the determination of the time that the monitor is worn during the monitoring period of the study is a major analytic decision. Population-based studies utilising accelerometer-based activity monitors typically monitor the behaviour for 7 days during waking hours. Wearing the monitor for at least 4 days/week (including a weekend day) with a minimum wear time of 10 h/day are usually required for data analysis [69]. Wear time is determined by subtracting non-wear time from total time in the day (wear time in 24 h—minus non-wear time). Non-wear time can be estimated by automated processes using published algorithms [35, 70] or by asking study participants to fill a log with times when they wore or did not wear the accelerometers.

The ActiGraph was used first for surveillance in the 2003–2004 National Health and Nutrition Examination Survey (NHANES) [35]. Nearly 15,000 individuals, aged 6 years and older, wore an accelerometer during non-sleeping hours for

7 days with a goal to assess the proportion of the US population meeting physical activity recommendations [35]. Using the same data, Matthews et al. [66] reported sedentary time in US adults, with older adolescents and adults >60 years spending nearly 60% of their waking time in sedentary pursuits. Based on the success of the US experience, accelerometers have been used in surveillance systems in multiple countries [37, 71]. The NHANES accelerometer data has been used to study associations between sedentary behaviours and health outcomes to include the metabolic syndrome [72], mobility disabilities [73], type 2 diabetes [74], sleep outcomes [75] and diabetic peripheral arterial disease [76] among other outcomes. Other studies that have used the ActiGraph accelerometer to assess exposure-outcome relations include the ten-country International Physical Activity and the Environment Network (IPEN) Adult Study [77], Women's Health Study [39], Women's Health Initiative (WHI), Objective Physical Activity and Cardiovascular Health (OPACH) Study, an ancillary study of the WHI 2010–2015 Long Life Study [78] and the British Regional Heart Study [79], among others.

In addition to the cut-points approach with the ActiGraph, there are other accelerometers (activPAL, GENEActiv) that use linear approaches to determine time spent in sedentary behaviours. The activPAL® is a uniaxial accelerometer worn midline on the anterior aspect of the thigh that measures time in different postures (reclining, sitting, standing) and activity (stepping) using proprietary algorithms. While the activPAL® has demonstrated to be a valid and reliable instrument to assess sedentary behaviours [67, 80], it has not been used in population-based studies. Another accelerometer gaining interest among sedentary behaviour researchers is the GENEActiv®. The GENEActiv® is a wrist-worn triaxial accelerometer that estimates a person's posture using the gravitational component of the acceleration signal from the wrist orientation of the monitor [81, 82]. To date, the GENEActiv® has not been used in population-based studies.

Machine learning is an emerging technique used to identify the types of sedentary behaviours performed from the movement acceleration data obtained from accelerometers (either a single-unit or multi-unit). The statistical models used with machine learning provide activity recognition of the raw acceleration signals to estimate the types of movements performed. The machine learning approach to scoring and interpreting accelerometer data has shown substantial reductions in the error estimates of measuring sedentary behaviours, especially when multiple monitors are used as compared to using counts methods to estimate intensity [83, 84]. However, due to the high investigator burden in scoring and interpreting the data, machine learning methods have not been used in population studies to identify sedentary behaviours. For more details on machine learning, please refer to Chap. 4.

Many investigators use objective methods in population studies to measure sedentary behaviours because they provide data that are free of the systematic errors associated with self-report [45]. Accelerometer-based activity monitors have demonstrated feasibility and utility to assess sedentary time in large-scale surveillance studies [69], and because the information is time-stamped, it allows the extraction of data for specific segments of the day, including differentiating between weekdays and weekend days [29]. Further, with suitable techniques, obtaining raw data from tri-axial accelerometers makes it possible to perform activity recognition analyses [85].

While growing in popularity for use in population studies, single-unit methods to measure sedentary behaviour have limitations which should be considered. Most notably, the management of large volumes of data obtained with objective monitors can be a challenge for research staff. Initialising units, assuring participants wear the monitors correctly, downloading, cleaning and scoring the data are very time-consuming. For use in studies of sedentary behaviours, other challenges exist. There continues to be a lack of consensus about monitor initialisation, monitoring period and the most appropriate data-processing protocol, despite consensus documents published on this topic [29, 45]. There also is a lack of field standards for factors affecting the accuracy of estimations such as the location an accelerometer is worn on the body and how it is attached [45]. That said, wrist-worn accelerometers are gaining in popularity for objective, long-term measurement of sedentary behaviours in free-living environments with minimum obtrusiveness [86]. Another concern is that studies using the cut-point method to determine time spent in sedentary behaviours rely on the most commonly used cut-point of 100 counts/minute. However, this cut-point was not empirically derived [67]. Healy and colleagues [69] note that the most accurate cut-point to determine time spent in sedentary behaviours has yet to be established. Further, there is an inability to compare accelerometer outputs across brands due to manufacturer proprietary algorithms used to process the raw data into a score. This can limit the monitors used to a single brand (usually the ActiGraph). While the use of the ActiGraph enhances the ability to compare results among studies, it also limits comparability among different activity monitors [87]. Perhaps one of the greatest limitations of most accelerometers, except the activPAL®, is the inability to distinguish between postures of reclining, sitting and standing inclusive of most sedentary behaviours [34]. This latter point underscores the need to improve activity recognition techniques in the use of accelerometers to assess sedentary behaviours. For more details on the analysis and interpretation of sedentary behaviour data, please refer to Chap. 4.

3.4 New Horizons in Measurement Technology

In the short term, agreement of the construct of sedentary behaviour will generate innovative ways to assess sedentary behaviours. Investigators and research groups have introduced definitions for sedentary behaviour which will guide assessment methods to assure the instrument has good construct validity. The Sedentary Behaviour Research Network defines sedentary behaviour as follows:

> . . .any waking activity characterized by an energy expenditure ≤1.5 metabolic equivalents and a sitting or reclining posture. In general, this means that any time a person is sitting or lying down, they are engaging in sedentary behaviour. Common sedentary behaviours include TV viewing, video game playing, computer use (collective termed "screen time"), driving automobiles, and reading. [88]

This definition calls for the use of questionnaires that classify time spent in sedentary behaviours by intensity and postures while performing the activity. Riding a bicycle fulfils the notion of a sitting posture; however, the intensity of the behaviour exceeds 1.5 METs. Likewise, standing quietly is assigned a MET value of 1.3 in the 2011 Compendium of Physical Activities [33], but the standing posture excludes it from being classified as a sedentary behaviour. Thus, investigators will need to asses carefully the types of questionnaires they wish to use to comply with the definition of sedentary behaviours and develop innovative methods to obtain data using activity monitors.

The use of objective monitors to assess sedentary behaviours will grow in popularity as the costs for monitors decrease and the monitors are easier to use. Innovative methods will be developed to evaluate data that meet the definition of sedentary behaviour. In 2013, Rowlands et al. [82] introduced the concept of the sedentary sphere as a new name used to describe the energy cost ($\leq$1.5 METs) and postures (sitting and reclining) of sedentary behaviours. On the webpage developed by the Leicester-Loughborough Diet, Lifestyle and Physical Activity Biomedical Research Unit [33], researchers have provided open-access, custom-built Excel spreadsheets to calculate posture using the GENEActiv® accelerometer. Over the long term, machine learning techniques will be used more frequently to measure time spent in sedentary behaviours as data processing methods simplify scoring process and computational power needed to analyse large volumes of raw data are more available. Until then, innovative single-unit [81, 82] and multi-unit [43] methods will continue to be used to obtain objective measures of sedentary behaviours.

No doubt, the future of physical activity and sedentary behaviour measurement will rely on the combination of both subjective and objective methods and on the development of connected devices. Smartphone applications (apps) will continue to be developed that use sensor-assisted devices to measure sedentary behaviours. Dunton et al. [89] have developed a sensor-assisted, context-sensitive ecological momentary assessment (CS-EMA) app that allows for self-report of sedentary behaviours to record periods of motion, inactivity or no data from the phone. The app highlights the power of smartphones to assess movement and sedentary behaviours. These permit recording aspects of the Consensus Taxonomy of Sedentary Behaviours to include real-time measuring of the type and purpose of activity performed, enjoyment and social and physical features of the activity setting. Smartphones with built-in inclinometers, GPS and accelerometers that are worn all day will provide multiple sources of information about posture, movement- types, context of the movement and travel patterns. Smartphones also can be connected with other devices such as watches that are able to measure heart rate and movement. Accordingly, smartphones likely will be at the centre of technologies to assess sedentary behaviours. For more examples of smartphone applications for the assessment of sedentary behaviour, please refer to Chaps. 11, 21, and 23.

3.5 Summary

The measurement of sedentary behaviours in surveillance and in population studies is a relatively new practice. The definition of sedentary behaviours has matured from merely being the opposite of physical activity to a combination of energy expenditure ≤1.5 METs and sitting or reclining postures. Questionnaire and monitor methods have been developed to assess sedentary behaviours, some with higher validity and reliability than others. The use of a consistent definition and measurement methodologies to assess sedentary behaviours enhances the opportunities to compare data from surveillance systems across demographic groups and to conduct population studies designed to establish relationships between sedentary behaviour exposures and health-related outcomes.

References

1. Bakker EA, Hartman YAW, Hopman MTE, Hopkins ND, Graves LEF, Dunstan DW, et al. Validity and reliability of subjective methods to assess sedentary behaviour in adults: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2020;17(1):75.
2. Prince SA, LeBlanc AG, Colley RC, Saunders TJ. Measurement of sedentary behaviour in population health surveys: a review and recommendations. PeerJ. 2017;5:e4130.
3. Phillips SM, Summerbell C, Hobbs M, Hesketh KR, Saxena S, Muir C, et al. A systematic review of the validity, reliability, and feasibility of measurement tools used to assess the physical activity and sedentary behaviour of pre-school aged children. Int J Behav Nutr Phys Act. 2021;18(1):141.
4. Heesch KC, Hill RL, Aguilar-Farias N, van Uffelen JGZ, Pavey T. Validity of objective methods for measuring sedentary behaviour in older adults: a systematic review. Int J Behav Nutr Phys Act. 2018;15(1):119.
5. Boerema ST, van Velsen L, Vollenbroek MM, Hermens HJ. Pattern measures of sedentary behaviour in adults: a literature review. Digit Health. 2020;6:2055207620905418.
6. Lucas RM, McMichael AJ. Association or causation: evaluating links between "environment and disease". Bull World Health Organ. 2005;83(10):792–5.
7. Terwee CB, Mokkink LB, van Poppel MNM, Chinapaw MJM, van Mechelen W, de Vet HCW. Qualitative attributes and measurement properties of physical activity questionnaires: a checklist. Sports Med. 2010;40(7):525–37.
8. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR Jr, Tudor-Locke C, Greer JL, Vezina J, Whitt-Glover MC, Leon AS. Compendium of physical activities: a second update of codes and MET values. Med Sci Sports Exerc. 2011;43(8):1575–81.
9. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. JAMA. 2003;289 (14):1785–91.
10. Chastin SFM, Schwarz U. Skelton development of a consensus taxonomy of sedentary behaviors (SIT): report of Delphi round 1. PLoS One. 2013;8(12):e82313.
11. European Commission. Special Eurobarometer 412 sport and physical activity. Sleep Breath. 2014;18(1):133–6.
12. European Commission. Eurobarometer on sport and physical activity Brussels: Communication Department of the European Commission; 2014 [updated March 24, 2014. Memo/14/207]. http://europa.eu/rapid/press-release_MEMO-14-207_en.htm

13. Ford E, Schulze MB, Kroger J, Pischon T, Bergmann MM, Boeing H. Television watching and incident diabetes: findings from the European Prospective Investigation into Cancer and Nutrition–Potsdam Study. J Diabetes. 2010;2:23–7.
14. Deforche B, Van Dyck D, Deliens T, De Bourdeaudhuij I. Changes in weight, physical activity, sedentary behaviour and dietary intake during the transition to higher education: a prospective study. Int J Behav Nutr Phys Act. 2015;12:16.
15. Busschaert C, De Bourdeaudhuij I, Van Cauwenberg J, Cardon G, De Cocker K. Intrapersonal, social-cognitive and physical environmental variables related to context-specific sitting time in adults: a one-year follow-up study. Int J Behav Nutr Phys Act. 2016;13(1):28.
16. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35(8):1381–95.
17. Rosenberg DE, Bull FC, Marshall AL, Sallis JF, Bauman AE. Assessment of sedentary behavior with the international physical activity questionnaire. J Phys Activ Health. 2008;5 (1):S30–44.
18. Clark BK, Thorp AA, Winkler EA, Gardiner PA, Healy GN, Owen N, Dunstan DW. Validity of self-reported measures of workplace sitting time and breaks in sitting time. Med Sci Sports Exerc. 2011;43(10):1907–0912.
19. Gardiner PA, Healy GN, Eakin EG, Clark BK, Dunstan DW, Shaw JE, Zimmet PZ, Owen N. Associations between television viewing time and overall sitting time with the metabolic syndrome in older men and women: the Australian Diabetes, Obesity and Lifestyle study. J Am Geriatr Soc. 2011;59(5):788–96.
20. Clark BK, Winkler E, Healy GN, Gardiner PG, Dunstan DW, Owen N, Reeves MM. Adults' past-day recall of sedentary time: reliability, validity, and responsiveness. Med Sci Sports Exerc. 2013;45(6):1198–207.
21. Rosenberg DE, Norman GJ, Wagner N, Patrick K, Calfas KJ, Sallis JF. Reliability and validity of the sedentary behavior questionnaire (SBQ) for adults. J Phys Activ Health. 2010;7:697–705.
22. Neilson HK, Ullman R, Robson PJ, Friedenreich CM, Csizmadi I. Cognitive testing of the STAR-Q: insights in activity and sedentary time reporting. J Phys Activ Health. 2013;10(3): 379–89.
23. Whitfield GP, Pettee Gabriel KK, Kohl HW. Assessing sitting across contexts: development of the multi-context sitting time questionnaire. Res Q Exercise Sport. 2013;84(3):323–8.
24. Golubic R, May AM, Benjaminsen Borch K, Overvad K, Charles MA, Diaz MJ, et al. Validity of electronically administered recent physical activity questionnaire (RPAQ) in ten European countries. PLoS One. 2014;9(3):e92829.
25. Besson H, Brage S, Jakes RW, Ekelund U, Wareham NJ. Estimating physical activity energy expenditure, sedentary time, and physical activity intensity by self-report in adults. Am J Clin Nutr. 2010;91(1):106–14.
26. Wijndaele K, Bourdeaudhuij I, Godino JG, Lynch BM, Griffin SJ, Westgate K, Brage S. Reliability and validity of a domain-specific last 7-d sedentary time questionnaire. Med Sci Sports Exerc. 2014;46(6):1248–60.
27. Van Cauwenberg J, Van Holle V, De Bourdeaudhuij I, Owen N, Deforche B. Older adults' reporting of specific sedentary behaviors: validity and reliability. BMC Public Health. 2014;14 (1):734.
28. Scholes S, Bridges S, Ng Fat L, Mindell JS. Comparison of the physical activity and sedentary behaviour assessment questionnaire and the short-form international physical activity questionnaire: an analysis of health survey for England data. PLoS One. 2016;11(3):e0151647.
29. Atkin AJ, Gorely T, Clemes SA, Yates T, Edwardson C, Brage S, Salmon J, Marshall SJ, Biddle SJ. Methods of measurement in epidemiology: sedentary behaviour. Int J Epidemiol. 2012;41 (5):1560–471.
30. Chang E-T, Yang M-C, Wang H-M, Lai H-L. Snoring in a sitting position and neck circumference are predictors of sleep apnea in Chinese patients. Sleep Breath. 2014;18(1):133–1316.

31. Ainsworth BE, Caspersen CJ, Matthews CE, Masse LC, Baranowski T, Zhu W. Recommendation to improve the accuracy of estimates of physical activity derived from self report. J Phys Activ Health. 2012;9(1):S76–84.
32. Ainsworth BE, Flórez Pregonero A, Rivière F. Assessing sedentary behavior using questionnaires. In: Zhu W, Owen N, editors. Sedentary behavior and health: concepts, evidence, assessment and intervention. Champaign, IL: Human Kinetics; 2017.
33. Ainsworth BE HW, Herrmann SD, Meckes N, Bassett Jr DR, Tudor-Locke C, Greer JL, Vezina J, Whitt-Glover MC, Leon AS. The compendium of physical activities tracking guide School of Nutrition and Health Promotion. Arizona State University, 2011. https://sites.google.com/site/compendiumofphysicalactivities/
34. Chen KY, Bassett DR Jr. The technology of accelerometry-based activity monitors: current and future. Med Sci Sports Exerc. 2015;37(11):S490–500.
35. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc. 2008;40(1):181–8.
36. Katzmarzyk PT, Barreira TV, Broyles ST, Champagne CM, Chaput JP, Fogelholm M, et al. The international study of childhood obesity, lifestyle and the environment (ISCOLE): design and methods. BMC Public Health. 2013;13:900.
37. Hagströmer M, Kwak L, Oja P, Sjöström M. A 6 year longitudinal study of accelerometer-measured physical activity and sedentary time in Swedish adults. J Sci Med Sport. 2015;18(5):553–7.
38. Lee I-M, Shiroma EJ. Using accelerometers to measure physical activity in large-scale epidemiological studies: issues and challenges. Br J Sport Med. 2014;48(3):197–201.
39. Shiroma EJ, Cook NR, Manson JE, Buring JE, Rimm EB, Lee IM. Comparison of self-reported and accelerometer-assessed physical activity in older women. PLoS One. 2015;10(12):e0145950.
40. Zhu W, Howard VJ, Wadley VG, Hutto B, Blair SN, Vena JE, Colabianchi N, Rhodes D, Hooker SP. Association between objectively measured physical activity and cognitive function in older adults-the reasons for geographic and racial differences in stroke study. J Am Geriatr Soc. 2015;63(12):2447–54.
41. Griffiths LJ, Sera F, Cortina-Borja M, Law C, Ness A, Dezateux C. Objectively measured physical activity and sedentary time: cross-sectional and prospective associations with adiposity in the Millennium Cohort Study. BMJ Open. 2016;6(4):e010366.
42. Gao L, Bourke AK, Nelson J. Evaluation of accelerometer based multi-sensor versus single-sensor activity recognition systems. Med Eng Phys. 2014;36(6):779–85.
43. Bassett DR, John D, Conger SA, Rider BC, Passmore RM, Clark JM. Detection of lying down, sitting, standing, and stepping using two activPAL monitor. Med Sci Sports Exerc. 2014;46(10):2025–9.
44. Leask CF, Harvey JA, Skelton DA, Chastin SF. Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). Eur Rev Aging Phys Act. 2015;12(1):1–8.
45. Matthews CE, Hagströmer M, Pober DM, Bowles HR. Best practices for using physical activity monitors in population-based research. Med Sci Sports Exerc. 2012;44(1):S68–76.
46. Craig CL, Cameron C, Griffiths JM, Tudor-Locke C. Descriptive epidemiology of youth pedometer-determined physical activity: CANPLAY. Med Sci Sports Exerc. 2010;42(9):1639–43.
47. Craig CL, Cameron C, Tudor-Locke C. CANPLAY pedometer normative reference data for 21,271 children and 12,956 adolescents. Med Sci Sports Exerc. 2013;45(1):123–9.
48. Cameron C, Craig CL, Bauman A, Tudor-Locke C. CANPLAY study: secular trends in steps/day amongst 5-19year-old Canadians between 2005 and 2014. Prev Med. 2016;86:28–33.
49. Hirvensalo M, Telama R, Schmidt MD, Tammelin TH, Yang X, Magnussen CG, Vkari JS, Raitakari OT. Daily steps among Finnish adults: variation by age, sex, and socioeconomic position. Scand J Public Health. 2011;39(7):669–77.

50. Inoue S, Ohya Y, Tudor-Locke C, Tanaka S, Yoshiike N, Shimomitsu T. Time trends for step-determined physical activity among Japanese adults. Med Sci Sports Exerc. 2011;43(10):1913–9.
51. Schneider PL, Crouter S, Bassett DR Jr. Pedometer measures of free-living physical activity: comparison of 13 models. Med Sci Sports Exerc. 2004;36(2):331–5.
52. Steeves JA, Tyo BM, Connolly CP, Gregory DA, Stark NA, Bassett DR Jr. Validity and reliability of the Omron HJ-303 tri-axial accelerometer-based pedometer. J Phys Activ Health. 2011;8(7):1014–20.
53. Bergman RJ, Bassett DR Jr, Muthukrishnan S, Klein DA. Validity of 2 devices for measuring steps taken by older adults in assisted-living facilities. J Phys Activ Health. 2008;5(Suppl 1):166–75.
54. Nakae S, Oshima Y, Ishii K. Accuracy of spring-levered and piezo-electric pedometers in primary school Japanese children. J Physiol Anthropol. 2008;27(5):233–9.
55. Nelson MB, Kaminsky LA, Dickin DC, Montoye AH. Validity of consumer-based physical activity monitors for specific activity types. Med Sci Sports Exerc. 2016;48(8):1619–28.
56. Tudor-Locke C, Bassett DR Jr. How many steps/day are enough? Preliminary pedometer indices for public health. Sports Med. 2004;34(1):1–8.
57. Tudor-Locke C, Hatano Y, Pangrazi RP, Kang M. Revisiting “How many steps are enough?”. Med Sci Sports Exerc. 2008;40(7):S537–43.
58. Tudor-Locke C, Craig CL, Beets MW, Belton S, Cardon GM, Duncan S, Hatano Y, Lubans DR, Olds TS, Raustorp A, Rowe DA, Spence JC, Tanaka S, Blair SN. How many steps/day are enough? For children and adolescents. Int J Behav Nutr Phys Act. 2011;8:78.
59. Tudor-Locke C, Bell RC, Myers AM, Harris SB, Lauzon N, Rodger NW. Pedometer-determined ambulatory activity in individuals with type 2 diabetes. Diabetes Res Clin Pract. 2002;55(3):191–9.
60. Tudor-Locke C, Pangrazi RP, Corbin CB, Rutherford WJ, Vincent SD, Raustorp A, Tomson LM, Cuddihy TF. BMI-referenced standards for recommended pedometer-determined steps/day in children. Prev Med. 2004;38(6):857–64.
61. Tudor-Locke C, Bassett DR Jr, Rutherford WJ, Ainsworth BE, Chan CB, Croteau K, Giles-Corti B, Le Masurier G, Moreau K, Mrozek J, Oppert JM, Raustorp A, Strath SJ, Thompson D, Whitt-Glover MC, Wilde B, Wojcik JR. BMI-referenced cut points for pedometer-determined steps per day in adults. J Phys Activ Health. 2008;5(1 Suppl):S126–S39.
62. Tudor-Locke C, Craig CL, Thyfault JP, Spence JC. A step-defined sedentary lifestyle index: <5000 steps/day. Appl Physiol Nutr Metabol. 2013;38:100–14.
63. Crouter SE, Clowers KG, Bassett DR. A novel method for using accelerometer data to predict energy expenditure. J Appl Physiol. 2006;100(4):1324–31.
64. Crouter SE, Kuffel E, Haas JD, Frongillo EA, Bassett DRB. Refined two-regression model for the ActiGraph accelerometer. Med Sci Sports Exerc. 2010;42(5):1029–37.
65. Esliger DW, Rowlands AV, Hurst TL, Catt M, Murray P, Eston RG. Validation of the GENEA accelerometer. Med Sci Sports Exerc. 2011;43(6):1085–93.
66. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, Troiano RP. Amount of time spent in sedentary behaviors in the United States, 2003-2004. Am J Epidemiol. 2008;167(7):875–81.
67. Kozey-Keadle S, Libertine A, Lyden K, Staudenmayer J, Freedson PS. Validation of wearable monitors for assessing sedentary behavior. Med Sci Sports Exerc. 2011;43(8):1561–7.
68. Silva P, Aires L, Santos RM, Vale S, Welk G, Mota J. Lifespan snapshot of physical activity assessed by accelerometry in Porto. J Phys Activ Health. 2011;8(3):352–60.
69. Healy GN, Clark BK, Winkler EA, Gardiner PA, Brown WJ, Matthews CE. Measurement of adults’ sedentary time in population-based studies. Am J Prev Med. 2011;41(2):216–27.
70. Choi L, Liu Z, Matthews CE, Buchowski MS. Validation of accelerometer wear and nonwear time classification algorithm. Med Sci Sports Exerc. 2011;43(2):357–64.
71. Troiano RP, McClain JJ, Brychta RJ, Chen KY. Evolution of accelerometer methods for physical activity research. Br J Sport Med. 2014;48(13):1019–23.

72. Bankoski A, Harris TB, McClain JJ, Brychta RJ, Caserotti P, Chen KY, Berrigan D, Troiano RP, Koster A. Sedentary activity associated with metabolic syndrome independent of physical activity. Diabetes Care. 2011;34(2):497–503.
73. Manns P, Ezeugwu V, Armijo-Olivo S, Vallance J, Healy GN. Accelerometer-derived pattern of sedentary and physical activity time in persons with mobility disability: National Health and Nutrition Examination Survey 2003 to 2006. J Am Geriatr Soc. 2015;63(7):1314–23.
74. Loprinzi PD, Gilham B, Cardinal BJ. Association between accelerometer-assessed physical activity and objectively measured hearing sensitivity among U.S. adults with diabetes. Res Q Exercise Sport. 2014;85(3):390–7.
75. Vallance JK, Buman MP, Stevinson C, Lynch BM. Associations of overall sedentary time and screen time with sleep outcomes. Am J Health Behav. 2015;39(1):62–7.
76. Loprinzi PD, Abbott K. Association of diabetic peripheral arterial disease and objectively-measured physical activity: NHANES 2003-2004. J Diabetes Metab Disord. 2014;13:63.
77. Van Dyck D, Cerin E, De Bourdeaudhuij I, Hinckson E, Reis RS, Davey R, Sarmiento OL, Mitas J, Troelsen J, MacFarlane D, Salvo D, Aguinaga-Ontoso I, Owen N, Cain KL, Sallis JF. International study of objectively-measured physical activity and sedentary time with body mass index and obesity: IPEN adult study. Int J Obesity. 2015;39(2):199–207.
78. Evenson KR, Wen F, Herring AH, Di C, LaMonte MJ, Fels-Tinker L, Lee I-M, Rillamas-Sun E, LaCroix AZ, Buchner DM. Calibrating physical activity intensity for hip-worn accelerometry in women age 60 to 91 years: the Women's Health Initiative OPACH calibration study. Pre Med Rep. 2015;2:750–6.
79. Jefferis BJ, Sartini C, Shiroma E, Whincup PH, Wannamethee SG, Lee IM. Duration and breaks in sedentary behaviour: accelerometer data from 1566 community-dwelling older men (British Regional Heart Study). Br J Sport Med. 2015;49(24):1591–4.
80. Lyden K, Kozey Keadle SL, Staudenmayer JW, Freedson PS. Validity of two wearable monitors to estimate breaks from sedentary time. Med Sci Sports Exerc. 2012;44(11):2243–52.
81. Rowlands AV, Olds TS, Hillsdon M, Pulsford R, Hurst TL, Eston RG, Gomersall SR, Johnston K, Langford J. Assessing sedentary behavior with the GENEActiv: introducing the sedentary sphere. Med Sci Sports Exerc. 2014;46(6):1235–47.
82. Rowlands AV, Yates T, Olds TS, Davies M, Khunti K, Edwardson CL. Sedentary sphere: wrist-worn accelerometer-brand independent posture classification. Med Sci Sports Exerc. 2016;48 (4):748–54.
83. Staudenmayer J, Zhu W, Catellier DJ. Statistical considerations in the analysis of accelerometry-based activity monitor data. Med Sci Sports Exerc. 2012;44(1):561–S567.
84. Mannini A, Sabatini AM. Machine learning methods for classifying human physical activity from on-body accelerometers. Sensors. 2010;10(2):1154–75.
85. Ravi N, Dandekar N, Mysore P, Littman ML. Activity recognition from accelerometer data, vol. 5. Association for the Advancement of Artificial Intelligence; 2005. p. 1541–6.
86. Fairclough SJ, Noonan R, Rowlands AV, Van Hees V, Knowles Z, Boddy LM. Wear compliance and activity in children wearing wrist- and hip-mounted accelerometers. Med Sci Sports Exerc. 2016;48(2):245–53.
87. Welk GJ, McClain J, Ainsworth BE. Protocols for evaluating equivalency of accelerometry-based activity monitors. Med Sci Sports Exerc. 2012;44(1 Suppl):S39–49.
88. Sedentary Behaviour Research Network. Standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metabol. 2012;37:540–2.
89. Dunton GF, Dzubur E, Kawabata K, Yanez B, Bo B, Intille S. Development of a smartphone application to measure physical activity using sensor-assisted self-report. Front Public Health. 2014;2:12.

Chapter 4
Analysis and Interpretation of Sedentary Behaviour Data

Weimo Zhu

Abstract Never before, perhaps due to widely available wearable devices and the ubiquity of mobile phones, has it been so easy and convenient to collect physical activity and sedentary behaviour data. Yet, the available large and rich data sets do not guarantee that the correct information will be generated from them. For example, many inappropriate, *p*-value-based conclusions were made based on the available mass data. To address these problems and challenges, this chapter is to help readers understand key characteristics of sedentary behaviour data, become aware of common problems and challenges in analysing sedentary behaviour data, become familiar with methods that could address these problems and challenges, appropriately interpret statistical findings and understand the principles to establish causality and critical issues remaining in sedentary behaviour research.

What Is New?

Since the publication of the first edition of this book in 2017, progress has been made in analysing sedentary behaviour data, and at the same time, new challenges have emerged:

- Compositional data analysis became routine in analysing sedentary behaviour data.
- Machine learning was applied to sedentary behaviour data analysis.
- New statistical procedures, such as testing equating, were introduced to link multiple measures to the same scale.
- Because most measurement devices are worn on the wrist, new noise was introduced to the sedentary behaviour data, making it challenging to determine intensity cut points.

W. Zhu (✉)
University of Illinois at Urbana-Champaign/Yunnan Plateau Thermal Health Industry Innovation Research Institute, Champaign, IL, USA
e-mail: weimozhu@illinois.edu

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_4

4.1 Introduction

After any data have been collected, the next set of questions to a researcher naturally will be the following:

'How should the data be analysed so that accurate and meaningful information can be generated?'

- 'Can conventional statistical methods, such as correlation, *t*-test, ANOVA, etc., be applied directly to the data?'
- 'How can the results of the data analysis be correctly and appropriately interpreted?'

This is especially true in sedentary behaviour research. Therefore, this chapter addresses these questions concerning using sedentary behaviour data. After a review of the characteristics of sedentary behaviour data, the challenges in analysing sedentary behaviour data will be described. Specifically, the limitations of conventional statistical methods in analysing these data and inconsistencies in defining sedentary behaviour will be outlined and described. New and appropriate statistical methods will then be introduced. Thereafter, some practical suggestions on how to analyse and report sedentary behaviour data will be explained. Finally, how to establish causality in sedentary behaviour research will be discussed.

4.2 Sedentary Behaviour Data Characteristics

Understanding the characteristics of a data set is essential in any data analysis procedure. Without knowing the specific aspects of a data set, statistical methods for the data analysis may not be appropriately selected. As a result, the information generated will likely be inaccurate or even misleading. What then are the characteristics of sedentary behaviour data?

One of the features of sedentary behaviour data is that the data belong to a class of compositional data, which is defined as data with relative portions summing up to 1 or 100%. Compositional data are common: proportion of allocated time of a day for certain activities, proportion of energy provided by different meals and percentages of students in a class from different geographical areas are just a few examples. Physical activity data are compositional data, in which total physical activity, depending on how operationally defined, may be seen to consist of light, moderate and vigorous physical activity. This same principle also applies to sedentary behaviour data, which can be further broken down as TV viewing, reading, computer and video game times, etc. Please note that current physical activity research literature often considers sedentary behaviour to be on the physical activity continuum. To distinguish 'sedentary behaviour' from 'physical activity', sedentary behaviour was intentionally not placed on the physical activity continuum in this chapter. For future

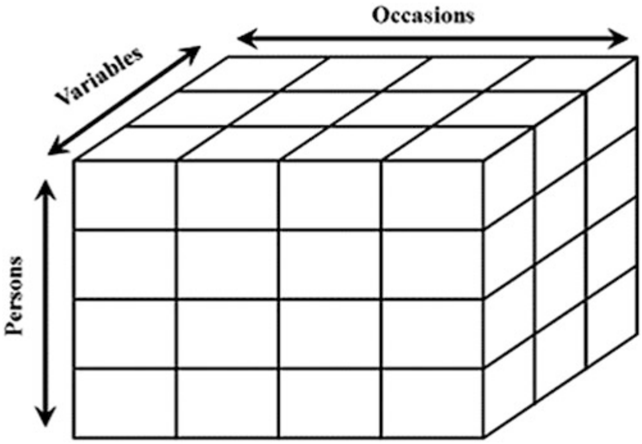

Fig. 4.1 Illustration of Cattell's data box

research including sedentary behaviour on such a continuum, the continuum would be better called the 'physical- and sedentary-activity continuum'.

According to van den Boogaart and Tolosana-Delgado [1], each part of a compositional construct is called a component, which has an amount representing its contribution to the total. The amount could be presented in its original measurement units, e.g. time, weight, size or the proportion or percentage, which can be determined by the component amount divided by the total. Depending on the units of interest chosen for the composite measure, the actual portions of the parts in a total can vary. For example, percentages of time spent on different types of physical activity or sedentary behaviour could be different from the percentages of energy spent in different behaviours during the same time period. A portion can be further broken down by sub-portions. For example, sedentary behaviour is a proportion of the total of the actions performed during waking hours, and it can be further broken down into different types of sedentary behaviours, e.g. watching TV, playing video games, using a computer, driving and reading.

The second known characteristic of sedentary behaviour data is that the data are often collected, especially for device-derived data, in continuous time-stamped series for each person. As a result, large and rich time series data are generated. A time series is a sequence of observations that are ordered by time of occurrence. It should be pointed out that, although most sedentary data are continuous, they can also be discrete, e.g. if a specific behaviour, such as playing video games, occurs in a specific time interval. There are two ways to look at time series data from a data structure point of view.

First, according to Cattell's well-known data box [2, 3], time series data integrate three primary dimensions, those of persons, variables (e.g. physical activity and sedentary behaviour time) and occasions (see Fig. 4.1), from which at least six different structural relationships can be utilised to address specific research questions: (1) variables over persons, fixed occasion; (2) persons over variables, fixed occasion; (3) persons over occasions, fixed variables; (4) occasions over persons, fixed variables; (5) variables over occasions, fixed persons; and (6) occasions over variables, fixed persons.

Second, time series data can also be considered as a multilevel data structure, with occasion-related variables at the within-person level and persons' demographics or group membership at the person level [4, 5]. An example may be helpful to explain this structure. Below listed are hypothetical time series data with four time points and n persons:

ID_j	O_i	X_{ij}	Y_{ij}	W_j
1	0	x_{11}	y_{11}	w_1
1	1	x_{21}	y_{21}	w_1
1	2	x_{31}	y_{31}	w_1
1	3	x_{41}	y_{41}	w_1
2	0	x_{12}	y_{12}	w_2
2	1	x_{22}	y_{22}	w_2
2	2	x_{32}	y_{32}	w_2
2	3	x_{42}	y_{42}	w_2
...				
n	0	x_{1n}	y_{1n}	w_n
n	1	x_{2n}	y_{2n}	w_n
n	2	x_{3n}	y_{3n}	w_n
n	3	x_{4n}	y_{4n}	w_n

where ID is the identification of the individual person, O is the occasion or time points (it is common to use a code '0' for the first observation), X is an independent variable (e.g. physical activity and sedentary behaviour), Y is a dependent variable (e.g. heart rate or energy expenditure) and W is a predictor variable that varies between persons only (e.g. sex, exercise intervention vs. control). Thus, the X and Y variables belong to the within-person level variables, and W belongs to the between-person variables.

In addition, several other specific features are related to time series data. First, there is usually a trend component in the time series data, which is often represented by the changes in a dependent variable over time in relation to the independent variable individually or jointly with other independent variables. The changes further include the underlying direction (e.g. an upward or downward movement) and the rate of change. Second, there is often a cyclical component, which describes a dependent variable's regular fluctuations or cycle in relation to the independent variable. Weekday and weekend physical activity is a recognisable cycle that is a good example of this component. Third, there could be a seasonal component, which indicates that the variations in the time series data are related to the time of year. An increase or decrease in outdoor physical activities or indoor sedentary behaviours across seasons is a good example of this component. Conceptually, the seasonal component can be considered as a special case of the cyclical component since the former is the cycle only related to seasons, while the latter is related to any cycles in the data. Finally, the last component in studying time series data is called the irregular component. Also known as 'noise', this component accounts for the variation in the remaining data after taking into account other components.

The third characteristic is related to the variation of the data. While this characteristic has not been well studied and many physical activity and sedentary behaviour researchers are not aware of it, we learned from the field's physical activity and sedentary data analysis experiences that both low-intensity physical activity data and sedentary behaviour data may have larger variation than moderate and vigorous intensity data, which is true for both total physical activity time or total minutes and for the proportion of the total time (see Table 4.1). Researchers have learned, when running statistical analysis, that large variation, expressed in standard deviation for example, often has led to a 'nonsignificant' result or a smaller effect size even if there is an obvious difference between groups. This characteristic means that even if an intervention already has resulted in a reduction in sedentary time, our statistical analysis may not be able to detect it or even allow for its detection.

In addition to all the above characteristics, another critical issue in analysing sedentary data is related to its operational definition. While sedentary behaviour itself has been well described and defined in the literature [6, 7], how to measure it using a specific device is individually defined and can be done so inconsistently. As described by Cain et al. in 2013 [8], for the youth population alone, there are already 11 sedentary behaviour cut points for the ActiGraph accelerometer, the most popular accelerometry device being used for physical activity and sedentary behaviour research. It is to be expected that more cut points are being set. In addition, not all sitting is alike in terms of health impact (e.g. TV view sitting vs. Zen meditation sitting, which differ greatly in terms of the use of postural muscles), and most of the current measures of sedentary behaviour have ignored the distinctive natures of different types of sitting and are actually incapable of being able to distinguish them from each other.

4.3 Statistical Analysis of Sedentary Behaviour Data

Currently, most sedentary behaviour data have been analysed using conventional parametric tests, such as correlation, regression, *t*-test, ANOVA, MANOVA, etc. Unfortunately, due to the structure and characteristics of sedentary behaviour data as described above, these statistical tests are sometimes not appropriate or do not take full advantage of what information the data could provide. This is because one of the fundamental assumptions of all of these conventional statistical methods is that the data should be independent of each other. Sedentary behaviour and physical activity data belong to compositional or sub-compositional data, which means the data can be correlated to each other. In addition, these conventional statistical methods assume normal distributions for estimates and estimation errors, which conflicts with the bounded frequency distributions of composition data. Therefore, simply applying conventional statistical methods to compositional data may not be

Table 4.1 Descriptive statistics of physical activity (PA) and sedentary behaviour in the 2005–2006 National Health and Nutrition Examination Survey (NHANES) data

	Activity type and ratio to total	*N*	Mean	SD	Maximum	Minimum	Sex ratio
Total	Sedentary mins per day	6344	459.20	125.72	1044.86	67.50	48.22% male
	Light PA mins per day	6344	344.73	100.30	769.43	16.00	
	Moderate PA mins per day	6344	25.53	22.90	307.00	0.00	
	Vigorous PA mins per day	6344	5.04	9.96	115.00	0.00	
	MVPA mins per day	6344	30.57	28.61	331.00	0.00	
	Sedentary mins per day/total	6344	0.55	0.13	0.98	0.10	
	Light PA mins per day/total	6344	0.41	0.11	0.79	0.02	
	Moderate PA mins per day/total	6344	0.03	0.03	0.32	0.00	
	Vigorous PA mins per day/total	6344	0.01	0.01	0.15	0.00	
	MVPA mins per day/total	6344	0.04	0.03	0.39	0.00	
Adults ≥ 18	Sedentary mins per day	4130	478.29	124.97	1044.86	67.50	47.77% male
	Light PA mins per day	4130	333.65	105.19	769.43	16.00	
	Moderate PA mins per day	4130	22.97	24.71	307.00	0.00	
	Vigorous PA mins per day	4130	0.98	3.53	53.00	0.00	
	MVPA mins per day	4130	23.95	26.23	331.00	0.00	
	Sedentary mins per day/total	4130	0.57	0.13	0.98	0.10	
	Light PA mins per day/total	4130	0.40	0.12	0.79	0.02	
	Moderate PA mins per day/total	4130	0.03	0.03	0.32	0.00	
	Vigorous PA mins per day/total	4130	0.00	0.00	0.08	0.00	

(continued)

Table 4.1 (continued)

	Activity type and ratio to total	*N*	Mean	SD	Maximum	Minimum	Sex ratio
	MVPA mins per day/total	4130	0.03	0.03	0.39	0.00	
Children < 18	Sedentary mins per day	2214	423.61	119.25	965.20	110.71	49.05% male
	Light PA mins per day	2214	365.40	86.78	639.43	22.50	
	Moderate PA mins per day	2214	30.30	18.13	159.14	0.00	
	Vigorous PA mins per day	2214	12.61	13.14	115.00	0.00	
	MVPA mins per day	2214	42.91	28.78	252.14	0.00	
	Sedentary mins per day/total	2214	0.51	0.12	0.97	0.14	
	Light PA mins per day/total	2214	0.44	0.10	0.74	0.03	
	Moderate PA mins per day/total	2214	0.04	0.02	0.21	0.00	
	Vigorous PA mins per day/total	2214	0.02	0.02	0.15	0.00	
	MVPA mins per day/total	2214	0.05	0.03	0.33	0.00	

Note. MVPA = moderate-to-vigorous physical activity

appropriate and could lead to problems such as spurious correlation, constant-sum, negative-bias, null-correlation and closure problems [9].

Another common inappropriate practice in analysing sedentary behaviour data is to ignore the rich information embedded in continuous data that can be derived, for example, from accelerometers. Too often, only the daily average of sedentary time has been computed and analysed in reported research studies. In contrast, recent physical activity and sedentary behaviour research indicates that examining patterns of physically active and sedentary behaviour can be more informative and can identify attributes critical to health. According to Owen et al. [6], for example, someone could be ‘physically active, but also highly sedentary’, and ‘move often’ could be as important as ‘move more’, i.e. a ‘breaker’ person who has more breaks from prolonged sitting, will likely be healthier than a ‘prolonger’, who has less breaks [10–12]. Accordingly, the traditional way of analysing physical activity data, in which only a specific type of activity, e.g. moderate and vigorous physical activity or sedentary behaviour time, is analysed individually, clearly cannot take advantage of the rich information embedded within physical activity and sedentary behaviour time series data.

Finally, as pointed out earlier, inconsistencies in setting cut points is a concern. While a great deal of attention has been devoted on how to set cut points for accelerometers or similar devices (most often, these correlate with signals generated from the devices with an intensity measure, such as VO_2 consumption, % of VO_2 max and % maximal heart rate), there remains the need to further validate the developed cut points.

Fortunately, a set of methods and solutions are already available to address the problems and challenges described above. They will be briefly addressed in this section. More specific details can be found in the cited references.

4.3.1 Matching Data Structure, Research Questions and Methods

With a theoretical framework and understanding of a specific data structure, statistical methods can be appropriately selected for specific research questions. As an illustration, under the framework of Cattell's data box [2, 3], R-technique (e.g. a commonly used approach to factor analysis) can be used for the data dimension of 'variables over persons, fixed occasion'; Q-technique (e.g. cluster analysis for subgroups of persons) for the dimension of 'persons over variables, fixed occasion'; S-technique (e.g. persons clustering based on growth patterns) for the dimension of 'persons over occasions, fixed variables'; T-technique (e.g. time-dependent clusters based on persons) for the dimension of 'occasions over persons, fixed variables'; O-technique (e.g. time-dependent (historical) clusters) for the dimension of 'variables over occasions, fixed persons'; and finally, P-technique (e.g. intra-individual time series analyses) for the dimension of 'occasions over variables, fixed persons'. In fact, many modern statistical methods are either derived from these techniques (e.g. dynamic P-technique, which is useful in examining relationships among dynamic constructs in a single individual or small group of individuals over time) [13] or can be interpreted under the framework of Cattell's data box (e.g. growth curve modelling and longitudinal factor analysis) [14].

The multilevel structure of time series data provides another useful aspect to help select the appropriate statistical method for analysis. For example, if the research interest is to determine if there is a change or pattern in within-person level variables (X, Y or the relations between X and Y), and, if there is, the change or pattern caused by between-person variables, in this case multilevel statistical methods, such as the hierarchical linear models [15, 16], can be employed for data analysis. If the interest is at when the Y variable varies at both levels, or X-to-Y relations exist at both levels, and time as a third variable, or in the random effects (i.e. between-subject heterogeneity) and auto-correlated errors, a set of intensive longitudinal methods are available [4].

4.3.2 Compositional Data Analysis

That there are problems that occur when applying conventional statistical methods to compositional data is not a new revelation. In fact, Karl Pearson [17] pointed out such problems in his well-known paper on spurious correlations more than 100 years ago. Then, the geologist Felix Chayes [18] took up the problem and warned against the application of standard multivariate analysis to compositional data. But it was John Aitchison, whose works in the 1980s [19–23] made compositional data analysis a sub-discipline in statistical data analysis, who proved that log ratios are easier to handle mathematically than ratios, and after the log ratio translations, standard unconstrained multivariate statistics can be applied to the transformed data, and statistical inferences can be made subsequently. Around 2000, a new set of statistical methods based on the principle of working in coordinates were further developed and applied (e.g. Billheimer et al. [24]; Pawlowsky-Glahn and Egozcue [25]; for more information on the development of compositional data analysis, see the good summary by Pawlowsky-Glahn et al. [26]). In addition, a number of textbooks on compositional data analysis have been published:

- *The Statistical Analysis of Compositional Data* by J. Aitchison [27]
- *Compositional Data Analysis in the Geosciences: From Theory to Practice* by A. Buccianti, G. Mateu-Figueras and V. Pawlowsky-Glahn [28]
- *Compositional Data Analysis: Theory and Applications* by V. Pawlowsky-Glahn and A. Buccianti [29]
- *Modeling and Analysis of Compositional Data (Statistics in Practice)* by V. Pawlowsky-Glahn, J.J. Egozcue and R. Tolosana-Delgado [26]

Finally, R-based computational analytical procedures have been developed for compositional data analysis as presented in the book *Analyzing Compositional Data with R* by van den Boogaart and Tolosana-Delgado [1].

Most progress made in sedentary behaviour data analysis since the first edition of this book is the wide acceptance and application of compositional data analysis to sedentary behaviour data. For example, Gupta et al. [30] compared standard and compositional data analysis of sedentary behaviour and physical activity data and called for applying composition data analysis so that the compositional nature of sedentary behaviour and physical activities can be adequately addressed. Verswijveren et al. [31] used compositional data analysis to explore the accumulation of sedentary behaviour, physical activities and health in youth. For more information in this area, see the systematic review by Janssen et al. [32].

4.3.3 Machine Learning

Machine learning is a subset of artificial intelligence, which utilises a collection of algorithms that help computers learn from data. Through machine learning, prediction gets better with experience, and it is a method useful often for analysing large volumes of data since it allows recognising of patterns and classifying outcomes [33]. Machine learning algorithms are based on 'supervised' or 'unsupervised' approaches. Supervised learning occurs when the outcomes are known and the machine learns to predict outcomes given new cases. A set of training data, where both inputs and outcome variables are known, is used to build a model. The model is then applied to a set of new test data where the input variables are classified and compared to actual outcome variables. Supervised learning algorithms include regression (for continuous variables) and classification (for discrete variables) problems. Unsupervised learning problems do not assume a set of specific outcome variables, and the algorithms used are aimed at finding patterns and clusters in the input variables.

Machine learning algorithms have been in fact successfully used for the analysis of accelerometer-derived physical activity data mainly focusing on the physical activity mode prediction [34–37]. Some studies to connect physical activity patterns to posture recognition and fall detection were conducted in a controlled environment with known activities [38, 39]. Others focused on activity recognition have been conducted in realistic conditions outside of a clinical environment [34, 40]. Accelerometer-derived physical activity patterns in cattle, data that was collected in a free-living environment, have also been studied using machine learning algorithms with the main focus of classifying cattle movements into lying, standing, grazing, etc. [41–43]. A study by O'Connell et al. [44] aimed to connect cattle behaviour monitored by accelerometers with reproductive status based on progesterone levels, which suggests that machine learning methods may successfully be applied not only for classifying accelerometer-derived physical activity into activity types but also for recognising patterns in movement that help predict health status. In addition, machine learning algorithms have also been applied to accelerometers data for diagnosis of tremor-related disease such as Parkinson's, the classification and assessment of severity of levodopa-induced dyskinesia and recognition of involuntary gestures in babies with cerebral palsy [45]. Thus, machine learning methods show promise in recognising unique movement patterns for classification of disease status. In fact, some progress has been made in this area. For example, Kańtoch [46] used machine learning to recognise sedentary behaviour data when analysing telemedical assessment data for early detection of increased cardiovascular risk. Bhattacharjee et al. [47] reported how to use machine learning to analyse sleep and sedentary behaviour data.

4.3.4 Error Grid Analysis for Real-Time Monitoring

With a few exceptions (e.g. a reminder to people when sitting too long), most physical activity and sedentary behaviour monitors currently are employed to provide summary information (e.g. the minutes of moderate-to-vigorous physical activity time) although long term, real-time physical activity and sedentary

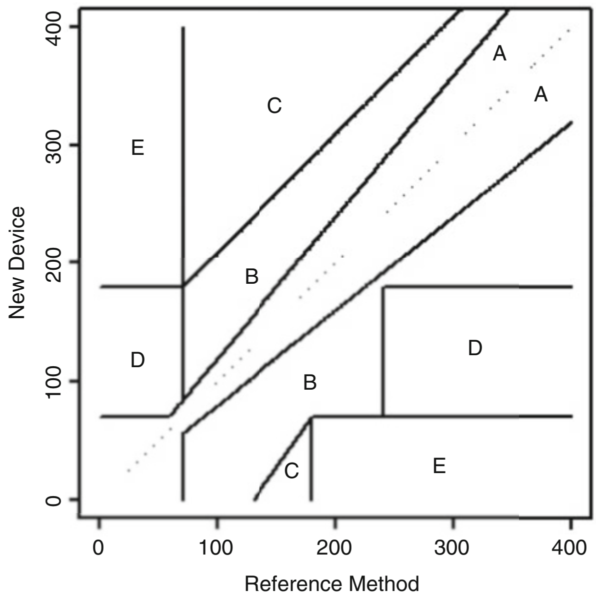

Fig. 4.2 Illustration of Clarke's error grid analysis (EGA)

behaviour wearable devices are already widely used in practice. For effective training, intervention or rehabilitation, the ability to control exercise intensity or behaviour within a targeted zone is extremely important and valuable. For similar purposes, a set of variability control methods has been developed in diabetes care for the purpose of glucose monitoring. Among them, Clarke's error grid analysis (EGA) [48] is mostly studied and applied. EGA breaks down a scatterplot of a reference glucose monitor and an evaluated glucose metre into five areas (see Fig. 4.2):

A. Where the values are within 20% of the reference sensor?
B. Where the values are outside of 20%, but would not lead to inappropriate treatment?
C. Where the values could lead to unnecessary treatment?
D. Where the values indicate a potentially dangerous failure to detect hypoglycaemia or hyperglycaemia?
E. Where the values could confuse treatment of hypoglycaemia for hyperglycaemia and vice versa?

Many new methods and useful information has been generated since then [49–52]. Physical activity and sedentary behaviour research and practice would benefit from taking greater advantage of these methods and the novel information that they can generate.

4.3.5 Linking Multiple Measures Using Test Equating

In measurement practice, it is common to use multiple measures to assess the same construct, and, among the measures used, there are always one or two that are well developed, but due to other needs, e.g. financial or practical issues, new measures were developed. These latter measures, however, often cannot be readily used because they lack scientific evidence for credibility, such as validity, reliability and evaluation standards. This is also true in assessing physical activity and sedentary behaviour. For example, ActiGraph, a device by ActiGraph LLC., is the most well-developed and widely used field measures of physical activity. Yet, ActiGraph is expensive and has been used mainly for research purposes. As a result, many new, accelerometry-based wearable devices have been developed, but they were not comparable to findings of the ActiGraph since their data were set according to their own scale.

To address this problem, John et al. [53] developed a platform called 'Monitor-Independent Movement Summary (MIMS)' to link different accelerometer devices. Technically, MIMS is a unit defined by the accumulation of acceleration over time, and it represents accelerations caused by physical movement during a specific epoch, e.g. 1 minute, 1 hour or 1 day. MIMS per minute thus could be used to index the intensity of physical activity. The advantage of the MIMS algorithm, therefore, is compatibility across accelerometry data from all brands of devices, while the ActiGraph's 'count' can be derived only from ActiGraph accelerometry data. The limitation of MIMS is that intensity cut points have not been established for MIMS, making it ineffective at assessing physical activity and sedentary behaviour since certain critical information, e.g. sedentary and moderate-to-vigorous physical activities (MVPA) cannot be computed.

Fortunately, these limitations can be addressed by applying test equating methods, a statistical method to examine the relationship between two or more tests or to transform test scores from different tests into the same scale [54]. Test equating has been used, in fact, to transform different fitness test scores into the same scales [55], and it was also successfully used to help set MIMS into the scale of ActiGraph counts by a recent effort by Qin et al. [56]. As a result, through MIMS and the conversion relationship developed, all ActiGraph count-related information, e.g. energy expenditure, risk of cardiovascular disease, bone loading, can now be shared with other devices, and study results can be compared even when different devices were used.

4.3.6 Validating Cut Points

Because of differences in samples and criterion measures employed in validation studies, it is expected that inconsistency in setting cut points for physical activity and sedentary behaviour data derived from accelerometers and related devices will continue. Meanwhile, a systematic effort should be made after a cut point is set up so that additional validity evidence can be accumulated and the credibility of the cut points can be further evaluated. When validating a cut point or standard, Kane [57] proposed collecting four kinds of validity evidence, including (1) the conceptual coherence of the standard setting process (e.g. if the standard-setting method and related assessment procedure are consistent with the conception of achievement underlying the decision procedure, such as if a new device can correctly distinguish sitting that involves purposeful task performance, from more passive forms of sitting such as television viewing); (2) procedural evidence for the descriptive and policy assumptions (e.g. if the standards were set up in a reasonable way by persons who are knowledgeable about the purpose of the standards and familiar with the standard setting procedure); (3) internal consistency evidence (e.g. if the presumed relationship between a performance standard, which could be very important in real-time long-term monitoring and a cut point can be confirmed); and (4) agreement with external criteria (e.g. if the decision made is consistent with other assessment-based decision procedures or outcome variables). One should expect some differences when different health outcome variables (say cardiovascular health vs. bone health) were employed to examine the external validity. In addition, the role of consequences in standard setting and associated arbitrariness in standards must be examined (see also Zhu [58] for a discussion from the kinesiology's view on standard and cut point setting).

Because most wearable devices for assessing physical activity and sedentary behaviour are worn on the wrist, some additional challenges in setting standards have been observed. This is because in the real-life, free-living conditions, hands could move fast, e.g. when a child is playing computer or video games, but the activity itself will bring little physiological impact and health benefit to children and youth. These kinds of sedentary 'hands-only' activities may be termed 'sedentary active behaviour' and could add noise to the data, leading to misclassification of sedentary behaviour as MVPA. Studies to address this issue are urgently needed.

4.4 Interpretation of Sedentary Behaviour Data

There is never any guarantee that the findings will be interpreted correctly even when the appropriate analytical methods were employed. One ongoing problem in all areas of research is that statistical findings in physical activity and sedentary behaviour research have often been interpreted based on *p*-values only; therefore, the data were incorrectly interpreted. As an example, when validating a physical activity measure, many low correlations were called 'significant' simply because a less than 0.05 *p*-value was achieved. Even though the interpretation of statistical finding based only on *p*-values has long been criticised [59], this practice continues in the field of physical activity and sedentary behaviour research [60]. For correlational and regression research, statistical interpretation should be based on either absolute criteria or variance percentages explained by the predictors; for inferential statistical findings, the interpretation should be based on the effect size or the confidence intervals [60, 61]. In addition, the true meaning of the statistics and practical significance of the outcome variables should be studied (e.g. for a specific age range and sex group, how many sedentary minutes should be reduced to result in a meaningful change in health?). For real-time, long-term monitoring, rich ‘baseline’ information should be taken into consideration so that real or meaningful individual change can be determined from a person’s baseline information.

4.5 Causality in Sedentary Behaviour Epidemiology

Understanding cause-effect relations is essential to any scientific research, which is also true for epidemiologic studies. Lazarsfeld [62] established three criteria for causal relations: (1) there is a temporal order, i.e. for A caused B, A must occur before B; (2) there is empirically relationship; and more importantly (3) the observed empirical relationship between two variables cannot be explained away as the result of a third variable that causes both A and B. A number of criteria have also been set specifically for causal inference in epidemiology, and among them, Hill’s yard stick [63] is perhaps the most popular one, which includes nine specific criteria:

1. Strength (e.g. Is there a strong relationship between prolonged sitting time and obesity?)
2. Consistency (e.g. Has the relationship between sedentary behaviour and cancer been confirmed in many studies?)
3. Specificity (e.g. Is low back pain found only in certain professionals with prolonged sitting?)
4. Temporal relationship (e.g. Low back pain did not occur until one changed to a prolonged sitting job.)
5. Biological gradient (e.g. Is there a dose-response relationship between prolonged sitting and increased incident rates of high blood pressure?)
6. Plausibility (e.g. Can we explain from our biological knowledge why prolonged sitting could cause low-bone mineral density?)
7. Coherence (e.g. Is the relationship between sedentary behaviour and health supported by existing theoretical, factual, biological and statistical reasoning and evidence?)
8. Experiment (e.g. Can low back pain be reduced if a standing desk intervention is introduced in office settings?)
9. Analogy (e.g. If prolonged sitting can cause obesity, it will likely lead to diabetes).

It should be pointed out that although these criteria were received and applied in practice, they were also questioned and criticised. Interested readers are referred to Kundi [64] for more detail.

A well-controlled experimental design is also very important to establish causality. In epidemiologic studies, the randomised clinical trial (RCT) is the gold standard research design to provide the most convincing evidence of a relationship between cause and effect. The RCT, however, is very expensive to run and is not appropriate to answer certain types of questions and may be unethical (e.g. to assign persons to certain treatment or comparison groups) in clinical settings. Instead, nonexperimental or observational study designs in which persons are observed currently, prospectively or retrospectively are often employed in research practice. The effect of the 'third variable', i.e. other covariates or confounding variables, however, is often unavoidable due to non-random selection when forming the study groups. This is perhaps the reason that we often hear about inconsistent, confusing findings covered by the media. Fortunately, a set of statistical methods known as propensity score analysis [65, 66], in which selection bias is removed, or the covariates are balanced, have been introduced and applied to epidemiologic studies. Sedentary behaviour researchers, however, have not taken the full strength and advantage of this method.

4.6 Conclusions

With the increased awareness on the adverse impact sedentary behaviour has on health and the availability and greater use of wearable physical activity monitoring devices, the 'big data' era for physical activity and sedentary behaviour research has arrived. Yet, the field of physical activity and sedentary behaviour research and practice has just started to take full advantage of new statistical methods and practices that can better analyse physical activity and sedentary data. In fact, some current practices are either inappropriate (e.g. misclassification of sedentary behaviour as MVPA) and/or incorrect (e.g. interpretation of statistical findings based only on *p*-values, which are biased by the sample size). To address these problems and challenges, the current chapter discussed the structure of real-time, long-term physical activity and sedentary behaviour data and how to select the appropriate statistical method based on the particular data structure and research interest at hand. A number of novel statistical methods capable of addressing these problems were introduced and described, and principles to establish causality and remaining challenges in sedentary behaviour epidemiology were described. The application of these methods and concepts will increase our understanding of physical activity and sedentary behaviour as such data are appropriately analysed.

References

1. van den Boogaart KG, Tolosana-Delgado R. Analyzing compositional data with R. New York: Springer; 2013.
2. Cattell RB. The three basic factor-analytic research designs-their interrelations and derivatives. Psychol Bull. 1952;49:499–520.

3. Cattell RB. The data box: its ordering of total resources in terms of possible relational systems. In: Nesselroade JR, Cattell RB, editors. Handbook of multivariate experimental psychology. 2nd ed. Chicago, IL: Rand McNally; 1988. p. 69–130.
4. Bolger N, Laurenceau J-P. Intensive longitudinal methods: an introduction to diary and experience sampling research. New York: Guilford; 2013.
5. Zhu W. A multi-level analysis of school factors associated with health-related fitness. Res Q Exercise Sport. 1997;68:124–35.
6. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38:105–9. https://doi.org/10.1097/JES.0b013e3181e373a2.
7. Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary". Exerc Sport Sci Rev. 2008;36:173–8.
8. Cain KL, Sallis JF, Conway TL, Van Dyck D, Calhoon L. Using accelerometers in youth physical activity studies: a review of methods. J Phys Act Health. 2013;10:437–50.
9. Aitchison J, Barcelo-Vidal C, Pawlowsky-Glahn V. Some comments on compositional data analysis in archaeometry, in particular the fallacies in Tangri and Wright's dismissal of log ratio analysis. Archaeometry. 2002;44:295–304.
10. Dunstan DW, Healy GN, Sugiyama T, Owen N. Too much sitting and metabolic risk – has modern technology caught up with us? Eur Endocrinol. 2010;6:19–23. https://doi.org/10.17925/EE.2010.06.00.19.
11. Healy G, Dunstan D, Salmon J, Cerin E, Shaw J, Zimmet P, Owen N. Breaks in sedentary time: beneficial associations with metabolic risk. Diabetes Care. 2008;31:661–6.
12. Healy GN, Matthews CE, Dunstan DW, Winkler EAH, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 200306. Eur Heart J. 2011;32:590–7.
13. Engle R, Watson M. A one-factor multivariate time series model of metropolitan wage rates. J Am Stat Assoc. 1981;76:774–81.
14. Ram N, Grimm K. Growth curve modeling and longitudinal factor analysis. In: Overton WF, Molenaar PCM, editors. Handbook of child psychology and developmental science: Vol. 1. Theory and method. 7th ed. Hoboken, NJ: Wiley; 2015. p. 758–88. https://doi.org/10.1002/9781118963418.childpsy120.
15. Raudenbush SW, Bryk AS. Hierarchical linear models: applications and data analysis methods. 2nd ed. Newbury Park, CA: Sage; 2002.
16. Zhu W, Erbaugh SJ. Assessing changes in swimming skills using the hierarchical linear model. Meas Phys Educ Exerc Sci. 1997;1:179–201.
17. Pearson K. Mathematical contributions to the theory of evolution - on a form of spurious correlation which may arise when indices are used in the measurement of organs. Proc R Soc Lond. 1897;60:489–98. https://doi.org/10.1098/rspl.1896.0076.
18. Chayes F. On correlation between variables of constant sum. J Geophys Res. 1960;65:4185–93.
19. Aitchison J. A new approach to null correlations of proportions. MathGeo. 1981;13:175–89.
20. Aitchison J. The statistical analysis of compositional data (with discussion). J Roy Stat Soc B. 1982;44:139–77.
21. Aitchison J. Principal component analysis of compositional data. Biometrika. 1983;70:57–65.
22. Aitchison J. The statistical analysis of geochemical compositions. Math Geo. 1984;16:531–64.
23. Aitchison J. The statistical analysis of compositional data, monographs on statistics and applied probability. 1986. Reprint with additional material. Caldwell, NJ: The Blackburn Press; 2003.
24. Billheimer D, Guttorp P, Fagan W. Statistical interpretation of species composition. J Am Stat Assoc. 2001;96:1205–14.
25. Pawlowsky-Glahn V, Egozcue JJ. Geometric approach to statistical analysis on the simplex. Stoch Env Res Risk A. 2001;15:384–98.
26. Pawlowsky-Glahn V, Egozcue JJ, Tolosana-Delgado R. Modelling and analysis of compositional data (Statistics in practice). Hoboken, NJ: Wiley; 2015.
27. Aitchison J. The statistical analysis of compositional data. Caldwell, NJ: The Blackburn Press; 2004.

28. Buccianti A, Mateu-Figueras G, Pawlowsky-Glahn V, editors. Compositional data analysis in the geosciences: from theory to practice. London: Geological Society of London; 2006.
29. Pawlowsky-Glahn V, Buccianti A, editors. Compositional data analysis: theory and applications. Hoboken, NJ: Wiley; 2011.
30. Gupta N, Mathiassen SE, Mateu-Figueras G, Heiden M, Hallman DM, Jørgensen MB, Holtermann A. A comparison of standard and compositional data analysis in studies addressing group differences in sedentary behavior and physical activity. Int J Behav Nutr Phys Act. 2018 Jun 15;15(1):53. https://doi.org/10.1186/s12966-018-0685-1.
31. Verswijveren SJJM, Lamb KE, Martín-Fernández JA, Winkler E, Leech RM, Timperio A, Salmon J, Daly RM, Cerin E, Dunstan DW, Telford RM, Telford RD, Olive LS, Ridgers ND. Using compositional data analysis to explore accumulation of sedentary behavior, physical activity and youth health. J Sport Health Sci. 2022 Mar;11(2):234–43. https://doi.org/10.1016/j.jshs.2021.03.004.
32. Janssen I, Clarke AE, Carson V, Chaput JP, Giangregorio LM, Kho ME, Poitras VJ, Ross R, Saunders TJ, Ross-White A, Chastin SFM. A systematic review of compositional data analysis studies examining associations between sleep, sedentary behaviour, and physical activity with health outcomes in adults. Appl Physiol Nutr Metab. 2020 Oct;45(10):S248–57. https://doi.org/10.1139/apnm-2020-0160.
33. Hastie T, Tibshirani R, Friedman J. The elements of statistical learning: data mining, inference, and prediction. 2nd ed. 2009. Corr. 7th printing 2013 edition. New York: Springer; 2013.
34. Bao L, Intille SS. Activity recognition from user-annotated acceleration data. Pervasive Computing. 2004:1–17. https://doi.org/10.1007/b96922.
35. Mannini A, Sabatini AM. Machine learning methods for classifying human physical activity from on-body accelerometers. Sensors (Basel, Switzerland). 2010;10(2):1154–75. https://doi.org/10.3390/s100201154.
36. Pober DM, Staudenmayer J, Raphael C, Freedson PS. Development of novel techniques to classify physical activity mode using accelerometers. Med Sci Sports Exerc. 2006;38(9):1626–34. https://doi.org/10.1249/01.mss.0000227542.43669.45.
37. Staudenmayer J, Pober DR, Crouter S, Bassett D, Freedson PS. An artificial neural network to estimate physical activity energy expenditure and identify physical activity type from an accelerometer. J Appl Physiol. 2009;107(4):1300–7. https://doi.org/10.1152/japplphysiol.00465.2009.
38. Giansanti D. Investigation of fall-risk using a wearable device with accelerometers and rate gyroscopes. Physiol Meas. 2006;27(11):1081–90. https://doi.org/10.1088/0967-3334/27/11/003.
39. Gjoreski H, Lustrek M, Gams M. Accelerometer placement for posture recognition and fall detection. In: 2011 Seventh International Conference on Intelligent Environments. New York: IEEE. p. 47–54. https://doi.org/10.1109/IE.2011.11.
40. Ermes M, Pärkka J, Mantyjarvi J, Korhonen I. Detection of daily activities and sports with wearable sensors in controlled and uncontrolled conditions. IEEE Trans Inf Technol Biomed. 2008;12(1):20–6. https://doi.org/10.1109/TITB.2007.899496.
41. Guo Y, Poulton G, Corke P, Bishop-Hurley GJ, Wark T, Swain DL. Using accelerometer, high sample rate GPS and magnetometer data to develop a cattle movement and behaviour model. Ecol Model. 2009;220(17):2068–75. https://doi.org/10.1016/j.ecolmodel.2009.04.047.
42. Martiskainen P, Järvinen M, Skön JP, Tiirikainen J, Kolehmainen M, Mononen J. Cow behaviour pattern recognition using a three-dimensional accelerometer and support vector machines. Appl Anim Behav Sci. 2009;119(1–2):32–8. https://doi.org/10.1016/j.applanim.2009.03.005.
43. Robert B, White BJ, Renter DG, Larson RL. Evaluation of three-dimensional accelerometers to monitor and classify behavior patterns in cattle. Comput Electron Agric. 2009;67(1–2):80–4. https://doi.org/10.1016/j.compag.2009.03.002.

44. O'Connell J, Tøgersen FA, Friggens NC, Løvendahl P, Højsgaard S. Combining cattle activity and progesterone measurements using hidden Semi-Markov models. J Agric Biol Environ Stat. 2010;16(1):1–16. https://doi.org/10.1007/s13253-010-0033-7.
45. Tsipouras MG, Tzallas AT, Rigas G, Bougia P, Fotiadis DI, Konitsiotis S. Automated Levodopa-induced dyskinesia assessment. In: Conference of the IEEE Engineering in Medicine and Biology Society. IEEE; 2010. p. 2411–4. https://doi.org/10.1109/IEMBS.2010.5626130.
46. Kańtoch E. Recognition of sedentary behavior by machine learning analysis of wearable sensors during activities of daily living for telemedical assessment of cardiovascular risk. Sensors (Basel). 2018 Sep 24;18(10):3219. https://doi.org/10.3390/s18103219.
47. Bhattacharjee P, Kar SP, Rout NK. Sleep and sedentary behavior analysis from physiological signals using machine learning. In: 2020 2nd International Conference on Innovative Mechanisms for Industry Applications (ICIMIA). IEEE; 2020. p. 240–4. https://doi.org/10.1109/ICIMIA48430.2020.9074883.
48. Clarke WL, Cox D, Gonder-Frederick LA, Carter W, Pohl SL. Evaluating clinical accuracy of systems for self-monitoring of blood glucose. Diabetes Care. 1987;10:622–8.
49. Breton M, Kovatchev B. Analysis, modeling, and simulation of the accuracy of continuous glucose sensors. J Diabetes Sci Technol. 2008;2:853–62.
50. Gilliam LK, Hirsch IB. Practical aspects of real-time continuous glucose monitoring. Diabetes Technol Therap. 2009;1:75–82. https://doi.org/10.1089/dia.2008.0135.
51. Rice MJ, Coursin DB. Continuous measurement of glucose: facts and challenges. Anesthesiology. 2012;116:199–204.
52. Wentholt IM, Hoekstra JB, DeVries JH. A critical appraisal of the continuous glucose-error grid analysis. Diabetes Care. 2006;29:1805–11.
53. John D, Tang Q, Albinali F, Intille S. An open-source monitor-independent movement summary for accelerometer data processing. J Meas Phys Behav. 2019 Dec;2(4):268–81. https://doi.org/10.1123/jmpb.2018-0068.
54. Zhu W. Test equating: what, why, how? Res Q Exerc Sport. 1998 Mar;69(1):11–23. https://doi.org/10.1080/02701367.1998.10607662.
55. Zhu W, Plowman SA, Park Y. A primer-test centered equating method for setting cut-off scores. Res Q Exerc Sport. 2010 Dec;81(4):400–9. https://doi.org/10.1080/02701367.2010.10599700.
56. Qin X, Zhu W, Zhu L, Liu J, Liao J. Linking MIMS with ActiGraph count: an equating study. Meas Phys Educ Exerc Sci. 2022;27:97–104. https://doi.org/10.1080/1091367X.2022.2072688.
57. Kane M. Validating the performance standards associated with passing scores. Rev Educ Res. 1994;64:425–61.
58. Zhu W. Science and art of setting performance standards and cutoff scores in kinesiology. Res Q Exerc Sport. 2013;84:456–68.
59. Cohen J. The earth is round ($p < 0.05$). Am Psychol. 1994;49:997–1003.
60. Zhu W. Sadly, the earth is still round ($p < 0.05$). J Sport Health Sci. 2012;1:9–11. https://doi.org/10.1016/j.jshs.2012.02.002.
61. Zhu W. Sadly, the earth is still round ($p < 0.05$). J Sport Health Sci. 2016;5:77–9. https://doi.org/10.1016/j.jshs.2012.02.002.
62. Lazarsfeld PF. Problems in methodology. In: Merton RK, Broom L, Cottrell Jr LS, editors. Sociology today: problems and prospects, vol. 1. New York: Basic Books; 1959. p. 39–72.
63. Hill AB. The environment and disease: association or causation? Proc R Soc Med. 1965;58:295–300.
64. Kundi M. Causality and the interpretation of epidemiologic evidence. Environ Health Perspect. 2006;114:969–74.
65. Rosenbaum P, Rubin DB. The central role of the propensity score in observational studies for causal effects. Biometrika. 1983;70(1):41–55.
66. Guo S, Fraser MW. Propensity score analysis: statistical methods and applications. Thousand Oaks, CA: Sage; 2010.

Part II
Health Effects of Sedentary Behaviour

Chapter 5
Physiological Responses to Sedentary Behaviour

Ana J. Pinto, Audrey Bergouignan, and Paddy C. Dempsey

Abstract Sedentary behaviours—i.e. 'too much sitting as distinct from too little exercise'—are ubiquitous in modern societies. Accumulating epidemiological evidence indicates that higher volumes of sedentary behaviour are associated with elevated risks for all-cause mortality, cardiovascular disease incidence and mortality, type 2 diabetes incidence and some cancers, particularly among those who are not achieving recommended amounts of moderate-to-vigorous intensity physical activity. Based on these observations, and in part on a growing body of experimental research, it has been proposed that sedentary behaviour influences health risk through some mechanisms that act similarly or independently of physical inactivity. However, the observational evidence is well ahead of evidence on the physiological

A. J. Pinto
Division of Endocrinology, Metabolism, and Diabetes, Anschutz Health and Wellness Center, University of Colorado Anschutz Medical Campus, Aurora, CO, USA

Applied Physiology & Nutrition Research Group, School of Physical Education and Sport, Rheumatology Division, Faculdade de Medicina FMUSP, Universidade de Sao Paulo, São Paulo, SP, Brazil
e-mail: ana.pinto@cuanschutz.edu

A. Bergouignan
Division of Endocrinology, Metabolism, and Diabetes, Anschutz Health and Wellness Center, University of Colorado Anschutz Medical Campus, Aurora, CO, USA

Département d'Ecologie, Physiologie et Ethologie (DEPE), Institut Pluridisciplinaire Hubert Curien (IPHC), Centre National de la Recherche Scientifique (CNRS), UMR7178, Université de Strasbourg, Strasbourg, France
e-mail: audrey.bergouignan@cuanschutz.edu

P. C. Dempsey (✉)
MRC Epidemiology Unit, Institute of Metabolic Science, University of Cambridge, Cambridge Biomedical Campus, Cambridge, UK

Diabetes Research Centre, University of Leicester, Leicester, UK

Baker Heart and Diabetes Institute, Melbourne, VIC, Australia

Institute for Physical Activity and Nutrition (IPAN), School of Exercise and Nutrition Sciences, Deakin University, Geelong, Victoria, Australia
e-mail: Paddy.Dempsey@baker.edu.au

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_5

responses to sedentary behaviour, leaving uncertainties around the potential biological mechanisms that may explain the observed associations. Here, we summarise and discuss experimental evidence to date on the physiological effects of sedentary behaviours, including potential solutions-oriented research aiming to address sedentary behaviour as a health risk. We also highlight future research that is needed to fully ascertain the specific impact of sedentary behaviour on altering human physiology.

What Is New?

- Epidemiological evidence suggests that the deleterious associations of sedentary behaviour with all-cause mortality can be modified by time spent in moderate-to-vigorous intensity physical activity. In this context, physically inactive and highly sedentary individuals are at the highest risk for poorer health-related outcomes.
- Meta-analytic evidence supports the role of interrupting sitting at acutely (usually ~3–8 hours) improving postprandial glycemia and insulinemia and vascular function. However, studies investigating the potential mechanisms underlying these benefits are lacking. Clarity is also needed on the specific role of posture and/or skeletal muscle inactivity, as per current sedentary behaviour definitions, on disease-specific pathologies (e.g. dysmetabolism, vascular dysfunction, cognition, central and peripheral neural effects, etc).
- A growing variety of health-related outcomes are now being studied, including brain function and cognitive performance, musculoskeletal pain/discomfort and fatigue and oxidative stress and inflammatory markers. However, more high-quality evidence on the impact of (interrupting) prolonged sitting on these outcomes and chronic disease (e.g. cancer, dementia, inflammatory diseases, depression, etc.) risk/symptoms is still needed.
- A growing number of longer-term interventions targeting sedentary behaviour are now being published. Overall, evidence suggests these interventions are effective in reducing mean sedentary time by ~30–45 min/day. There is also some evidence of effectiveness for improving cardiometabolic risk factors to a small degree, including: weight, waist circumference, percentage body fat, systolic blood pressure, insulin, glycated haemoglobin, HDL-cholesterol and vascular function. However, further high-quality, longer-term intervention studies are required to determine dose-response relationships, the moderating role of moderate-to-vigorous intensity physical activity and other behaviours (e.g. light activity and sleep), and potential underlying mechanisms.
- Sedentary behaviour is highly prevalent in a variety of populations, varying under different cultural and environmental contexts and person-specific

(continued)

factors. In addition to better understanding potential underlying mechanisms, future studies should consider how any intervention effects are modified by context, type, and purpose of sedentary behaviour and by other key factors, including but not limited: to age, sex, race/ethnicity, menopausal, pregnancy and lactating statuses, medications, cardiorespiratory fitness and baseline exercise levels, and populations with or at increased risk of chronic disease.

5.1 Introduction

Regular moderate-to-vigorous intensity physical activity, generally 30–60 minutes continuous exercise on 3–5 days/week, provides numerous health benefits, with the greatest improvements occurring when sedentary/inactive individuals become more physically active [1]. However, while physical activity recommendations (i.e. at least 150 min/week of moderate-to-vigorous intensity physical activity or 75 min/week of vigorous-intensity physical activity [2]) are based on strong and consistent evidence, the potential health benefits of increasing moderate-to-vigorous intensity physical activity remain largely unrealised at the population level. Indeed, the majority of the global population, particularly those from high-income countries, spend increasing amounts of time in environments that not only limit physical activity but also necessitate prolonged periods sedentary.

Time spent in sedentary behaviours, defined as any sitting or reclining behaviour during waking hours with low-energy expenditure (≤1.5 metabolic equivalent (MET)of task—of note, 1.0 MET corresponds to the resting metabolic rate of the population under study (in adults without mobility impairment or chronic diseases, a metabolic equivalent is deemed to be 3.5 ml O_2/kg/min) [3, 4]), has emerged as an additional element within concerns about physical activity and health [5–7]. Indeed, it is possible to meet or exceed the public health guidelines for moderate-to-vigorous physical activity and yet also spend most waking hours sedentary. Consistent epidemiologic evidence now shows deleterious associations of sedentary behaviour with all-cause mortality, cardiovascular disease incidence and mortality, type 2 diabetes incidence and some cancers in adults [8]. However, recent harmonised meta-analytic evidence also suggests that the associations between sedentary behaviour and mortality can be modified by the time spent in moderate-to-vigorous intensity physical activity [9, 10]. Similarly, associations between moderate-to-vigorous intensity physical activity may also depend on the balance of time spent in light-intensity physical activity and sedentary behaviour [11, 12]. These recent findings highlight the *interdependent* and potentially synergistic nature of these physical behaviours. They also reemphasise that physically inactive (i.e. one that present an insufficient physical activity level to meet current physical activity recommendations [4]) and highly sedentary individuals remain a highly prevalent group with the highest risk of all-cause mortality and chronic disease and thus in particular need of clinical and public health attention.

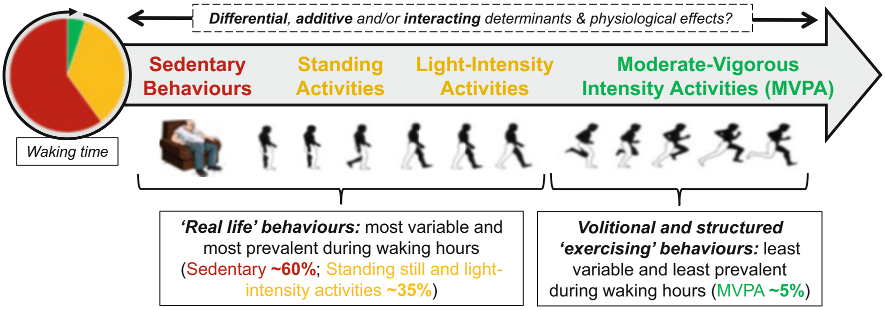

Fig. 5.1 The human movement spectrum—sedentary behaviour, light and moderate vigorous intensity activities—and their relative contributions to activity levels during waking hours (based on accelerometer data in overweight adults from adults in the *National Health and Nutrition Examination Survey* (NHANES)). Note that, on average, sedentary and light intensity activities (~95%) comprise a much larger proportion of total waking time than moderate-to-vigorous intensity physical activity (~5%). Adapted from Tremblay et al. [13] and from Dempsey and Thyfault [14]

As a result, researchers are increasingly studying moderate-to-vigorous intensity physical activity and sedentary behaviour (and, by definition, standing and light-intensity activity) as distinct but interrelated behaviours (Fig. 5.1), with their own unique determinants and health consequences [13, 14]. However, relative to our knowledge on the acute and longer-term effects of moderate-to-vigorous intensity physical activity, much less is known about the specific physiological responses to sedentary behaviour (prolonged sitting) or the potential biological mechanisms underlying the associations of sedentary behaviour with adverse health outcomes. Developing our understanding of *whether*, *how* and *why* sedentary behaviour is causally related to adverse health outcomes is therefore important [15] and may help inform more specific/tailored intervention or therapeutic targets aimed at ameliorating the potentially detrimental health impacts of prolonged sedentary behaviour.

In this chapter, we focus on the physiological responses to sedentary behaviour in adults. In particular, the prolonged periods of unbroken sitting that occur daily in large segments of the population. We highlight the following:

- The merits of differentiating sedentary behaviour from physical inactivity
- The nuances of difference between experimental models of sedentary behaviour and inactivity physiology and how they can further inform our knowledge on physiological responses, potential mechanisms and health outcomes
- Experimental evidence on the physiological responses to prolonged periods of sedentary behaviour and the potential benefits of reducing and interrupting these sedentary exposures
- Future research needs and opportunities in the field of sedentary behaviour

5.2 The Physiology of Sedentary Behaviour: An Operational Framework

From a physiological perspective, differentiating between ‘sedentary behaviours’ and ‘physical inactivity’ may initially seem rather semantic. Indeed, recent reviews have already summarised the evidence to date on numerous physiological responses as they relate to imposed physical inactivity [16–18]. These include reduced cardiovascular function, bone demineralisation, muscle atrophy, a shift in muscle fibres towards fast-twitch glycolytic type, skeletal muscle and whole-body insulin resistance, a reduced mitochondrial oxidative capacity, a reduced capacity to utilise fat as a substrate for adenosine triphosphate (ATP) production, hyperlipidaemia, ectopic fat storage, increased central and peripheral adiposity, low-grade inflammation and disruption of iron metabolism [16, 17, 19]. However, one must realise that moderate-to-vigorous intensity physical activity, light-intensity (non-exercise and daily body movements) physical activity and sedentary behaviour all coexist within the spectrum of activities that constitute the waking day [13]. Thus, examining the physiological responses and adaptations (i.e. acute and longer-term) within and across each behavioural construct is informative, as there may be *differential*, *additive* and/or *interacting* determinants or physiological effects to consider (Fig. 5.1).

Focussing on sedentary behaviours as distinct from physical inactivity also offers some unique opportunities. A key feature being a renewed emphasis on shifting the balance of sedentary behaviours towards more light-intensity physical activities, rather than solely focussing on increasing moderate-to-vigorous intensity physical activity. This shift in emphasis is now reflected in more recent guidelines [2, 8, 20] but has also included the development of countermeasures to specifically address sedentary behaviours, with a growing body of experimental studies aiming to *reduce and interrupt prolonged sitting time* providing some important insights.

5.3 Experimental Models Used to Study Sedentary Behaviour and/or Inactivity Physiology

Physical inactivity and/or sedentary behaviour-induced physiological changes have been studied under a variety of different models and contexts (see Table 5.1 for human models). Each of these approaches (i.e. animal models, detraining, bed rest, bed rest combined with exercise, limb immobilisation/casting, imposed physical inactivity and interrupting sitting time) are justified depending on the question at hand and provide complimentary information. However, it is important to recognise and understand the different goals, methodologies and assumptions made under these models when attempting to interpret and generalise their findings.

Table 5.1 Key characteristics of human physical inactivity experimental models and intervention models of interrupting sedentary time

	Training cessation or detraining	Limb immobilisation	Enforced bed rest	Enforced bed rest + exercise	Imposed physical inactivity	Interrupting sitting time
Participants' level of baseline physical activity or capacity	Extremely active (i.e. trained)	Usually physically active (meeting PA guidelines)	Usually physically active (meeting PA guidelines)	Usually physically active (meeting PA guidelines)	Usually physically active (meeting PA guidelines)	Usually not physically active
Participants' level of sedentary behaviour	Not specified	Not specified	Not specified	Not specified	Not specified	Usually >5 h/day total self-reported sitting, but not always specified
Participant characteristics	Healthy-young	Healthy-young or middle age or sometimes older adults	Usually healthy-young or older adults or 'at risk' for type 2 diabetes or born with low birth weight	Healthy-young or sometimes middle-age	Usually healthy-young or sometimes middle age or older adults or adults with overweight/obesity	Mixture of healthy-young or 'at risk' overweight/obese or with chronic disease
Modality focus	Abrupt reduction in high training/exercise load	Imposed immobilisation of one or two limbs	Imposed lying down (head-tilt or not)	Imposed lying down (head-tilt) + aerobic and/or resistance exercise	Abrupt reduction in physical activity levels or daily steps number	Non-exercise activities (e.g. standing, light ambulation, moderate activity)
Reference comparator	Prior training activity	Prior habitual activity and/or the other non-immobilised limb	Prior habitual activity	Prior habitual activity and/or control enforced bed rest group	Prior habitual activity	Imposed prolonged uninterrupted sitting (usually ~3–8 hours)
Change in intervention activity level	Very active (trained) → inactive (detrained)	Active → immobilised	Active → bed resting/dry immersion/spaceflight	Active → bed resting + exercise	Active → inactive	Inactive/'sedentary' → more standing or light activity or moderate activity
	High	High	High	High	Moderate	Moderate-low

Inconvenience and/or burden/ disruption for study participants						
Potential scientific insights provided	Effects, adaptations and potential mechanisms of reduced training load	Effects, adaptations and potential mechanisms of limb immobilisation, particularly in tissues affected by immobilisation	Effects, adaptations and potential mechanisms to short- or long-term simulated or actual microgravity and physical inactivity	Effects, adaptations and potential mechanisms to exercise as a counter-measure to microgravity- and physical inactivity-induced effects but also of sedentary behaviours per se	Effects, adaptations and potential mechanisms to reduced physical activity	Effects, adaptations and potential mechanisms to prolonged sitting and non-exercise activity

5.3.1 Animal Models

Animal models ensure compliance with interventions while controlling for environmental confounders (e.g. diet, circadian rhythms and environmental stimuli) over longer periods of time, while also enabling more in-depth analyses and invasive procedures (e.g. to examine tissue-specific mechanisms). Research in the 'inactivity physiology' context is examined primarily using *wheel lock* and *hind limb unloading* methodologies. The key objective of these studies is to better understand how physical inactivity (or immobility) initiates maladaptations linked to chronic disease. Here, we provide a condensed summary of these models and of key findings most pertinent to sedentary behaviour physiology.

Wheel lock models involve periods of habitual or voluntary activity (3–6 weeks; typically, 5–10 km/day of running) which is suddenly restricted (running wheel locked) to cage movement only for up to 7 days. In a series of rodent studies conducted by Booth and colleagues, while daily wheel running increased insulin-stimulated glucose uptake in isolated skeletal (epitrochlearis) muscle, a rapid decrease in insulin sensitivity to sedentary levels was reported within 2 days of wheel lock and reduced activity [21]. This reduction in insulin-stimulated glucose transport was linked to reduced activation of the insulin-signalling pathway and reduced GLUT4 protein content. Rapid gains (25–48%) in intra-abdominal fat mass were also reported within 1 week of week lock [22, 23]. Interestingly, lowering food intake immediately after the wheel lock did not significantly change fat mass enlargement compared to the rats that fed ad libitum, suggesting that the fat storage was the result of physical inactivity per se, rather than overfeeding or positive energy balance [22].

Hind limb unloading models (or simulated weightlessness) involve suspending rats by their tail, preventing any weight-bearing activities of the lower limbs and allowing researchers to tightly control when immobilisation in those limbs begins and ends. Similar to wheel lock, hind limb unloading studies of 'inactivity physiology' have also reported on the rapid development of insulin resistance after 1 day of unloading [24]. In addition, Hamilton and colleagues have shown that distinctive physiological pathways are activated with hind limb unloading (~10 h/day over an 11 day period), particularly the expression and enzyme activity of lipoprotein lipase (LPL), which seems to remain largely unaffected by moderate-to-vigorous intensity physical activity [25]. Using hind limb unloading, Hamilton and colleagues demonstrated that rat skeletal muscle triglyceride uptake was reduced by 75% and LPL protein mass and enzymatic activity were rapidly suppressed during acute (1–18 h) and chronic (~10 h/day over 11 days) periods, an effect which was reversible only with light-intensity contractile activity. Moreover, while LPL activity associated with exercise was linked to increases in LPL mRNA levels, LPL mRNA expression was not changed after 11 days of hind limb unloading—suggesting that the changes in LPL activity and protein level were likely due to transcriptional or posttranslational changes [25, 26]. This point was further highlighted in a global gene-expression profiling study, which identified 38 genes in muscle that were upregulated by just 12 hours of hind limb unloading, 27 of which remained above control levels after returning to normal standing and ambulation for 4 hours [27]. Although confirmation is still required in humans, it is intriguing to consider what minimum thresholds of acute baseline (or incidental) activity may be required to prevent maladaptations like these from occurring.

Other research groups have also focused on the impact of hind limb unloading in other health outcomes, organs and systems. Periods of hind limb unloading (up to 15 days) in rats reduced extensor digitorum longus, soleus and/or gastrocnemius weight [28–31] and twitch force and cross-sectional area of the extensor digitorum longus and/or soleus muscles [29, 30]; inhibited the anabolic Akt-mammalian target of rapamycin (mTOR) signalling pathways; increased activity of the catabolic ubiquitin-proteasome pathway [28]; shifted towards more fast-twitch muscle fibre type [28]; reduced bone mass, bone formation [32], bone mineral density [30, 33] and femoral load to break [30]; induced deterioration of trabecular and cortical bone [33]; reduced mitochondrial respiratory capacity [30]; induced insulin resistance [30]; increased resting heart rate [30]; increased IL-6 mRNA levels [31] and ceramides accumulation [34] in the skeletal muscle and altered iron metabolism by increased hepcidin in the liver and spleen iron content [31]; and reduced serum iron concentration and transferrin saturation [28, 31].

5.3.2 Human Models

Training Cessation and/or Detraining Models

Training cessation and/or detraining models assume a relatively extreme level and capacity of baseline physical activity prior to a discontinuation of exercise training—usually in competitive athletes (see Table 5.1). Defined by a partial or complete loss of training-induced adaptations in response to an insufficient training stimulus [35], detraining is characterised by significant differences in exercise-induced responses in the cardiorespiratory (maximal oxygen uptake, cardiac output and ventilator efficiency) and metabolic (increased reliance on carbohydrate metabolism and lowered oxidative enzyme activities, glycogen level and lactate threshold during exercise and reduced insulin sensitivity) systems that ultimately result in compromised athletic performance [35, 36]. Moreover, studies in endurance athletes have provided initial insights into the physiological effects of physical inactivity (or reduced training load). For example, two studies have shown that insulin sensitivity in skeletal muscle, measured by hyperglycaemic-euglycemic clamps, is reduced to the level measured in non-exercising age-matched controls after only 2 days of training cessation [37, 38]. However, as far as we know, no studies have examined other types of physical activity (i.e. light-intensity) or sedentary behaviour following training cessation. Thus, these models provide limited evidence on the effects of sedentary behaviour in the general population.

Enforced Bed Rest Models

Enforced bed rest, dry immersion and/or spaceflight models are characterised by a lack of muscle activity and postural change, accomplished via immobilisation and/or elimination of gravitational stimuli (head tilt) for extended periods of time (ranging from days to multiple months). Similar to detraining, these studies impose extreme immobility that is unlikely to be representative of daily living and typically include young, healthy-active individuals [16, 19, 39], but sometimes include older adults [40] or people at risk for type 2 diabetes [41, 42] or born with low birth weight [43, 44]. Therefore, they require cautious interpretation, as they can cause physiological changes (such as haemodynamic shifts as a result of postural change that mimic reduced gravity) that are distinct from sitting interspersed with incidental movement. Despite this, bed rest and dry immersion models can provide important mechanistic hints, illustrating the fundamental physiological adaptations and potential mechanisms to short- or longer-term immobilisation, as physical activity, energy intake and other environmental factors (e.g. temperature, day/night cycle and water intake) are tightly controlled in these studies. Therefore, data obtained in bed rest studies can be independent of confounders, which means that they are the result of imposed physical inactivity and/or sedentary behaviour per se. Five to 10 days bed rest has been shown to induce dysglycaemia and dramatic reductions in whole body, muscle, and vascular insulin sensitivity in healthy participants [42, 45, 46]. Bed rest also induces reduced aerobic fitness, muscle atrophy, shifts towards more fast-twitch muscle fibre type, changes in fat oxidation capacity and storage, metabolic inflexibility (inability to adjust substrate use to changes in substrate availability), hypertriglyceridemia and ectopic fat storage [16, 47]. Those changes are similar to the trajectory of pathways observed in the metabolic dysregulation associated with obesity, type 2 diabetes and/or metabolic syndrome, thus supporting a key role of physical inactivity in the aetiology of metabolic diseases [16].

Enforced Bed Rest and/or Spaceflight Models Combined with Exercise

Enforced bed rest and/or spaceflight models combined with exercise are characterised by periods with lack of muscle activity and postural change, as described in the previous subtopic, combined with regular sessions of resistance and/or aerobic exercise, which usually last extended periods of time (ranging from days to months). These studies typically include young, healthy-active individuals and impose extreme immobility, which is unlikely to be representative of daily living even when accounting for the active periods (exercise sessions) [19]. Therefore, as for enforced bed rest models, these studies also require cautious interpretation. Despite this, bed rest models combined with exercise can provide important mechanistic hints, illustrating the physiological adaptations and potential mechanisms to short- or longer-term exposure to a highly sedentary (immobilisation) yet physically active (regular exercise sessions) condition in a tightly controlled environment. As mentioned above, prolonged bed rest reduces cardiorespiratory and muscle function, muscle mass, mitochondrial volume, oxidative capacity and whole-body, muscle and vascular insulin sensitivity and induces fat accumulation in visceral adipose depot and ectopic fat storage in the muscle, liver and bone [16, 19, 42, 45, 46]. In contrast, resistance exercise combined or not with aerobic exercise has been shown to prevent or at least partially counteract most of the deleterious effects associated with bed rest alone [19]. However, some maladaptations to enforced physical inactivity, such as those observed on lipid metabolism, are not prevented by exercise training even when physical activity is far above the recommended levels [19]. These results provide evidence that excessive sedentary behaviour may be detrimental even in the presence of adequate levels of moderate-to-vigorous intensity physical activity. It further supports the idea that sedentary behaviour may have adverse health effects independent of physical activity and the importance of non-exercising physical activity (i.e. other daily living physical activities performed throughout the day) to maintain overall health.

Limb Immobilisation/Casting

Limb immobilisation/casting models are characterised by periods in which a limb is immobilised using casting. Particularly in lower limb immobilisation, participants are given crutches and asked to refrain from weight-bearing activity on the immobilised leg [48, 49]. These studies typically include young, healthy-active individuals, but sometimes include older adults, and result in muscle disuse on the affected limb, which mimic the disuse expected from a casting protocol that occur following an injury. Therefore, they also require cautions interpretation, as the casting-induced effects are usually restricted to the immobilised limb and adaptations are more severe than the ones observed in daily living (e.g. during periods of reduced physical activity or aging). Limb immobilisation/casting results in rapid and pronounced reduction in muscle mass and strength [50–52]. Moreover, periods of muscle disuse are associated with the development of anabolic resistance (i.e. blunted increase in postprandial muscle protein synthesis following protein ingestion) [53], accumulation of intramyocellular lipids [54, 55], decreased fatty acids oxidative capacity [55], expression of proteins related to insulin signalling [54], basal limb blood flow and arterial lumen diameter [56] and increased risk of venous thromboembolism [57].

Imposed Physical Inactivity Models

Imposed physical inactivity models involve studies whereby participants' transition from high/normal to low daily ambulatory activity (or increased sedentary time). Changes in physical activity are applied to mimic the range of physical activity patterns that occur in the human population. For example, participants with habitually high physical activity levels ($>$10,000 steps/day) are asked to lower their daily step count to around <1500 steps/day [17, 58]. Imposed physical inactivity models are more pragmatic than detraining, bed rest and limb immobilisation/casting for studying everyday living in the majority of the population. However, these studies have typically been conducted in young active individuals, and thus, assume higher habitual physical activity patterns than that observed in population-based surveys. Moreover, they tend not to measure or focus on sedentary (sitting) behaviours per se, although increases in sedentary time have been reported in more recent studies [58–60]. Imposed physical inactivity studies have reported that transitioning from high to low activity patterns for only 3–5 days reduces endothelial function [61], insulin sensitivity, glycaemic control [62, 63], with notable restorations in insulin sensitivity once activity levels were returned back to normal. A longer duration study where participants lowered their step count from >10,000 to <1500 steps/day for 2–3 weeks showed even more robust changes, including reduced skeletal muscle insulin sensitivity and signalling, increased central adiposity, and reduced aerobic capacity (VO_{2max}), lower limb muscle mass [60, 64] and reduced capacity to burn fat as fuel along with de novo lipogenesis and ectopic fat storage [58].

For more information on experimental studies that used models of detraining, bed rest, or reduced activity in order to elucidate the biological mechanisms that may explain the underlying biological mechanisms linking sedentary behaviour to poor health outcomes, please refer to Sect. "What Other Variables Related to Physical Activity and Sedentary Behaviour May Be Important for Mortality Risk?" in Chap. 14.

5.4 Physiological Responses to Sedentary Behaviour in Humans

5.4.1 Characterising Prolonged Sitting in Humans

Physiologically, sitting postures can be characterised by low-energy expenditure demand, as measured by indirect [65, 66] and whole-room calorimetry, where the average energy cost of common sedentary behaviours (reclining, watching TV, reading and typing on a computer) are narrowly banded around ~1.0 METs at various times of day, even in the postprandial state [67]. In addition, while contractile activity of skeletal muscles is important for common activities involved in being upright (i.e. standing and ambulation), this muscle activity largely 'flatlines' during sitting postures—as demonstrated by an unloading of the major locomotor muscle groups in studies measuring muscle electromyographic (EMG) activity [26, 68]. These key energetic and postural features of prolonged sitting are what define the control groups of experimental studies aiming to reduce and interrupt prolonged sitting exposures.

5.4.2 *Intervening on Prolonged Sitting Exposures*

As highlighted in Table 5.1, interventions that reduce and interrupt sitting time are a relatively new approach in which the focus has shifted from investigating the effects of increased sedentary behaviour (or imposed inactivity) in relatively healthy-active individuals, to a treatment paradigm, whereby inactive-sedentary individuals replace or interrupt prolonged sitting time with brief bouts of non-exercise physical activity. While inactivity models are conducted with a focus on understanding the physiological effects of imposed physical inactivity, *reducing and interrupting sitting time* interventions have been described as more 'solutions focused', in theory transitioning participants from their 'normal' sedentary state (sitting) to more active (reduced- or non-sitting) states [69]. Importantly, unlike detraining, bed rest, limb immobilisation/casting and, to a lesser extent, imposed physical inactivity models, reducing and interrupting sitting time interventions target the large proportion of the population in which sitting time, not active time, is the predominant behaviour [70].

Against this background, and in the interest of keeping the summary of evidence focussed on prolonged sitting behaviours, rather than intermingling with detraining, bed rest and lack of physical activity per se, we aim to concentrate our evidence synthesis primarily on the following two themes:

1. The physiological responses in adults to experimental models involving prolonged sitting exposures
2. The physiological impact of reducing or interrupting sitting exposures with various forms of physical activity

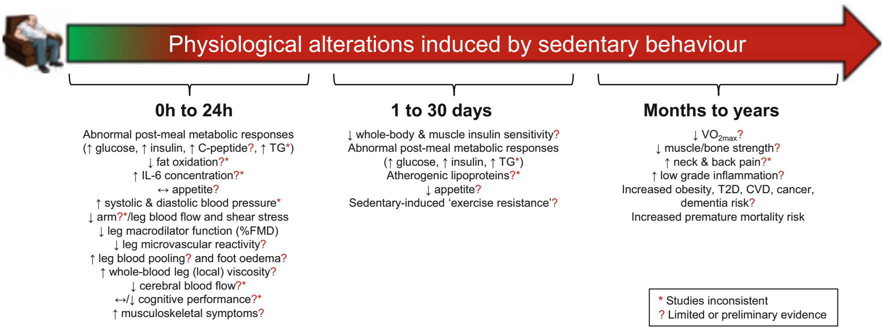

Fig. 5.2 A conceptual timeline of the various physiological alterations induced by acute and more prolonged sedentary behaviour. *Note:* based on evidence from a variety of studies and population subsets that have included prolonged sitting exposures and/or interventions to reduce or interrupt prolonged sitting. Changes beyond 1 day imply approximately >6–8 h/day spent sedentary over consecutive days. Abbreviation: CVD, cardiovascular diseases; FMD, flow-mediated dilatation, indicative of macrovascular dilator function; IL-6, interleukin 6; T2D, type 2 diabetes; TPR, total peripheral resistance; VO_{2max}, cardiorespiratory fitness. Adapted from Dempsey and Thyfault [14]

As a point of reference based on the evidence to date, Fig. 5.2 provides a conceptual timeline for the various physiological alterations induced by acute and longer-term exposures to sedentary behaviour.

5.5 Effects of Sedentary Behaviour on Metabolic Risk Factors

The strongest and most consistent epidemiologic and meta-analytic evidence on the deleterious associations of sedentary time have been reported for metabolic risk markers and risk of developing type 2 diabetes [71, 72]. Moreover, a growing number of acute human intervention studies examining metabolic risk outcomes are being published that have included prolonged sitting exposures in a variety of population groups. The majority of studies have focused on tightly controlling the amount and pattern of sitting and activity bouts in a laboratory setting, while examining participants' metabolic responses concurrently (i.e. in a postprandial state) or the day after sitting exposures. The acute duration of these sitting exposures (mostly <1 day but some up to 5 waking days) provides greater assurances that metabolic responses are not confounded by longer-term energy surplus and/or associated changes such as body composition. On the other hand, a small number of studies have sought to examine participants under more free-living settings [73–79].

Glucose and insulin responses: Glycaemic benefits have been observed when prolonged sitting is reduced or interrupted with slow bouts of post-meal walking, ranging from 15 to 40 minutes in length [80–82]. Prolonged sitting interrupted by brief (<5 minutes) intermittent bouts of light- [83–86] or moderate-intensity [84, 87] ambulation have also demonstrated improved glycaemic control in both active-healthy, overweight/obese-sedentary and dysglycaemic populations [88]. However, findings from studies in which sitting was replaced with standing only bouts have been less consistent for glucose and/or insulin responses, with some showing significant reductions [89–91], while other have not [83, 86, 92–94]. Interestingly, the studies showing beneficial glycaemic effects with standing bouts have tended to be in more office-based environments, in overweight/obese adults and particularly in those with impaired glucose regulation [95].

There is some evidence to suggest that markers of insulin sensitivity may also be altered to exposures as short as 1 day of prolonged sedentary behaviour [96]. This evidence corroborates with reports of reduced glycaemic control and insulin action observed following longer periods of bed rest (at least 3 days) [16, 97–99] and 3–14 days of reduced stepping [62, 64]. However, 3 days of interrupting prolonged sitting with regular light-intensity activity bouts (2 minutes every 20 minutes) had no sustained benefit for postprandial glucose and insulin responses beyond the first day [85]. The benefits associated with interrupting sitting on postprandial glucose and insulin responses are supported by meta-analytic evidence. Overall, frequent, short bouts of light-intensity physical activity improve postprandial glucose responses by 17.5% and insulin responses by 25.1% compared to prolonged sitting in healthy and metabolically impaired individuals [100]. With respect to the intensity of physical activity interruptions, both light- and moderate-intensity bouts improved postprandial glucose and insulin responses, while standing interruptions did not significantly affected these responses [101, 102]. Interestingly, a pooled analysis using data from three randomised crossover trials that examined the postprandial blood glucose- and insulin-lowering effects of prolonged sitting versus sitting interrupted by regular brief activity breaks in overweight/obese adults who had normal or impaired glucose metabolism (two trials) or type 2 diabetes not treated by insulin (one trial) suggested that those with higher underlying levels of insulin resistance may derive greater metabolic benefits from regularly interrupting prolonged sitting than their healthier counterparts [103]. This finding has been corroborated by meta-analytic subgroup analysis indicating that benefits observed for glycemia were more prominent in metabolically impaired individuals [100, 104]. Moreover, body mass index (BMI) is significantly associated with postprandial glucose and insulin responses, as indicated by meta-regressions [104], suggesting that the observed benefits are larger in individuals with overweight/obesity. Finally, both male and female can benefit from interrupting prolonged sitting; however, meta-analytic evidence [104] and original studies [105, 106] suggest that females may benefit more from this strategy when compared to their male counterparts.

There is still limited evidence regarding the mechanisms underpinning the glycaemic benefits of interrupting prolonged sitting. So far, only one research group reported differences in molecular signalling pathways in the skeletal muscle (*vastus lateralis*) [107, 108]. Frequent, brief bouts of altered expression of ten genes involved in carbohydrate metabolism, including increased expression of dynein light chain, which may regulate translocation of the glucose transporter 4 (GLUT-4) [108]. Moreover, 1 day of interrupting prolonged sitting associated with an upregulation of the contraction stimulated, adenosine monophosphate-activated protein kinase (AMPK)-mediated glucose uptake pathway, while three consecutive days of interrupting sitting demonstrated a transition towards upregulation of the Akt-mediated insulin-sensitive glucose uptake pathway [107]. In the subcutaneous abdominal adipose tissue, the same research group showed that interrupting prolonged sitting with light- or moderate-intensity walking led to differential regulation of adipose tissue metabolic networks and inflammatory pathways, increased insulin signalling, modulation of adipocyte cell cycle and facilitated crosstalk between adipose tissue and other organs [109]. Interestingly, upregulation of pathways involved in oxidative metabolism and immunity were greater for light-intensity interruptions, although moderate-intensity interruptions showed similar directional trends [109]. As for nutrient oxidation, De Jong et al. [110] showed, in people with overweight/obesity, that frequent interruptions in sitting time (5-minute bouts of brisk walking every hour for 9 hours) primarily relies upon carbohydrate as fuel over 4 days of intervention. This suggests that the beneficial effect of interrupting sedentary time on glucose control is likely related to a greater reliance upon carbohydrate oxidation; importantly, this effect does not appear to be related to energy expenditure and balance, but rather to increasing the frequency of muscle contractions spread across the day [110]. These initial mechanistic findings provide a basis by which interrupted sitting time improves glucose metabolism and insulin sensitivity.

Lipid responses: Findings from experimental studies examining the effects of interrupting prolonged sitting on fasting [73, 74] and postprandial plasma lipid responses [83, 85–87, 90, 91, 111–113] have been less consistent than that of glucose and insulin responses. In healthy young adults, a 30-minute continuous exercise bout in the morning was more effective for lowering postprandial triglyceride responses than interrupting prolonged sitting time with regular walking bouts (~1.5-minute walking bouts every ~15–20 minutes for 8 to 9 hours in healthy adults and postmenopausal women [87, 112] or 5-minute brisk walking bouts every hour, for 9 hours, in people with overweight/obesity [110]) or with intermittent standing bouts (6 × 45 minutes) in healthy adults over a 2-day trial [86]. This lack of effect on triglycerides for brief activity bouts was also observed in interventions switching between sitting and standing every 30 minutes in overweight/obese sedentary adults [91], or interspersing sitting with brief standing or walking bouts every 20–-30 minutes in normal-weight adults [83] or overweight/obese sedentary postmenopausal women [90]. However, the later study by Henson et al. [90] observed that interrupting prolonged sitting with hourly standing and walking bouts attenuated the suppression of nonesterified fatty acids. Moreover, Kim et al. [111] showed reductions in postprandial triglycerides when prolonged sitting was interrupted with brief bouts of light-intensity walking of different durations, in sedentary type 2 diabetes patients and in young healthy individuals. Findings from repeated- or multiday exposures to sedentary behaviours [73, 74, 85, 91] have largely observed no effect on fasting lipids. Only one of these studies showed an effect on fasting plasma triglycerides and atherogenic lipoprotein levels (non-HDL-cholesterol and Apo B) in 20 healthy university students [73]. In this study, participants were instructed to a replace 6 hours of sitting with 4 hours of walking at a leisurely pace and with 2 hours of standing on each of the 4 consecutive days. Finally, one study investigated the effects of interrupting prolonged sitting on postprandial lipidomic profile of adults with type 2 diabetes. Grace et al. [114] showed that light-intensity walking and simple resistance activities interruptions were associated with reductions in lipids related to inflammation, increased concentrations of lipids related to antioxidant capacity and differential changes in species related to platelet activation.

Discrepancies in results from animal and bed rest studies and between studies utilising a prolonged sitting approach for lipid responses is unclear. Findings appear to be influenced by the populations studied, as well as the experimental designs, meals and/or interventions utilised, highlighting the complex interplay these factors may have on lipid metabolism. As mentioned previously, studies in animals have reported reductions in LPL activity with prolonged immobility [25], while a significant decrease in LPL activity was accompanied by increases in plasma VLDL triglycerides and decreases in HDL following 20 days bed rest in healthy participants [99]. However, in the human studies where prolonged sitting was interrupted, the activity stimulus (standing vs. regular activity breaks vs. a continuous bout) or the duration of studies may not have been sufficient to induce changes in triglyceride metabolism, which can be more delayed and vary depending upon the meal composition (i.e. high fat vs. high glucose) [115, 116] or population studied (i.e. healthy vs. obese vs. type 2 diabetes) [117].

Ultimately, meta-analytic evidence has also been inconsistent, with two meta-analyses indicating no effect of interruptions of prolonged sitting on postprandial triglycerides levels [100, 101] and one meta-analysis indicating a small but significant effect, which was driven by multiday studies [104]. Moreover, subgroup analysis and meta-regressions also indicated that the intensity of physical activity interruptions, meal composition and BMI do not seem to affect triglycerides responses [101].

In summary, compelling evidence suggest that frequent, short interruptions to prolonged sitting improves postprandial glucose and insulin responses compared to prolonged sitting. However, results related to postprandial triglycerides responses are inconsistent, with the majority of the evidence suggesting the absence of acute effects of physical activity interruptions on this cardiometabolic marker. Caution is warranted when interpreting these results, as most studies presented herein have been acute in nature, precluding inferences about longer-term exposures.

5.6 Effects of Sedentary Behaviour on Cardiovascular Function

Higher sitting time has been associated with an increased risk of cardiovascular disease and all-cause mortality [71]. For further detail, please refer to Chaps. 8 and 14. However, compared to the number of acute experimental studies on postprandial metabolism, there are far fewer randomised experimental studies that have examined the physiological effects of prolonged sitting on cardiovascular function and/or risk markers [83, 118–124]. Nonetheless, experimental studies that have included prolonged sitting exposures are starting to provide an interesting picture of the marked vulnerability of the vasculature to prolonged sitting.

Haemodynamic: In contrast to standing or lying down, a seated posture creates bends in major blood vessels, such as the femoral and popliteal arteries in the legs. Bends in these arteries may exhibit turbulent blood flow patterns that have been linked to atherosclerosis [125, 126]. Moreover, prolonged sitting does not promote skeletal muscle contractions (which aid in venous return via the muscle pump), nor does it promote blood flow or vascular shear stress—physiological stressors that may underlie the health benefits of activity on the endothelium [127]. Increased hydrostatic pressure within the leg vasculature due to prolonged gravitational forces may also cause blood to pool within the venous circulation [121]. Indeed, in healthy and metabolically impaired individuals, shear rate (an estimate of shear stress without adjustment for blood viscosity) in the lower limbs (assessed in femoral, popliteal or tibial arteries), but not in the upper limbs, is reduced after only 30 minutes of sitting

[120, 128]. By ~2 hours, blood pools in the calf and whole-blood leg viscosity are reduced [118]. After 3 hours, lower limb blood flow decreases along with a more pronounced reduction in shear rate [128]. Greater than 3 hours of sitting has been shown to increase cardiovascular risk markers of total peripheral resistance, systolic and diastolic blood pressure and mean arterial pressure (in the arm and leg) [120, 122]. Increases in lower leg and foot venous pressure/swelling have also been observed, which has potential implications for the regulation of capillary fluid filtration and oedema formation in the feet [129]. Interestingly, these latter effects were shown to be largely attenuated with modest leg activity while seated for 8 hours [130].

To date, 16 experimental studies have examined the impact of interrupting sitting time on blood pressure responses [131]. In young-healthy individuals, Younger et al. [124] observed significant increases in mean arterial pressure over 5 hours of prolonged sitting. However, a recent meta-analysis suggests no impact of prolonged sitting on mean arterial pressure in healthy and metabolically impaired populations [128]. With respect to the effects of interrupting prolonged sitting, Younger et al. [124] and Bailey et al. [83] showed significant blood pressure changes when sitting was interrupted with 2-minute intermittent walking/standing bouts or a continuous 30-minute bout of exercise. In contrast, Larsen et al. [119] recently reported, in inactive overweight/obese adults, that interrupting sitting time with brief bouts of either light or moderate intensity walking significantly lowered resting systolic and diastolic by ~2–3 mmHg. Moreover, it was recently reported in overweight/obese adults that accumulating 2.5 hours of standing or light-intensity physical activity during an 8-hour workday equally improved ambulatory blood pressure during and after work hours, compared to prolonged sitting [132]. The latter two studies are suggestive that interrupting prolonged sitting may disturb the haemodynamic and potentially hypertensive impact of prolonged sitting in older and more at risk populations.

A systematic review showed that one out of six studies found significant reductions in blood pressure responses following standing interruptions to prolonged sitting, whereas five out of nine and two out of three studies found significant improvements on blood pressure responses following light- and moderate-intensity walking interruptions, respectively, in individuals at risk for type 2 diabetes [131]. Due to the limited number of studies, it is not clear whether these effects are population dependent. Therefore, further studies are warranted, particularly in at-risk populations or individuals with chronic diseases such as hypertension, type 2 diabetes and cardiovascular disease, as most studies have focused on healthy, young individuals.

The risk of thrombosis: Deep vein thrombosis is a well-known and potentially life-threatening condition that has been linked to prolonged sitting, particularly during airplane travel (which may also be influenced by low humidity, reduced air pressure and relative hypoxia) [133–136] and more recently to people in office environments [137–139]. The mechanisms for the relationship of prolonged sitting with deep vein thrombosis, while unresolved, are likely related to alterations in venous haemodynamic, a loss of plasma volume, increased blood viscosity and reduced venous return (i.e. venous stasis)—which can increase the risk of hypercoagulation and blood clot formation in the lower limbs [140–142]. Venous stasis is also characterised by alterations in key blood viscosity parameters that influence blood flow, including plasma fibrinogen, haematocrit, haemoglobin, red blood cell count and reduced plasma volume [143, 144]. There is also some evidence in both rats and humans suggesting that muscle inactivity may contribute to haemostatic disorders, independent of decreased blood flow, via genes suppressed locally in muscles such as LPP1—a gene known for its role in degrading prothrombotic and proinflammatory lysophospholipids [145]. Interestingly, despite limited evidence of preventive effects from exercise training per se, recent studies suggest that frequent localised muscle contractions, simple foot movements [145–149], or brief walking interruptions in prolonged sitting time may play an important role in improving leg blood flow [128] and haemostatic and/or pro-coagulant risk factors [150].

Vascular function: Endothelial dysfunction (the inability of the blood vessels to dilate appropriately) is a mechanism that is postulated to unify the aetiology of type 2 diabetes and cardiovascular disease [151, 152]. Persistent inactivity over time may mediate oxidative stress and endothelial dysfunction [153, 154]. Indeed, reduced daily steps (from >10,000 to <5000 steps) impairs popliteal artery flow-mediated dilatation (FMD—indicative of macrovascular dilator function) and highlights the beneficial vascular effects of being physically active [61]. However, three recent well-controlled studies have also provided evidence on the potential effects of prolonged sitting on vascular function [120, 121, 123]. Padilla et al. [120] observed that 3 hours of sitting attenuated popliteal artery shear; however, this observed reduction in shear rate was not paralleled by a concomitant reduction in FMD (albeit measured in the supine position). In contrast, Thosar et al. [123] reported a reduction in FMD (measured this time in the seated position for all measurements) for the superficial femoral artery (lower limbs), but not the brachial artery (arms), following 3 hours of uninterrupted sitting. This was paralleled by a decline in mean and antegrade shear rate, and notably, the decline in FMD was prevented when sitting time was interrupted each hour by brief, 5-minute bouts of light-intensity walking.

Using both FMD and reactive hyperaemia to isolate the effects on macro- and microvascular function, Restaino et al. [121] provided further insights, demonstrating that prolonged sitting differentially influences vascular function in a limb-specific manner. They showed that 6 hours of uninterrupted sitting impairs microvascular dilator function (via hyperaemic blood flow responses to cuff occlusion—indicative of microvascular reactivity) in both the upper and lower limbs, but that only lower limb FMD was impaired. This may have been related to the fact that participants were allowed some upper limb movement or that shear stress of the brachial artery does not fluctuate dramatically between light activity and sitting conditions. Importantly, measurements were also completed after participants had walked for 10 minutes at a self-selected pace.

These results are supported by meta-analytic evidence suggesting that an exposure to prolonged sitting results in a reduction in lower limb vascular function, but not upper-limb [128, 155]. While no significant reductions were observed for shorter exposures (less than 2 hours of prolonged sitting), there was a clear trend for lower limb FMD to decline as exposure to prolonged sitting increased [128]. Importantly, the prolonged sitting-induced reduction in lower limb FMD was significant in heathy individuals but not in metabolically impaired individuals [128].

Only eight studies to date have examined the impact of interrupting sitting time on FMD [123, 156–162], and, so far, three meta-analyses have summarised available evidence. Two of those indicate that vascular dysfunction can be prevented by simply interrupting prolonged sitting with aerobic or simple resistance activities [155, 163]. However, the most recent meta-analysis suggests only a small but nonsignificant effects of physical activity interruptions on FMD [128]. Nonetheless, further studies are warranted, particularly in at-risk populations or individuals with chronic diseases, as most studies (six out of the eight available studies) have focused on healthy, young individuals.

Cardiorespiratory fitness: As previously noted, acute and persistent haemodynamic and vascular responses may ultimately exert influence on longer-term cardiovascular structural adaptations and cardiorespiratory fitness (VO_{2max}) [164, 165]. However, limited interventional evidence exists for changes in these longer-term cardiovascular outcomes in relation to prolonged sitting. In a small, 12-week, 4-condition, pilot intervention study in 57 sedentary, overweight/obese men and women, Keadle et al. [166] uniquely examined the independent and combined effects of exercise training and reducing sedentary behaviour on cardiometabolic risk factors, including VO_{2max}. The four conditions included (1) EX: 40-minute moderate exercise session, 5 days/week; (2) rST: reduce ST and increase light-intensity physical activity; (3) EX-rST: a combination of EX and rST; and (4) maintain behaviour (control). Compared to control, both the EX and EX-rST significantly improved VO_{2max} (9.3% and 11.8%, respectively); however, the rST group alone was not significantly improved. For perspective, these improvements in VO_{2max} during the EX and EX-rST conditions were similar in magnitude to reductions observed in young healthy men when asked to drastically reduce their daily physical activity for a period of 14 days [64, 167]. These findings reinforce the notion that improvements in VO_{2max} are specific to the intensity of the physical activity employed. However, it was interesting to note that replacing sedentary time (measured by inclinometer; mean decrease ~50 min/day) with more light-intensity physical activity (rST) was sufficient to at least *maintain* VO_{2max} levels. Given that VO_{2max} is a strong predictor of early mortality and disease risk [168, 169], these findings may hold important relevance for the ageing population with low levels of moderate-to-vigorous intensity physical activity. Nonetheless, more data are certainly needed to determine to what extent reducing sedentary time with activities in lower intensities (e.g. light-intensity walking) are effective at improving or at least maintaining VO_{2max} levels in the long term (years), particularly in older adults and individuals at-risk for or with chronic diseases or physically inactive.

In summary, prolonged sitting appears to be linked with a number of factors that may predispose to thrombotic and/or cardiovascular disease risk, including a tendency for low blood flow and vascular shear stress, decreased endothelial function and increased venous stasis/pooling, blood pressure and pro-coagulation factors. Preliminary evidence highlights the potential importance of replacing prolonged periods of uninterrupted sitting with regular physical movement to attenuate some of these factors. However, the majority of studies to date have been acute in nature, precluding inferences about longer-term exposures. In addition, studies have mostly been conducted in healthy young male participants to avoid hormonal influences. Further studies in a range of population groups and in ecologically valid settings are still required.

5.7 Immunologic and Inflammatory Responses to Sedentary Behaviour

Chronic low-grade inflammation has been implicated in the pathogenesis of numerous chronic diseases, particularly type 2 diabetes and cardiovascular disease [170–172]. Observational studies in healthy individuals and those with or at risk of type 2 diabetes have reported associations between self-reported and accelerometer-derived sedentary behaviour and multiple adipokines (hormones released from adipose tissue) including C-reactive protein (CRP), interleukin-6 (IL-6), leptin, leptin/adiponectin ratio and tumour necrosis factor-alpha (TNF-α) [173–178], independent of time spent in moderate-to-vigorous intensity physical activity. Moreover, higher self-reported screen and sitting time have also been associated with shorter telomere length [179, 180]. Telomeres (repetitive sequences of non-coding DNA that protect chromosomes from damage) undergo erosion as a result of cell division, systemic oxidative stress and inflammation, and thus serve as a potential indicator of cellular ageing and cardiovascular disease risk. To date, the reported relationships between sedentary behaviour and inflammation are complicated by crude measurements of sedentary time and the potential mediating influences of numerous other factors (e.g. moderate-to-vigorous intensity physical activity, dietary habits). Accelerated abdominal obesity is a key potential confounder [181], which has been linked with inactivity and sedentary behaviour in numerous observational studies [182–185].

Evidence remains limited concerning the effects of exposures to prolonged sitting on inflammatory markers. To date, two studies suggest that acute exposure to prolonged sitting (3–5 hours) increases IL-6 levels in both apparently healthy individuals [186] and adults with central obesity [187], whereas another study suggest no significant changes in IL-6 levels following 7 hours of prolonged sitting [188]. Moreover, IL-6 responses were not affected by frequent, brief light- and moderate-intensity walking interruptions to sitting [187–189]. Pinto et al. [189] showed, in post-menopausal women with rheumatoid arthritis, that frequent, brief light-intensity walking interruptions decreased plasma IL-1β and IL-10 concentrations and increased IL-1ra concentrations when compared to 8 hours of prolonged sitting, a response that was not observed with the traditional single 30-minute bout of moderate-to-vigorous intensity exercise [189]. These results suggest that physical activity interruptions could be a potential immunoregulatory tool to attenuate the inflammatory milieu in a disease characterised by chronic high-grade systemic inflammation. Further studies are needed to determine whether acute adjustments in inflammatory markers in response to prolonged sitting and physical activity interruptions translate into chronic adaptations.

Longer-term intervention studies examining sedentary behaviour and inflammatory outcomes are needed to elucidate the mechanisms specifically linking sedentary behaviour to chronic inflammatory-related diseases and to help inform the likelihood of causality. Moreover, determining whether specific modifications in sedentary time with light-intensity physical activity have distinct anti-inflammatory effects alongside changes in diet, moderate-to-vigorous intensity physical activity, adiposity and other co-inflammatory factors will also be important. These studies will be challenging to conduct and interpret given the longer observation periods required to observe changes, the numerous potential influencers on inflammatory markers over time and the relatively subtle/variable nature of sedentary behaviours in this context.

5.8 Effects of Sedentary Behaviour on Hormonal Regulation of Appetite, Dietary Intake and Energy Balance

Appetite regulation is complex and highly variable between individuals, involving psychological factors such as perceptions of hunger and satiety, which interact with fluctuations in hormones related to energy balance (i.e. the difference between energy intake and energy expenditures) and appetite regulation. On a meal-to-meal basis, food intake is regulated by several secreted peptide hormones. These include acylated ghrelin—the only known circulating orexigenic (appetite-stimulating) hormone—and a number of anorexigenic (appetite-inhibiting) hormones, such as peptide-YY (PYY), glucagon-like peptide-1, cholecystokinin and oxyntomodulin [190, 191].

The relationship between sedentary behaviour, physical activity and appetite regulation has potentially important implications for weight management. Physical activity is known to alter hunger and satiety perceptions (termed ‘exercise-induced anorexia’), as well as suppress acylated ghrelin and increase PYY in the hours following an exercise bout [192]. A meta-analysis [193] indicated that young-healthy individuals tend not to compensate for the energy expended by altering food intake in the immediate hours after physical activity, suggesting it subsequently induces a transient negative energy balance. Further, the authors also observed that inactive individuals were more likely to experience appetite suppression immediately after physical activity, suggesting that inactivity may differentially influence appetite regulation.

There is emerging evidence that sedentary behaviours not only influence appetite and energy intake but also the hedonic and rewarding aspects of feeding behaviours. Examples of potential links include television advertisements, snacking and video games and food cravings in adolescents [194]. However, relative to studies of physical activity, much less is known about the impact of sedentary behaviours per se on appetite regulation and energy balance. Granados et al. [195] showed that 1 day of sitting decreased energy expenditure without a reduction in appetite, suggesting this would favour a positive energy balance and subsequent weight gain. This is consistent with Stubbs et al. [196], who observed no compensatory decline in ad libitum food intake in response to large reductions in energy expenditure. However, these findings are contrary to some bed rest studies in lean adults conducted over 2 months, where energy balance was maintained due to a spontaneous lowering of energy intake to match lower expenditure [197].

At present, we are aware of only four randomised crossover studies that have examined appetite and appetite-regulating hormone responses when interrupting prolonged sitting [198, 199]. In young obese participants with impaired fasting glucose, Holmstrup et al. [199] compared objective measures of satiety when participants consumed liquid meals every 2 hours over a 12 hours period and completed hourly 5-minute bouts of intermittent walking versus an energy matched 1-hour bout of walking in the morning. The intermittent bouts of walking lead to lower perceived hunger and increased satiety in the mid-afternoon hours, but the finding did not track with changes in PYY levels between conditions. Bergouignan et al. [200] showed no differences in hunger and desire of food consumption, but lower food cravings, after a 7.5-hour trial with regular, brief moderate-intensity walking interruptions and 2 meals (breakfast and lunch) compared to prolonged sitting in healthy, nonobese participants. In a shorter duration trial (5 hours) with a single test drink, Bailey et al. [198] observed no significant differences between condition for hunger, satiety or circulating gut hormone concentrations (total PYY and acylated ghrelin) when sedentary participants interrupted prolonged sitting time with 2-minute bouts of light- or moderate-intensity walking every 20 minutes. Interestingly, participants were also provided with a test meal (pasta) at the end of each condition, but no differences in ad libitum food intake were observed between conditions, which could have implications for longer term energy balance and weight management. Similarly, Mete et al. [201] showed that performing regular physical activity interruptions did not affect appetite response nor did it affect ad libitum intake of a meal when compared to prolonged sitting over a 2-day intervention period. However, longer-term studies would be required to elucidate this. Finally, in the short-term (4 weeks), reducing prolonged sitting time (−21%) with standing bouts at work resulted in reduced appetite and dietary intake in sedentary office workers [202].

5.9 Musculoskeletal Consequences of Sedentary Behaviour

It is easy to assume through anecdote that a strong relationship exists between a stiff lower back and long-distance travel or a long day at work. This may provide managerial staff or employees with sufficient incentive to seek alternate arrangements (e.g. sit-stand or treadmill desks) at work for both perceived comfort and productivity reasons [203, 204] and potential employee litigation issues. In some cases, this may be reasonable, as musculoskeletal disorders have been linked to sedentary work, specifically those of the hand and wrist, neck, upper back and lower back [204–209]. In addition, greater amounts of sedentary time have been associated with lower femoral bone mineral content and density levels in older women when controlling for physical activity, raising the possibility that reducing sedentary time with light-intensity activity could help lessen/maintain aging induced bone loss [210]. However, the evidence on sitting behaviours per se (as opposed to behaviours associated specifically with office work and computer use) and musculoskeletal issues is largely imprecise, anecdotal and thus equivocal at present. For example, despite suggestions of increased spinal loading and risk of disk herniation during sitting [211], a systematic review found no evidence for an association between leisure time sitting and low back pain [212].

Findings are also mixed in the occupational setting, with some systematic reviews [213, 214] showing associations between occupational sitting and musculoskeletal issues (e.g. neck and back pain) while others have shown no association [215–218]. It may be that static sitting or standing positions impact individuals in a variety of ways depending on their specific musculoskeletal pain, suggesting that in many cases transitioning between the two postures may be a preferable option to avoid musculoskeletal discomfort and fatigue [219–221], as meta-analytic evidence also suggests that acute prolonged standing results in musculoskeletal symptoms in the low back and lower extremities [222] and that 'substantial' occupational standing associated with low back symptoms episodes (odds ratio: 1.3 (95% confidence interval: 1.1 to 1.6)) [223]. In summary, there is at present preliminary but inconsistent observational evidence that prolonged sitting is associated with musculoskeletal issues.

Overall, experimental studies indicate that exposure to prolonged sitting increases perceived pain/discomfort [224, 225] and fatigue [188, 200, 224, 226, 227]. Interestingly, Kowalsky et al. [224] showed that participants reported lower upper and lower back discomfort, but higher leg discomfort, when performing 30-minute bouts of standing every 30 minutes of sitting compared to prolonged sitting. Participants in this study were highly inactive and not conditioned to use sit-stand desks, indicating that acute exposure to low-intensity interruptions to prolonged sitting may increase musculoskeletal discomfort in selected sites in populations that are not familiar with the activity protocol being tested. In contrast, interrupting sitting with standing or physical activity (cycling, simple resistance activities, light- and moderate-intensity walking) counteracts the observed increases in musculoskeletal pain/discomfort [224, 225] and fatigue [188, 200, 226] associated with prolonged sitting across different populations (healthy, normal weight adults, adults with overweight and obesity and adults and older adults with type 2 diabetes). Nonetheless, more high-quality evidence from longitudinal and longer-term interventional studies using both valid and context-specific and measures of sitting patterns and musculoskeletal health is still required.

5.10 Effects of Sedentary Behaviour on Brain and Nervous System Function

Physical activity acts on multiple pathways to elicit improvements in brain health [228]. However, most randomised controlled trials supporting the benefits of physical activity for brain function have focused on moderate-to-vigorous intensity physical activity [229, 230]. Much less attention has been given to time spent in sedentary behaviour, but early evidence hints to a potential detrimental effect of sedentary activities on brain function [231, 232]. Additionally, time spent in sedentary behaviour has been associated with decreased cerebral blood flow [233, 234] and impaired glucose and lipid metabolism [100, 101, 104], which are recognised as contributors to cognitive decline and dementia [235–238].

At present, we are aware of only three randomised crossover studies that have examined cerebral blood flow responses when interrupting prolonged sitting. Carter et al. [233] showed that 2-minute walking interruptions every 30 minutes of sitting increased middle cerebral artery blood flow velocity in healthy desk workers when compared to prolonged sitting over a 4-hour intervention period. However, when walking interruptions were performed in 8-minute bouts every 120 minutes, middle cerebral artery blood flow velocity was higher during interruptions, but not during the 4-hour intervention protocol, when compared to prolonged sitting [233], indicating that more frequent interruptions to sitting may be more effective in counteracting sitting-induced reductions in cerebral blood flow. In contrast, Wheeler et al. [234] showed that a single 30-minute bout of exercise increased middle cerebral artery blood flow velocity in healthy older adults compared to prolonged sitting. However, adding regular light-intensity walking interruptions to the bout of exercise did not counteract the decrease in mean middle cerebral artery blood flow velocity over the 7.5-hour period following exercise [234]. In older adults, 3 hours of sitting did not change cerebral blood flow but increased blood pressure and cerebrovascular resistance, which are known to negatively impact brain health in the long term. These outcomes were not affected by frequent walking interruptions to sitting [239]. Finally, in middle-aged inactive adults, Bojsen-Møller et al. [240] showed that 3-minute bouts of simple resistance activities every 30 minutes of sitting increased corticospinal excitability compared to prolonged sitting (3 hours), suggesting that frequent, brief activity interruptions may promote corticospinal neuroplasticity.

An increasing number of studies have focused on the impact of interrupting prolonged sitting on cognitive performance and mental fatigue. So far, results have been inconsistent, which might be at least partially attributed to the high heterogeneity of population studied (e.g. healthy office workers, individuals with overweight and obesity, older adults, etc.), activity interruptions protocol (e.g. standing, light- and moderate-intensity walking, simple resistance activities, interruptions combined with exercise) and outcome assessment (e.g. questionnaire vs. computer software, performing a familiarisation vs. not performing it). Overall, interrupting sitting has been shown to improve outcomes related to cognitive function, namely, attention [227], executive function [227], working memory (interruptions to sitting alone [241] or combined with exercise [242]), psychomotor function and attention [241], in three studies. However, six other studies suggest no effects of interrupting sitting on outcomes related to cognitive performance [188, 200, 243–245] and mental fatigue [224]. Nonetheless, no studies showed detrimental effects of interrupting sitting on cognitive performance, supporting the feasibility of performing this strategy during cognitive-based tasks.

To summarise, evidence on the effects of sedentary behaviour on brain function and cognitive performance remains scarce and inconclusive. Therefore, more studies investigating the association between sedentary behaviour and brain health are needed, specifically high-quality studies attempting to tease out the independent effects of sedentary behaviour from physical activity using objective measures. Also of importance is longer-term interventional studies using both valid and context-specific measures of sedentary behaviour to better understand the impact of (interrupting) prolonged sitting on brain health.

5.11 Chronic Effects of Reducing Sedentary Behaviour on Health-Related Outcomes

Sedentary behaviour research focused on longer-term interventions has grown exponentially in the past few years. Overall, meta-analytic evidence suggests that interventions focused on reducing sedentary behaviour are effective in reducing mean time spent in this behaviour by ~30 min/day in free-living conditions [246–249] and by ~40 min/8-hour workday in the workplace [250], which is considered a relatively small effect and the clinical and public health impact of such reductions is currently unknown. Of note, efficacy for short- to long-term interventions aimed at reducing/interrupting sedentary behaviour is highly variable between studies, which can be at least partially explained by study design and quality, intervention characteristics (aim/focus, strategy, setting, follow-up duration), population, outcomes assessment and type/assessment of sedentary behaviour [247–250]. In summary, there is a need for more high-quality randomised controlled studies with larger sample sizes and longer follow-up periods involving healthy, at-risk and clinical populations, so we can draw better conclusions regarding the efficacy of interventions aimed at reducing and interrupting prolonged sedentary behaviours.

Although the primary focus of chronic sedentary behaviour studies has been on the behavioural efficacy of the proposed interventions, some studies have also focused on the impact of reducing sedentary time in health-related outcomes. Hadgraft et al. [251] conducted a systematic review with meta-analysis to examine the effectiveness of intervention targeting sedentary behaviour on markers cardiometabolic risk. Pooled effects revealed a small, significant beneficial effects of reducing sedentary time on weight (~ −0.6 kg), waist circumference (~ −0.7 cm), percentage body fat (~ −0.3%), systolic blood pressure (~ −1.1 mmHg), insulin (~ −1.4 pM) and HDL-cholesterol (~ 0.04 mM) [251]. In a meta-analysis including only clinical populations (overweight/obesity, type 2 diabetes, cardiovascular, neurological/cognitive and musculoskeletal diseases), reducing sedentary time (−64 min/day) decreased glycated haemoglobin (−0.17%), percentage body fat (−0.66%) and waist circumference (−1.52 cm) [252]. Finally, meta-analytic evidence suggests that mid- to long-term (8 to 16 weeks) reductions in sedentary behaviour result in an increase in FMD (i.e. vascular function; 0.93%FMD) [163]. As for interventions focused on replacing sedentary time with standing, meta-analytic evidence suggests slight but significant reductions on fasting glucose (−2.53 mg/dL) and body fat mass (−0.75 kg) [95].

Overall, there is evidence of effectiveness for improving some cardiometabolic risk factors to a small degree. However, there is still limited evidence to evaluate other health-related outcomes, namely, inflammatory markers, brain function and cognitive performance, musculoskeletal function and symptoms and cardiorespiratory capacity. Key limitations of the available body of evidence include a paucity of high-quality intervention studies with longer follow-up periods and inclusion of clinical populations. The magnitude of changes in sedentary time that are necessary to elicit improvements in cardiometabolic risk factors is also not clear, nor if there is a dose-response between reduction in time spent sitting and improvements in health-related outcomes. Further studies are required to address these limitations and elucidate these questions, which may involve harmonisation of individual-participant data and controlling for participants' physical activity level (including participation in both light-intensity and moderate-to-vigorous intensity physical activity).

5.12 Conclusions: Research Needs and Future Opportunities

The science of sedentary behaviour, while still emergent from a physiological perspective, is beginning to highlight the potential role that all aspects along the human movement continuum (see Fig. 5.1) can play in influencing physiology. As illustrated conceptually in Fig. 5.2, prolonged sitting may exert specific physiological effects; however, much remains to be understood and clarified. To date, evidence on the physiological effects of prolonged sitting exposures and the potential impact of reducing and interrupting these periods raises several pertinent questions, research needs and opportunities. These include (1) how sedentary behaviour research models can complement the already vast knowledge base on physical inactivity; (2) the independent effects of sedentary behaviour on acute/chronic physiological processes or health outcomes and the specific mechanisms involved; and (3) how our evolving knowledge about sedentary behaviour and light-intensity physical activity can inform interventions and future public health recommendations. Hereafter, we provide a perspective on some of the priority areas for future work in sedentary physiology.

5.12.1 A Need for More Mechanistic Studies and Chronic Interventions

It has been proposed that sedentary behaviour influences health outcomes through some mechanisms that are independent from those related to a lack of moderate-to-vigorous intensity physical activity [26, 253]. Thus, understanding the specific physiological mechanisms underlying the associations between sedentary behaviour and adverse health outcomes remains an important area for future research [15]. Moreover, there is critical need for exposures to prolonged sitting time to be tested in longer-term interventions to provide more concrete evidence pertinent to chronic disease risk. Studies to date illustrate the short-term peripheral effects of engaging in prolonged sitting and how they may be mitigated even with light-intensity physical activity. However, more robust data on both the direct and indirect underlying cellular and molecular mechanisms associated with prolonged sitting and risk of disease/mortality will be garnered through the collection of tissue samples (e.g. muscle, bone, adipose tissue), including more direct and integrated physiological measurements (e.g. metabolic, vascular, magnetic resonance imaging), rather than surrogate markers. As examples, alterations in skeletal muscle insulin signalling [107] and gene expression associated with tissue-specific and small-molecule biochemistry, cellular development, growth and proliferation and carbohydrate metabolism [108] have been observed overweight/obese adults when prolonged sitting is interrupted with regular activity bouts. Additionally, alterations in the subcutaneous abdominal adipose tissue gene expression related to regulation of adipose tissue metabolic networks and inflammatory pathways, increased insulin signalling, modulation of adipocyte cell cycle and facilitated crosstalk between adipose tissue and other organs have been reported in the same population group and interruption strategy [109]. Further analyses of this nature will provide valuable insights on the site-specific regulatory systems and cellular and molecular processes underlying the physiological effects of prolonged sitting.

5.12.2 A Need for Studies Assessing Novel Outcomes and Modulators Related to Sedentary Behaviour and Light-Intensity Physical Activity

Based on the acute evidence to date, it is likely that the associations between sedentary behaviours and health outcomes will be dependent upon the health or physiological outcome measured and the population subsets involved, meaning future sedentary behaviour interventions and guidelines may have to be more specific to the key priorities and needs of the target population. With this in mind, it will also be important to move beyond cardiometabolic health concerns and uncover opportunities for collaborations between various areas of physiological expertise to gain a more integrated understanding. These could include, to name a few, integrative studies across metabolism, vascular physiology, molecular mediators, 'omics' technologies, central and peripheral neural effects, inflammation and musculoskeletal, bone health and cognitive effects. Such collaborations would allow for the assessment of novel markers of ageing, musculoskeletal and brain health, along with other clinical markers.

5.12.3 A Need to Identify Dose-Response Relationships and Optimal Physical Activity Patterns

While it is often more pragmatic to study specific activities within the physical activity spectrum in isolation, in day-to-day living, exercise, physical activity and sitting do not occur in isolation from each other. Thus, fundamental and pragmatic questions at the core of sedentary behaviour research include (1) what duration of sitting is too much and, importantly, (2) how often and with what activities should prolonged sitting time be replaced (e.g. 'Is just standing enough, or do I need to move/ambulate?'). (3) Do those who fail to meet the moderate-to-vigorous intensity physical activity guidelines, but who engage in large volumes of light activity, have more favourable health outcomes than those who meet moderate-to-vigorous intensity physical activity guidelines but sit for much of the day (e.g. the active office-based commuter)? Furthermore, what is the 'ideal' pattern of active and sedentary behaviours?

These questions are inevitably complex, as the 'ideal' patterning of sedentary and physical activity behaviours is likely to be based on the requirements (i.e. outcomes of most interest to the individual), context and activity/health status of the subpopulation, rather than 'one-size-fits-all' approach. However, in terms of potential solutions applicable to the population, it may be that certain minimal combinations or criterion of mode or posture (e.g. active sitting, fidgeting, acute or extended postural changes, standing, activities involving resistance and/or sit-to-stand transitions), volume or intensity (e.g. light-intensity physical activity and/or moderate-to-vigorous intensity physical activity) or patterning (e.g. activity bout, active around meals and/or standing length/accumulation) of physical movement are all that is required to derive some minimum, or optimum, physiological and health benefit. As an example, given that increasing both time spent in light-intensity activity (reducing sedentary time) and moderate-to-vigorous intensity physical activity seem to be acutely beneficial for glycaemic control, a logical next step could be to establish whether certain combinations of both behaviours has the potential to optimise glycaemic control [70]. However, one must also be cognisant that each physiological outcome measure may require different doses and types of intervention. In other words, whereas modifying sitting behaviour with light activity may positively affect glycaemic control, it may have less efficacy for improving outcomes that rely on 'working the system' at higher intensities, such as cardiorespiratory fitness.

Epidemiological studies findings highlight the *interdependent* and potentially *synergistic* nature of active and sedentary behaviours [8, 10, 12]. Although experimental research on this topic remains scarce, recent studies are showing the interactive effects of sedentary and active behaviours on health outcomes. Akins et al. [254] showed that a short exposure (4 days) to a highly sedentary and inactive lifestyle (~13.5 h/day of sitting and <4000 steps/day) prevented the traditional metabolic benefits (improvements on postprandial plasma glucose, insulin and triglycerides responses) derived from an acute 1-hour bout of exercise in healthy, young individuals. Similarly, Kim et al. [255] demonstrated that a 4-day exposure to prolonged sitting, using a similar experimental protocol, resulted in increased postprandial plasma triglycerides response regardless of energy balance, which was not attenuated by a single 1-hour bout of exercise. Importantly, this response was not observed in the condition in which participants engaged in low sedentary time (~8.4 h/day) and high time spent standing and in light-intensity physical activity (~17,000 steps) [255]. Additionally, daily levels of light-intensity physical activity were shown to be an independent predictor of improvements in VO_{2max} after an 8-week training program. Of note, baseline light-intensity physical activity also negatively associated with VO_{2max} [256]. Altogether these studies suggest that everyday life activities (i.e. sedentary behaviour and light-intensity physical activity) may impact 'trainability' (i.e. the capacity of an individual to benefit from exercise training). Further randomised controlled trials and longer-term interventions focused on identifying what are the differential, additive and/or interacting effects of active and sedentary behaviours for each population and health-related outcomes are still required. Integrating information from these studies is especially critical for developing an evidence base for quantitative-based and context-specific sedentary behaviour guidelines. Such information will also provide healthcare professionals with more information to begin providing personalised lifestyle prescriptions tailored to deliver optimal health benefit at an individual level.

5.12.4 A Need to Identify and Consider the Potential Differential Effects of Sedentary Behaviour

Sedentary behaviour exists in a variety of population subgroups and under different environmental contexts and personal factors within a spectrum of activity that make up the 24-hour day. Thus, it will be important to consider how the effects of prolonged sedentary time vary by contexts and purposes of sedentary behaviours and by other key factors, including but not limited to age, sex, race/ethnicity, genetic profiles, menopausal, pregnancy and lactating statuses, medications, dietary habits, cardiorespiratory fitness and baseline exercise levels, sleep duration and quality and populations with or at increased risk of various chronic conditions, as indicated by the 2020 World Health Organization (WHO) Guidelines Development Group [8, 20]. Identifying whether or not such factors hold significant importance will also help identify more 'at-risk' population groups and those who may derive more benefit from reductions in sedentary behaviour.

In this regard, accumulating acute experimental studies suggest that regular interruptions in prolonged sitting time may be particularly beneficial for glycaemic control in those with or at high risk of developing type 2 diabetes relative to healthy individuals, suggesting dysregulated metabolic responses to prolonged sitting in these individuals. Moreover, individuals with type 2 diabetes are more likely to be overweight/obese and deconditioned and be dealing with various complications and comorbidities. In this context, while displacing sitting time with brief bouts of light-intensity activity may be an effective management tool in its own right, it is also plausible that such activity breaks could provide a further behavioural or physiological 'stepping-stone' towards more participation in, tolerance of, or potentiate the effects of moderate-to-vigorous intensity physical activity. In the future, delivery of the most appropriate form of programme, intervention or communication, education or environmental and policy change at the right time to those who need them most, or who are most likely to derive benefit, would help minimise the likelihood of unhelpful intervention.

5.13 Summary

Excessive sitting is a ubiquitous, modern-day behaviour, co-existing alongside low adherence to structured exercise in much of the population. Acute controlled experimental studies are beginning to support epidemiologic research findings suggesting that sedentary behaviour may contribute to excess morbidity and mortality. However, as our evidence synthesis shows, the physiology underlying sedentary behaviour (see Fig. 5.2) and solutions to ameliorate the potentially deleterious effects remain in their infancy. Further research is necessary in a variety of scientific disciplines to elucidate specific physiological effects and responsible mechanisms of engaging in high volumes of sitting, but also periods of more prolonged sitting.

Interrupting prolonged sitting with light-intensity activities may be a practical strategy in preventing and treating multiple health disorders. However, further controlled experimental studies and evidence from high-quality longer-term and ecologically relevant free-living study designs is still required. While acute human experimental findings are promising and have provided useful insights, they have mostly focussed on decrements in glycaemic control, insulin sensitivity and vascular function. The use of novel physical activity and sedentary intervention models, ideally with high-quality measurements of physiological outcomes across a range of populations, will hopefully add further specificity to sedentary behaviour and physical activity guidelines and permit more explicit recommendations and tailored interventions in the future. In the meantime, it remains appropriate and prudent for healthcare professionals—in the interest of 'doing no harm'—to promote 'limiting sedentary time and replacing it with more physical activity of any intensity', as proposed by the 2020 WHO Guidelines on Physical Activity and Sedentary Behaviour [2].

References

1. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc. 2011;43(7):1334–59. https://doi.org/10.1249/MSS.0b013e318213fefb.
2. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54(24):1451–62. https://doi.org/10.1136/bjsports-2020-102,955.
3. Sedentary Behaviour Research Network. Letter to the Editor: standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab. 2012;37:540–2.
4. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary Behavior Research Network (SBRN) - Terminology consensus project process and outcome. Int J Behav Nutr Phys Act. 2017;14(1):75. https://doi.org/10.1186/s12966-017-0525-8.
5. Katzmarzyk PT, Powell KE, Jakicic JM, Troiano RP, Piercy K, Tennant B, et al. Sedentary behavior and health: update from the 2018 physical ACTIVITY GUIDELINES ADVISORY COMMITTEE. Med Sci Sports Exerc. 2019;51(6):1227–41. https://doi.org/10.1249/MSS.0000000000001935.
6. Young DR, Hivert MF, Alhassan S, Camhi SM, Ferguson JF, Katzmarzyk PT, et al. Sedentary behavior and cardiovascular morbidity and mortality: a science advisory from the American Heart Association. Circulation. 2016;134(13):e262–79. https://doi.org/10.1161/CIR.0000000000000440.
7. Colberg SR, Sigal RJ, Yardley JE, Riddell MC, Dunstan DW, Dempsey PC, et al. Physical activity/exercise and diabetes: a position statement of the American Diabetes Association. Diabetes Care. 2016;39(11):2065–79. https://doi.org/10.2337/dc16-1728.
8. Dempsey PC, Biddle SJH, Buman MP, Chastin S, Ekelund U, Friedenreich CM, et al. New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. Int J Behav Nutr Phys Act. 2020;17(1):151. https://doi.org/10.1186/s12966-020-01044-0.

9. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet. 2016;388(10051):1302–10. https://doi.org/10.1016/S0140-6736(16)30370-1.
10. Ekelund U, Tarp J, Fagerland MW, Johannessen JS, Hansen BH, Jefferis BJ, et al. Joint associations of accelero-meter measured physical activity and sedentary time with all-cause mortality: a harmonised meta-analysis in more than 44 000 middle-aged and older individuals. Br J Sports Med. 2020;54(24):1499–506. https://doi.org/10.1136/bjsports-2020-103,270.
11. Chastin S, McGregor D, Palarea-Albaladejo J, Diaz KM, Hagstromer M, Hallal PC, et al. Joint association between accelerometry-measured daily combination of time spent in physical activity, sedentary behaviour and sleep and all-cause mortality: a pooled analysis of six prospective cohorts using compositional analysis. Br J Sports Med. 2021;55(22):1277–85. https://doi.org/10.1136/bjsports-2020-102,345.
12. Chastin SFM, McGregor DE, Biddle SJH, Cardon G, Chaput JP, Dall PM, et al. Striking the right balance: evidence to inform combined physical activity and sedentary behavior recommendations. J Phys Act Health. 2021;18(6):631–7. https://doi.org/10.1123/jpah.2020-0635.
13. Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. Appl Physiol Nutr Metab. 2010;35(6):725–40. https://doi.org/10.1139/H10-079.
14. Dempsey PC, Thyfault JP. Physiological responses to sedentary behaviour. In: Leitzmann MF, Jochem C, Schmid D, editors. Sedentary behaviour epidemiology. Cham: Springer; 2018. p. 109–53.
15. Dempsey PC, Matthews CE, Dashti SG, Doherty AR, Bergouignan A, van Roekel EH, et al. Sedentary behavior and chronic disease: mechanisms and future directions. J Phys Act Health. 2020;17(1):52–61. https://doi.org/10.1123/jpah.2019-0377.
16. Bergouignan A, Rudwill F, Simon C, Blanc S. Physical inactivity as the culprit of metabolic inflexibility: evidences from bed-rest studies. J Appl Physiol. 2011;111(4):1201–10. https://doi.org/10.1152/japplphysiol.00698.2011.
17. Thyfault JP, Krogh-Madsen R. Metabolic disruptions induced by reduced ambulatory activity in free-living humans. J Appl Physiol (1985). 2011;111(4):1218–24. https://doi.org/10.1152/japplphysiol.00478.2011.
18. Booth FW, Roberts CK, Thyfault JP, Ruegsegger GN, Toedebusch RG. Role of inactivity in chronic diseases: evolutionary insight and pathophysiological mechanisms. Physiol Rev. 2017;97(4):1351–402. https://doi.org/10.1152/physrev.00019.2016.
19. Le Roux E, De Jong NP, Blanc S, Simon C, Bessesen DH, Bergouignan A. Physiology of physical inactivity, sedentary behaviours and non-exercise activity: insights from the space bedrest model. J Physiol. 2021;600(5):1037–51. https://doi.org/10.1113/JP281064.
20. Dempsey PC, Friedenreich CM, Leitzmann MF, Buman MP, Lambert E, Willumsen J, et al. Global public health guidelines on physical activity and sedentary behavior for people living with chronic conditions: a call to action. J Phys Act Health. 2020;18(1):76–85. https://doi.org/10.1123/jpah.2020-0525.
21. Kump DS, Booth FW. Alterations in insulin receptor signalling in the rat epitrochlearis muscle upon cessation of voluntary exercise. J Physiol. 2005;562(Pt 3):829–38. https://doi.org/10.1113/jphysiol.2004.073593.
22. Laye MJ, Thyfault JP, Stump CS, Booth FW. Inactivity induces increases in abdominal fat. J Appl Physiol (1985). 2007;102(4):1341–7. https://doi.org/10.1152/japplphysiol.01018.2006.
23. Kump DS, Booth FW. Sustained rise in triacylglycerol synthesis and increased epididymal fat mass when rats cease voluntary wheel running. J Physiol. 2005;565(Pt 3):911–25. https://doi.org/10.1113/jphysiol.2005.084525.
24. O'Keefe MP, Perez FR, Kinnick TR, Tischler ME, Henriksen EJ. Development of whole-body and skeletal muscle insulin resistance after one day of hindlimb suspension. Metabolism. 2004;53(9):1215–22.

25. Bey L, Hamilton MT. Suppression of skeletal muscle lipoprotein lipase activity during physical activity: A molecular reason to maintain daily low-intensity activity. J Physiol. 2003;551(2):673–82.
26. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes. 2007;56(11):2655–67.
27. Bey L, Akunuri N, Zhao P, Hoffman EP, Hamilton DG, Hamilton MT. Patterns of global gene expression in rat skeletal muscle during unloading and low-intensity ambulatory activity. Physiol Genom. 2003;13(2):157–67. https://doi.org/10.1152/physiolgenomics.00001.2002.
28. Nay K, Martin D, Orfila L, Saligaut D, Martin B, Horeau M, et al. Intermittent reloading does not prevent reduction in iron availability and hepcidin upregulation caused by hindlimb unloading. Exp Physiol. 2021;106(1):28–36. https://doi.org/10.1113/EP088339.
29. Nemoto A, Goyagi T. Tail suspension is useful as a sarcopenia model in rats. Lab Anim Res. 2021;37(1):7. https://doi.org/10.1186/s42826-020-00083-9.
30. Momken I, Stevens L, Bergouignan A, Desplanches D, Rudwill F, Chery I, et al. Resveratrol prevents the wasting disorders of mechanical unloading by acting as a physical exercise mimetic in the rat. FASEB J. 2011;25(10):3646–60. https://doi.org/10.1096/fj.10-177,295.
31. Cavey T, Pierre N, Nay K, Allain C, Ropert M, Loreal O, et al. Simulated microgravity decreases circulating iron in rats: role of inflammation-induced hepcidin upregulation. Exp Physiol. 2017;102(3):291–8. https://doi.org/10.1113/EP086188.
32. Grano M, Mori G, Minielli V, Barou O, Colucci S, Giannelli G, et al. Rat hindlimb unloading by tail suspension reduces osteoblast differentiation, induces IL-6 secretion, and increases bone resorption in ex vivo cultures. Calcif Tissue Int. 2002;70(3):176–85. https://doi.org/10.1007/s00223-001-2034-6.
33. Habold C, Momken I, Ouadi A, Bekaert V, Brasse D. Effect of prior treatment with resveratrol on density and structure of rat long bones under tail-suspension. J Bone Miner Metab. 2011;29(1):15–22. https://doi.org/10.1007/s00774-010-0187-y.
34. Salaun E, Lefeuvre-Orfila L, Cavey T, Martin B, Turlin B, Ropert M, et al. Myriocin prevents muscle ceramide accumulation but not muscle fiber atrophy during short-term mechanical unloading. J Appl Physiol (1985). 2016;120(2):178–87. https://doi.org/10.1152/japplphysiol.00720.2015.
35. Mujika I, Padilla S. Muscular characteristics of detraining in humans. Med Sci Sports Exerc. 2001;33(8):1297–303. https://doi.org/10.1097/00005768-200,108,000-00009.
36. Mujika I, Padilla S. Cardiorespiratory and metabolic characteristics of detraining in humans. Med Sci Sports Exerc. 2001;33(3):413–21. https://doi.org/10.1097/00005768-200,103,000-00013.
37. Oshida Y, Yamanouchi K, Hayamizu S, Nagasawa J, Ohsawa I, Sato Y. Effects of training and training cessation on insulin action. Int J Sports Med. 1991;12(5):484–6. https://doi.org/10.1055/s-2007-1,024,718.
38. Burstein R, Polychronakos C, Toews CJ, MacDougall JD, Guyda HJ, Posner BI. Acute reversal of the enhanced insulin action in trained athletes. Association with insulin receptor changes. Diabetes. 1985;34(8):756–60.
39. Rynders CA, Blanc S, DeJong N, Bessesen DH, Bergouignan A. Sedentary behaviour is a key determinant of metabolic inflexibility. J Physiol. 2018;596(8):1319–30. https://doi.org/10.1113/JP273282.
40. Hodgson H, Wilkinson M, Bowen S, Giannoudis P, Howard A. Older adults are not more susceptible to acute muscle atrophy after immobilisation compared to younger adults: a systematic review. Eur J Trauma Emerg Surg. 2021;48(2):1167–76. https://doi.org/10.1007/s00068-021-01694-0.
41. Sonne MP, Hojbjerre L, Alibegovic AC, Nielsen LB, Stallknecht B, Vaag AA, et al. Endothelial function after 10 days of bed rest in individuals at risk for type 2 diabetes and cardiovascular disease. Exp Physiol. 2011;96(10):1000–9. https://doi.org/10.1113/expphysiol.2011.058511.

42. Sonne MP, Alibegovic AC, Hojbjerre L, Vaag A, Stallknecht B, Dela F. Effect of 10 days of bedrest on metabolic and vascular insulin action: a study in individuals at risk for type 2 diabetes. J Appl Physiol (1985). 2010;108(4):830–7. https://doi.org/10.1152/japplphysiol.00545.2009.
43. Friedrichsen M, Ribel-Madsen R, Mortensen B, Hansen CN, Alibegovic AC, Hojbjerre L, et al. Muscle inflammatory signaling in response to 9 days of physical inactivity in young men with low compared with normal birth weight. Eur J Endocrinol. 2012;167(6):829–38. https://doi.org/10.1530/EJE-12-0498.
44. Mortensen B, Friedrichsen M, Andersen NR, Alibegovic AC, Hojbjerre L, Sonne MP, et al. Physical inactivity affects skeletal muscle insulin signaling in a birth weight-dependent manner. J Diabetes Complicat. 2014;28(1):71–8. https://doi.org/10.1016/j.jdiacomp.2013.09.002.
45. Hamburg NM, McMackin CJ, Huang AL, Shenouda SM, Widlansky ME, Schulz E, et al. Physical inactivity rapidly induces insulin resistance and microvascular dysfunction in healthy volunteers. Arterioscler Thromb Vasc Biol. 2007;27(12):2650–6. https://doi.org/10.1161/ATVBAHA.107.153288.
46. Alibegovic AC, Hojbjerre L, Sonne MP, van Hall G, Stallknecht B, Dela F, et al. Impact of 9 days of bed rest on hepatic and peripheral insulin action, insulin secretion, and whole-body lipolysis in healthy young male offspring of patients with type 2 diabetes. Diabetes. 2009;58(12):2749–56. https://doi.org/10.2337/db09-0369.
47. Rudwill F, O'Gorman D, Lefai E, Chery I, Zahariev A, Normand S, et al. Metabolic inflexibility is an early marker of bed-rest-induced glucose intolerance even when fat mass is stable. J Clin Endocrinol Metab. 2018;103(5):1910–20. https://doi.org/10.1210/jc.2017-02267.
48. Adams GR, Caiozzo VJ, Baldwin KM. Skeletal muscle unweighting: spaceflight and ground-based models. J Appl Physiol (1985). 2003;95(6):2185–201. https://doi.org/10.1152/japplphysiol.00346.2003.
49. Yasuda N, Glover EI, Phillips SM, Isfort RJ, Tarnopolsky MA. Sex-based differences in skeletal muscle function and morphology with short-term limb immobilization. J Appl Physiol (1985). 2005;99(3):1085–92. https://doi.org/10.1152/japplphysiol.00247.2005.
50. Dirks ML, Backx EM, Wall BT, Verdijk LB, van Loon LJ. May bed rest cause greater muscle loss than limb immobilization? Acta Physiol (Oxf). 2016;218(1):10–2. https://doi.org/10.1111/apha.12699.
51. Perkin O, McGuigan P, Thompson D, Stokes K. A reduced activity model: a relevant tool for the study of ageing muscle. Biogerontology. 2016;17(3):435–47. https://doi.org/10.1007/s10522-015-9613-9.
52. Suetta C, Hvid LG, Justesen L, Christensen U, Neergaard K, Simonsen L, et al. Effects of aging on human skeletal muscle after immobilization and retraining. J Appl Physiol (1985). 2009;107(4):1172–80. https://doi.org/10.1152/japplphysiol.00290.2009.
53. Wall BT, Snijders T, Senden JM, Ottenbros CL, Gijsen AP, Verdijk LB, et al. Disuse impairs the muscle protein synthetic response to protein ingestion in healthy men. J Clin Endocrinol Metab. 2013;98(12):4872–81. https://doi.org/10.1210/jc.2013-2098.
54. Black MN, Wilkinson JA, Webb EK, Kamal M, Bahniwal R, McGlory C, et al. Two weeks of single-leg immobilization alters intramyocellular lipid storage characteristics in healthy, young women. J Appl Physiol (1985). 2021;130(4):1247–58. https://doi.org/10.1152/japplphysiol.00878.2019.
55. Vigelso A, Gram M, Wiuff C, Hansen CN, Prats C, Dela F, et al. Effects of immobilization and aerobic training on proteins related to intramuscular substrate storage and metabolism in young and older men. Eur J Appl Physiol. 2016;116(3):481–94. https://doi.org/10.1007/s00421-015-3302-x.
56. Sugawara J, Hayashi K, Kaneko F, Yamada H, Kizuka T, Tanaka H. Reductions in basal limb blood flow and lumen diameter after short-term leg casting. Med Sci Sports Exerc. 2004;36(10):1689–94. https://doi.org/10.1249/01.mss.0000142410.45142.28.

57. Testroote M, Stigter W, de Visser DC, Janzing H. Low molecular weight heparin for prevention of venous thromboembolism in patients with lower-leg immobilization. Cochrane Database Syst Rev. 2008;4:CD006681. https://doi.org/10.1002/14651858.CD006681.pub2.
58. Damiot A, Demangel R, Noone J, Chery I, Zahariev A, Normand S, et al. A nutrient cocktail prevents lipid metabolism alterations induced by 20 days of daily steps reduction and fructose overfeeding: result from a randomized study. J Appl Physiol (1985). 2019;126(1):88–101. https://doi.org/10.1152/japplphysiol.00018.2018.
59. Shad BJ, Thompson JL, Holwerda AM, Stocks B, Elhassan YS, Philp A, et al. One week of step reduction lowers myofibrillar protein synthesis rates in young men. Med Sci Sports Exerc. 2019;51(10):2125–34. https://doi.org/10.1249/MSS.0000000000002034.
60. Bowden Davies KA, Sprung VS, Norman JA, Thompson A, Mitchell KL, Halford JCG, et al. Short-term decreased physical activity with increased sedentary behaviour causes metabolic derangements and altered body composition: effects in individuals with and without a first-degree relative with type 2 diabetes. Diabetologia. 2018;61(6):1282–94. https://doi.org/10.1007/s00125-018-4603-5.
61. Boyle LJ, Credeur DP, Jenkins NT, Padilla J, Leidy HJ, Thyfault JP, et al. Impact of reduced daily physical activity on conduit artery flow-mediated dilation and circulating endothelial microparticles. J Appl Physiol (1985). 2013;115(10):1519–25. https://doi.org/10.1152/japplphysiol.00837.2013.
62. Mikus CR, Oberlin DJ, Libla JL, Taylor AM, Booth FW, Thyfault JP. Lowering physical activity impairs glycemic control in healthy volunteers. Med Sci Sports Exerc. 2012;44(2):225–31. https://doi.org/10.1249/MSS.0b013e31822ac0c0.
63. Reynolds LJ, Credeur DP, Holwerda SW, Leidy HJ, Fadel PJ, Thyfault JP. Acute inactivity impairs glycemic control but not blood flow to glucose ingestion. Med Sci Sports Exerc. 2015;47(5):1087–94. https://doi.org/10.1249/MSS.0000000000000508.
64. Krogh-Madsen R, Thyfault JP, Broholm C, Mortensen OH, Olsen RH, Mounier R, et al. A 2-wk reduction of ambulatory activity attenuates peripheral insulin sensitivity. J Appl Physiol. 2010;108(5):1034–40. https://doi.org/10.1152/japplphysiol.00977.2009.
65. Judice PB, Hamilton MT, Sardinha LB, Zderic TW, Silva AM. What is the metabolic and energy cost of sitting, standing and sit/stand transitions? Eur J Appl Physiol. 2016;116(2):263–73. https://doi.org/10.1007/s00421-015-3279-5.
66. Mansoubi M, Pearson N, Clemes SA, Biddle SJ, Bodicoat DH, Tolfrey K, et al. Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour. BMC Public Health. 2015;15:516. https://doi.org/10.1186/s12889-015-1851-x.
67. Newton RL Jr, Han H, Zderic T, Hamilton MT. The energy expenditure of sedentary behavior: a whole room calorimeter study. PLoS One. 2013;8(5):e63171. https://doi.org/10.1371/journal.pone.0063171.
68. Tikkanen O, Haakana P, Pesola AJ, Hakkinen K, Rantalainen T, Havu M, et al. Muscle activity and inactivity periods during normal daily life. PLoS One. 2013;8(1):e52228. https://doi.org/10.1371/journal.pone.0052228.
69. Dunstan D, Howard B, Bergouignan A, Kingwell B, Owen N. Chapter 3: Physiological implications of sedentary behaviour: emerging human experimental evidence on reducing and breaking up sitting time. In: Sedentary behaviour and health: concepts, evidence, assessment and intervention. Urbana-Champaign, IL: Human Kinetics; 2020.
70. Dempsey PC, Owen N, Biddle SJ, Dunstan DW. Managing sedentary behavior to reduce the risk of diabetes and cardiovascular disease. Curr Diab Rep. 2014;14(9):522. https://doi.org/10.1007/s11892-014-0522-0.
71. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32. https://doi.org/10.7326/M14-1651.

72. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012;55(11):2895–905. https://doi.org/10.1007/s00125-012-2677-z.
73. Duvivier BM, Schaper NC, Bremers MA, van Crombrugge G, Menheere PP, Kars M, et al. Minimal intensity physical activity (standing and walking) of longer duration improves insulin action and plasma lipids more than shorter periods of moderate to vigorous exercise (cycling) in sedentary subjects when energy expenditure is comparable. PLoS One. 2013;8(2):e55542. https://doi.org/10.1371/journal.pone.0055542.
74. Lyden K, Keadle SK, Staudenmayer J, Braun B, Freedson PS. Discrete features of sedentary behavior impact cardiometabolic risk factors. Med Sci Sports Exerc. 2015;47(5):1079–86. https://doi.org/10.1249/MSS.0000000000000499.
75. Duvivier B, Bolijn JE, Koster A, Schalkwijk CG, Savelberg H, Schaper NC. Reducing sitting time versus adding exercise: differential effects on biomarkers of endothelial dysfunction and metabolic risk. Sci Rep. 2018;8(1):8657. https://doi.org/10.1038/s41598-018-26,616-w.
76. Duvivier B, Schaper NC, Koster A, van Kan L, Peters HPF, Adam JJ, et al. Benefits of substituting sitting with standing and walking in free-living conditions for cardiometabolic risk markers, cognition and mood in overweight adults. Front Physiol. 2017;8:353. https://doi.org/10.3389/fphys.2017.00353.
77. Duvivier BM, Schaper NC, Hesselink MK, van Kan L, Stienen N, Winkens B, et al. Breaking sitting with light activities vs structured exercise: a randomised crossover study demonstrating benefits for glycaemic control and insulin sensitivity in type 2 diabetes. Diabetologia. 2017;60(3):490–8. https://doi.org/10.1007/s00125-016-4161-7.
78. Remie CME, Janssens GE, Bilet L, van Weeghel M, Duvivier B, de Wit VHW, et al. Sitting less elicits metabolic responses similar to exercise and enhances insulin sensitivity in postmenopausal women. Diabetologia. 2021;64(12):2817–28. https://doi.org/10.1007/s00125-021-05558-5.
79. Smith JAB, Savikj M, Sethi P, Platt S, Gabriel BM, Hawley JA, et al. Three weeks of interrupting sitting lowers fasting glucose and glycemic variability, but not glucose tolerance, in free-living women and men with obesity. Am J Physiol Endocrinol Metab. 2021;321(2):E203–16. https://doi.org/10.1152/ajpendo.00599.2020.
80. Lunde MS, Hjellset VT, Hostmark AT. Slow post meal walking reduces the blood glucose response: an exploratory study in female Pakistani immigrants. J Immigr Minor Health. 2012;14(5):816–22. https://doi.org/10.1007/s10903-012-9574-x.
81. Nygaard H, Tomten SE, Hostmark AT. Slow postmeal walking reduces postprandial glycemia in middle-aged women. Appl Physiol Nutr Metab. 2009;34(6):1087–92. https://doi.org/10.1139/H09-110.
82. van Dijk JW, Venema M, van Mechelen W, Stehouwer CD, Hartgens F, van Loon LJ. Effect of moderate-intensity exercise versus activities of daily living on 24-hour blood glucose homeostasis in male patients with type 2 diabetes. Diabetes Care. 2013;36(11):3448–53. https://doi.org/10.2337/dc12-2620.
83. Bailey DP, Locke CD. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. J Sci Med Sport. 2015;18(3):294–8. https://doi.org/10.1016/j.jsams.2014.03.008.
84. Dunstan DW, Kingwell BA, Larsen R, Healy GN, Cerin E, Hamilton MT, et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes Care. 2012;35(5):976–83. https://doi.org/10.2337/dc11-1931.
85. Larsen RN, Kingwell BA, Robinson C, Hammond L, Cerin E, Shaw JE, et al. Breaking up of prolonged sitting over three days sustains, but does not enhance, lowering of postprandial plasma glucose and insulin in overweight and obese adults. Clin Sci (Lond). 2015;129(2):117–27. https://doi.org/10.1042/CS20140790.

86. Miyashita M, Park JH, Takahashi M, Suzuki K, Stensel D, Nakamura Y. Postprandial lipaemia: effects of sitting, standing and walking in healthy normolipidaemic humans. Int J Sports Med. 2013;34(1):21–7. https://doi.org/10.1055/s-0032-1,321,897.
87. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. Am J Clin Nutr. 2013;98(2):358–66. https://doi.org/10.3945/ajcn.112.051763.
88. Dempsey PC, Owen N, Yates TE, Kingwell BA, Dunstan DW. Sitting less and moving more: improved glycaemic control for type 2 diabetes prevention and management. Curr Diab Rep. 2016;16(11):114. https://doi.org/10.1007/s11892-016-0797-4.
89. Buckley JP, Mellor DD, Morris M, Joseph F. Standing-based office work shows encouraging signs of attenuating post-prandial glycaemic excursion. Occup Environ Med. 2014;71 (2):109–11. https://doi.org/10.1136/oemed-2013-101,823.
90. Henson J, Davies MJ, Bodicoat DH, Edwardson CL, Gill JM, Stensel DJ, et al. Breaking up prolonged sitting with standing or walking attenuates the postprandial metabolic response in postmenopausal women: a randomized acute study. Diabetes Care. 2016;39(1):130–8. https://doi.org/10.2337/dc15-1240.
91. Thorp AA, Kingwell BA, Sethi P, Hammond L, Owen N, Dunstan DW. Alternating bouts of sitting and standing attenuate postprandial glucose responses. Med Sci Sports Exerc. 2014;46 (11):2053–61. https://doi.org/10.1249/MSS.0000000000000337.
92. Altenburg TM, Rotteveel J, Serne EH, Chinapaw MJM. Standing is not enough: a randomized crossover study on the acute cardiometabolic effects of variations in sitting in healthy young men. J Sci Med Sport. 2019;22(7):790–6. https://doi.org/10.1016/j.jsams.2018.12.016.
93. Pulsford RM, Blackwell J, Hillsdon M, Kos K. Intermittent walking, but not standing, improves postprandial insulin and glucose relative to sustained sitting: a randomised cross-over study in inactive middle-aged men. J Sci Med Sport. 2017;20(3):278–83. https://doi.org/10.1016/j.jsams.2016.08.012.
94. Yates T, Edwardson CL, Celis-Morales C, Biddle SJH, Bodicoat D, Davies MJ, et al. Metabolic effects of breaking prolonged sitting with standing or light walking in older South Asians and White Europeans: a randomized acute study. J Gerontol A Biol Sci Med Sci. 2020;75(1):139–46. https://doi.org/10.1093/gerona/gly252.
95. Saeidifard F, Medina-Inojosa JR, Supervia M, Olson TP, Somers VK, Prokop LJ, et al. The effect of replacing sitting with standing on cardiovascular risk factors: a systematic review and meta-analysis. Mayo Clin Proc Innov Qual Outcomes. 2020;4(6):611–26. https://doi.org/10.1016/j.mayocpiqo.2020.07.017.
96. Stephens BR, Granados K, Zderic TW, Hamilton MT, Braun B. Effects of 1 day of inactivity on insulin action in healthy men and women: interaction with energy intake. Metabolism. 2011;60(7):941–9. https://doi.org/10.1016/j.metabol.2010.08.014.
97. Smorawinski J, Kaciuba-Uscilko H, Nazar K, Kubala P, Kaminska E, Ziemba AW, et al. Effects of three-day bed rest on metabolic, hormonal and circulatory responses to an oral glucose load in endurance or strength trained athletes and untrained subjects. J Physiol Pharmacol. 2000;51(2):279–89.
98. Mikines KJ, Dela F, Tronier B, Galbo H. Effect of 7 days of bed rest on dose-response relation between plasma glucose and insulin secretion. Am J Physiol. 1989;257(1 Pt 1):E43–8. https://doi.org/10.1152/ajpendo.1989.257.1.E43.
99. Yanagibori R, Kondo K, Suzuki Y, Kawakubo K, Iwamoto T, Itakura H, et al. Effect of 20 days' bed rest on the reverse cholesterol transport system in healthy young subjects. J Intern Med. 1998;243(4):307–12. https://doi.org/10.1046/j.1365-2796.1998.00303.x.
100. Chastin SFM, De Craemer M, De Cocker K, Powell L, Van Cauwenberg J, Dall P, et al. How does light-intensity physical activity associate with adult cardiometabolic health and mortality? Systematic review with meta-analysis of experimental and observational studies. Br J Sports Med. 2019;53(6):370–6. https://doi.org/10.1136/bjsports-2017-097563.

101. Saunders TJ, Atkinson HF, Burr J, MacEwen B, Skeaff CM, Peddie MC. The acute metabolic and vascular impact of interrupting prolonged sitting: a systematic review and meta-analysis. Sports Med. 2018;48(10):2347–66. https://doi.org/10.1007/s40279-018-0963-8.
102. Quan M, Xun P, Wu H, Wang J, Cheng W, Cao M, et al. Effects of interrupting prolonged sitting on postprandial glycemia and insulin responses: a network meta-analysis. J Sport Health Sci. 2021;10(4):419–29. https://doi.org/10.1016/j.jshs.2020.12.006.
103. Dempsey PC, Larsen RN, Winkler EAH, Owen N, Kingwell BA, Dunstan DW. Prolonged uninterrupted sitting elevates postprandial hyperglycaemia proportional to degree of insulin resistance. Diabetes Obes Metab. 2018;20(6):1526–30. https://doi.org/10.1111/dom.13254.
104. Loh R, Stamatakis E, Folkerts D, Allgrove JE, Moir HJ. Effects of interrupting prolonged sitting with physical activity breaks on blood glucose, insulin and triacylglycerol measures: a systematic review and meta-analysis. Sports Med. 2020;50(2):295–330. https://doi.org/10.1007/s40279-019-01183-w.
105. Dempsey PC, Larsen RN, Sethi P, Sacre JW, Straznicky NE, Cohen ND, et al. Benefits for type 2 diabetes of interrupting prolonged sitting with brief bouts of light walking or simple resistance activities. Diabetes Care. 2016;39(6):964–72. https://doi.org/10.2337/dc15-2336.
106. Henson J, Edwardson CL, Celis-Morales CA, Davies MJ, Dunstan DW, Esliger DW, et al. Predictors of the acute postprandial response to breaking up prolonged sitting. Med Sci Sports Exerc. 2020;52(6):1385–93. https://doi.org/10.1249/MSS.0000000000002249.
107. Bergouignan A, Latouche C, Heywood S, Grace MS, Reddy-Luthmoodoo M, Natoli AK, et al. Frequent interruptions of sedentary time modulates contraction- and insulin-stimulated glucose uptake pathways in muscle: ancillary analysis from randomized clinical trials. Sci Rep. 2016;6:32044. https://doi.org/10.1038/srep32044.
108. Latouche C, Jowett JB, Carey AL, Bertovic DA, Owen N, Dunstan DW, et al. Effects of breaking up prolonged sitting on skeletal muscle gene expression. J Appl Physiol (1985). 2013;114(4):453–60. https://doi.org/10.1152/japplphysiol.00978.2012.
109. Grace MS, Formosa MF, Bozaoglu K, Bergouignan A, Brozynska M, Carey AL, et al. Acute effects of active breaks during prolonged sitting on subcutaneous adipose tissue gene expression: an ancillary analysis of a randomised controlled trial. Sci Rep. 2019;9(1):3847. https://doi.org/10.1038/s41598-019-40,490-0.
110. De Jong NP, Rynders CA, Goldstrohm DA, Pan Z, Lange AH, Mendez C, et al. Effect of frequent interruptions of sedentary time on nutrient metabolism in sedentary overweight male and female adults. J Appl Physiol (1985). 2019;126(4):984–92. https://doi.org/10.1152/japplphysiol.00632.2018.
111. Kim IY, Park S, Trombold JR, Coyle EF. Effects of moderate- and intermittent low-intensity exercise on postprandial lipemia. Med Sci Sports Exerc. 2014;46(10):1882–90. https://doi.org/10.1249/MSS.0000000000000324.
112. Miyashita M, Edamoto K, Kidokoro T, Yanaoka T, Kashiwabara K, Takahashi M, et al. Interrupting sitting time with regular walks attenuates postprandial triglycerides. Int J Sports Med. 2016;37(2):97–103. https://doi.org/10.1055/s-0035-1,559,791.
113. Morris C, O'Grada CM, Ryan MF, Gibney MJ, Roche HM, Gibney ER, et al. Modulation of the lipidomic profile due to a lipid challenge and fitness level: a postprandial study. Lipids Health Dis. 2015;14:65. https://doi.org/10.1186/s12944-015-0062-x.
114. Grace MS, Dempsey PC, Sethi P, Mundra PA, Mellett NA, Weir JM, et al. Breaking up prolonged sitting alters the postprandial plasma lipidomic profile of adults with type 2 diabetes. J Clin Endocrinol Metab. 2017;102(6):1991–9. https://doi.org/10.1210/jc.2016-3926.
115. Cohen JC, Berger GM. Effects of glucose ingestion on postprandial lipemia and triglyceride clearance in humans. J Lipid Res. 1990;31(4):597–602.
116. Albrink MJ, Fitzgerald JR, Man EB. Reduction of alimentary lipemia by glucose. Metabolism. 1958;7(2):162–71.
117. Bergouignan A, Gozansky WS, Barry DW, Leitner W, MacLean PS, Hill JO, et al. Increasing dietary fat elicits similar changes in fat oxidation and markers of muscle oxidative capacity in

lean and obese humans. PLoS One. 2012;7(1):e30164. https://doi.org/10.1371/journal.pone.0030164.
118. Hitosugi M, Niwa M, Takatsu A. Rheologic changes in venous blood during prolonged sitting. Thromb Res. 2000;100(5):409–12.
119. Larsen RN, Kingwell BA, Sethi P, Cerin E, Owen N, Dunstan DW. Breaking up prolonged sitting reduces resting blood pressure in overweight/obese adults. Nutr Metab Cardiovasc Dis. 2014;24(9):976–82. https://doi.org/10.1016/j.numecd.2014.04.011.
120. Padilla J, Sheldon RD, Sitar DM, Newcomer SC. Impact of acute exposure to increased hydrostatic pressure and reduced shear rate on conduit artery endothelial function: a limb-specific response. Am J Physiol Heart Circ Physiol. 2009;297(3):H1103–8. https://doi.org/10.1152/ajpheart.00167.2009.
121. Restaino RM, Holwerda SW, Credeur DP, Fadel PJ, Padilla J. Impact of prolonged sitting on lower and upper limb micro- and macrovascular dilator function. Exp Physiol. 2015;100(7):829–38. https://doi.org/10.1113/EP085238.
122. Shvartz E, Gaume JG, White RT, Reibold RC. Hemodynamic responses during prolonged sitting. J Appl Physiol. 1983;54(6):1673–80.
123. Thosar SS, Bielko SL, Mather KJ, Johnston JD, Wallace JP. Effect of prolonged sitting and breaks in sitting time on endothelial function. Med Sci Sports Exerc. 2015;47(4):843–9. https://doi.org/10.1249/MSS.0000000000000479.
124. Younger AM, Pettitt RW, Sexton PJ, Maass WJ, Pettitt CD. Acute moderate exercise does not attenuate cardiometabolic function associated with a bout of prolonged sitting. J Sports Sci. 2016;34(7):658–63. https://doi.org/10.1080/02640414.2015.1068435.
125. Ku DN, Giddens DP, Zarins CK, Glagov S. Pulsatile flow and atherosclerosis in the human carotid bifurcation. Positive correlation between plaque location and low oscillating shear stress. Arteriosclerosis. 1985;5(3):293–302.
126. Liepsch D. An introduction to biofluid mechanics—basic models and applications. J Biomech. 2002;35(4):415–35.
127. Dempsey PC, Larsen RN, Dunstan DW, Owen N, Kingwell BA. Sitting less and moving more: implications for hypertension. Hypertension. 2018;72(5):1037–46. https://doi.org/10.1161/HYPERTENSIONAHA.118.11190.
128. Taylor FC, Pinto AJ, Maniar N, Dunstan DW, Green DJ. The acute effects of prolonged uninterrupted sitting on vascular function: a systematic review and meta-analysis. Med Sci Sports Exerc. 2021;54(1):67–76. https://doi.org/10.1249/MSS.0000000000002763.
129. Noddeland H, Ingemansen R, Reed RK, Aukland K. A telemetric technique for studies of venous pressure in the human leg during different positions and activities. Clin Physiol. 1983;3(6):573–6.
130. Noddeland H, Winkel J. Effects of leg activity and ambient barometric pressure on foot swelling and lower-limb skin temperature during 8 h of sitting. Eur J Appl Physiol Occup Physiol. 1988;57(4):409–14.
131. Whipple MO, Masters KS, Huebschmann AG, Scalzo RL, Reusch JE, Bergouignan A, et al. Acute effects of sedentary breaks on vascular health in adults at risk for type 2 diabetes: a systematic review. Vasc Med. 2021;26(4):448–58. https://doi.org/10.1177/1358863X211009307.
132. Zeigler ZS, Mullane SL, Crespo NC, Buman MP, Gaesser GA. Effects of standing and light-intensity activity on ambulatory blood pressure. Med Sci Sports Exerc. 2016;48(2):175–81. https://doi.org/10.1249/MSS.0000000000000754.
133. Scurr JH, Machin SJ, Bailey-King S, Mackie IJ, McDonald S, Smith PD. Frequency and prevention of symptomless deep-vein thrombosis in long-haul flights: a randomised trial. Lancet. 2001;357(9267):1485–9. https://doi.org/10.1016/s0140-6736(00)04645-6.
134. Kesteven P, Robinson B. Incidence of symptomatic thrombosis in a stable population of 650,000: travel and other risk factors. Aviat Space Environ Med. 2002;73(6):593–6.
135. Gallus AS. Travel, venous thromboembolism, and thrombophilia. Semin Thromb Hemost. 2005;31(1):90–6. https://doi.org/10.1055/s-2005-863810.

136. Ferrari E, Chevallier T, Chapelier A, Baudouy M. Travel as a risk factor for venous thromboembolic disease: a case-control study. Chest. 1999;115(2):440–4.
137. West J, Perrin K, Aldington S, Weatherall M, Beasley R. A case-control study of seated immobility at work as a risk factor for venous thromboembolism. J R Soc Med. 2008;101 (5):237–43. https://doi.org/10.1258/jrsm.2008.070366.
138. Healy B, Levin E, Perrin K, Weatherall M, Beasley R. Prolonged work- and computer-related seated immobility and risk of venous thromboembolism. J R Soc Med. 2010;103(11):447–54. https://doi.org/10.1258/jrsm.2010.100155.
139. Aldington S, Pritchard A, Perrin K, James K, Wijesinghe M, Beasley R. Prolonged seated immobility at work is a common risk factor for venous thromboembolism leading to hospital admission. Intern Med J. 2008;38(2):133–5. https://doi.org/10.1111/j.1445-5994.2007.01597.x.
140. Delis KT, Knaggs AL, Sonecha TN, Zervas V, Jenkins MP, Wolfe JH. Lower limb venous haemodynamic impairment on dependency: quantification and implications for the "economy class" position. Thromb Haemost. 2004;91(5):941–50. https://doi.org/10.1267/THRO04050941.
141. Malone PC. Air travel and risk of venous thromboembolism. Passengers should reduce consumption of alcohol on flights. BMJ. 2001;322(7295):1183–4.
142. Hamer JD, Malone PC. Experimental deep venous thrombogenesis by a non-invasive method. Ann R Coll Surg Engl. 1984;66(6):416–9.
143. Moyses C, Cederholm-Williams SA, Michel CC. Haemoconcentration and accumulation of white cells in the feet during venous stasis. Int J Microcirc Clin Exp. 1987;5(4):311–20.
144. El-Sayed MS, Ali N, El-Sayed AZ. Haemorheology in exercise and training. Sports Med. 2005;35(8):649–70.
145. Zderic TW, Hamilton MT. Identification of hemostatic genes expressed in human and rat leg muscles and a novel gene (LPP1/PAP2A) suppressed during prolonged physical inactivity (sitting). Lipids Health Dis. 2012;11:137. https://doi.org/10.1186/1476-511x-11-137.
146. Collins C, Fitzgerald P, Kennedy DM, Corrigan T, Jerrams S, Bouchier-Hayes DJ. The Tromped: a solution for flight-related deep vein thrombosis? Angiology. 2008;59(1):72–6.
147. Lurie F, Kistner RL, Eklof B, Tsukamoto JK. Prevention of air travel-related deep venous thrombosis with mechanical devices: active foot movements produce similar hemodynamic effects. J Vasc Surg. 2006;44(4):889–91. https://doi.org/10.1016/j.jvs.2006.06.019.
148. Hitos K, Cannon M, Cannon S, Garth S, Fletcher JP. Effect of leg exercises on popliteal venous blood flow during prolonged immobility of seated subjects: implications for prevention of travel-related deep vein thrombosis. J Thromb Haemost. 2007;5(9):1890–5.
149. Morishima T, Restaino RM, Walsh LK, Kanaley JA, Fadel PJ, Padilla J. Prolonged sitting-induced leg endothelial dysfunction is prevented by fidgeting. Am J Physiol Heart Circ Physiol. 2016;311(1):H177–82. https://doi.org/10.1152/ajpheart.00297.2016.
150. Howard BJ, Fraser SF, Sethi P, Cerin E, Hamilton MT, Owen N, et al. Impact on hemostatic parameters of interrupting sitting with intermittent activity. Med Sci Sports Exerc. 2013;45 (7):1285–91. https://doi.org/10.1249/MSS.0b013e318285f57e.
151. Meigs JB, Hu FB, Rifai N, Manson JE. Biomarkers of endothelial dysfunction and risk of type 2 diabetes mellitus. JAMA. 2004;291(16):1978–86. https://doi.org/10.1001/jama.291.16.1978.
152. Meigs JB, O'Donnell CJ, Tofler GH, Benjamin EJ, Fox CS, Lipinska I, et al. Hemostatic markers of endothelial dysfunction and risk of incident type 2 diabetes: the Framingham Offspring Study. Diabetes. 2006;55(2):530–7.
153. Thosar SS, Johnson BD, Johnston JD, Wallace JP. Sitting and endothelial dysfunction: The role of shear stress. Med Sci Monit. 2012;18(12):RA173–80.
154. Takahashi M, Miyashita M, Park JH, Sakamoto S, Suzuki K. Effects of breaking sitting by standing and acute exercise on postprandial oxidative stress. Asian J Sports Med. 2015;6(3): e24902. https://doi.org/10.5812/asjsm.24902.

155. Paterson C, Fryer S, Zieff G, Stone K, Credeur DP, Barone Gibbs B, et al. The effects of acute exposure to prolonged sitting, with and without interruption, on vascular function among adults: a meta-analysis. Sports Med. 2020;50(11):1929–42. https://doi.org/10.1007/s40279-020-01325-5.
156. Carter SE, Draijer R, Holder SM, Brown L, Thijssen DHJ, Hopkins ND. Effect of different walking break strategies on superficial femoral artery endothelial function. Physiol Rep. 2019;7(16):e14190. https://doi.org/10.14814/phy2.14190.
157. Carter SE, Gladwell VF. Effect of breaking up sedentary time with callisthenics on endothelial function. J Sports Sci. 2017;35(15):1508–14. https://doi.org/10.1080/02640414.2016.1223331.
158. Caldwell HG, Coombs GB, Rafiei H, Ainslie PN, Little JP. Hourly staircase sprinting exercise "snacks" improve femoral artery shear patterns but not flow-mediated dilation or cerebrovascular regulation: a pilot study. Appl Physiol Nutr Metab. 2021;46(5):521–9.
159. Peddie MC, Kessell C, Bergen T, Gibbons TD, Campbell HA, Cotter JD, et al. The effects of prolonged sitting, prolonged standing, and activity breaks on vascular function, and postprandial glucose and insulin responses: a randomised crossover trial. PLoS One. 2021;16(1): e0244841.
160. Climie RE, Wheeler MJ, Grace M, Lambert E, Cohen N, Owen N, et al. Simple intermittent resistance activity mitigates the detrimental effect of prolonged unbroken sitting on arterial function in overweight and obese adults. J Appl Physiol (1985). 2018;125(6):1787–94. https://doi.org/10.1152/japplphysiol.00544.2018.
161. Taylor FC, Dunstan DW, Homer AR, Dempsey PC, Kingwell BA, Climie RE, et al. Acute effects of interrupting prolonged sitting on vascular function in type 2 diabetes. Am J Physiol Heart Circ Physiol. 2020;320(1):H393–403. https://doi.org/10.1152/ajpheart.00422.2020.
162. Kruse NT, Hughes WE, Benzo RM, Carr LJ, Casey DP. Workplace strategies to prevent sitting-induced endothelial dysfunction. Med Sci Sports Exerc. 2018;50(4):801–8. https://doi.org/10.1249/MSS.0000000000001484.
163. Zheng C, Zhang X, Sheridan S, Ho RS, Sit CH, Huang Y, et al. Effect of sedentary behavior interventions on vascular function in adults: a systematic review and meta-analysis. Scand J Med Sci Sports. 2021;31(7):1395–410. https://doi.org/10.1111/sms.13947.
164. Santos R, Mota J, Okely AD, Pratt M, Moreira C, Coelho-e-Silva MJ, et al. The independent associations of sedentary behaviour and physical activity on cardiorespiratory fitness. Br J Sports Med. 2014;48(20):1508–12. https://doi.org/10.1136/bjsports-2012-091610.
165. Prince SA, Blanchard CM, Grace SL, Reid RD. Objectively-measured sedentary time and its association with markers of cardiometabolic health and fitness among cardiac rehabilitation graduates. Eur J Prev Cardiol. 2016;23(8):818–25. https://doi.org/10.1177/2047487315617101.
166. Kozey Keadle S, Lyden K, Staudenmayer J, Hickey A, Viskochil R, Braun B, et al. The independent and combined effects of exercise training and reducing sedentary behavior on cardiometabolic risk factors. Appl Physoil Nutr Metab. 2014;39(7):770–80. https://doi.org/10.1139/apnm-2013-0379.
167. Olsen RH, Krogh-Madsen R, Thomsen C, Booth FW, Pedersen BK. Metabolic responses to reduced daily steps in healthy nonexercising men. JAMA. 2008;299(11):1261–3. https://doi.org/10.1001/jama.299.11.1259.
168. Kokkinos P, Myers J, Kokkinos JP, Pittaras A, Narayan P, Manolis A, et al. Exercise capacity and mortality in black and white men. Circulation. 2008;117(5):614–22. https://doi.org/10.1161/circulationaha.107.734764.
169. Blair SN, Kohl HW 3rd, Paffenbarger RS Jr, Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality. A prospective study of healthy men and women. JAMA. 1989;262(17):2395–401.
170. Williams MD, Nadler JL. Inflammatory mechanisms of diabetic complications. Curr Diabetes Rep. 2007;7(3):242–8.

171. Tataranni PA, Ortega E. A burning question: does an adipokine-induced activation of the immune system mediate the effect of overnutrition on type 2 diabetes? Diabetes. 2005;54 (4):917–27.
172. Pickup JC, Crook MA. Is type II diabetes mellitus a disease of the innate immune system? Diabetologia. 1998;41(10):1241–8. https://doi.org/10.1007/s001250051058.
173. Allison MA, Jensky NE, Marshall SJ, Bertoni AG, Cushman M. Sedentary behavior and adiposity-associated inflammation: the multi-ethnic study of atherosclerosis. Am J Prev Med. 2012;42(1):8–13. https://doi.org/10.1016/j.amepre.2011.09.023.
174. Falconer CL, Cooper AR, Walhin JP, Thompson D, Page AS, Peters TJ, et al. Sedentary time and markers of inflammation in people with newly diagnosed type 2 diabetes. Nutr Metab Cardiovasc Dis. 2014;24(9):956–62. https://doi.org/10.1016/j.numecd.2014.03.009.
175. Henson J, Yates T, Edwardson CL, Khunti K, Talbot D, Gray LJ, et al. Sedentary time and markers of chronic low-grade inflammation in a high risk population. PLoS One. 2013;8(10): e78350. https://doi.org/10.1371/journal.pone.0078350.
176. Yates T, Khunti K, Wilmot EG, Brady E, Webb D, Srinivasan B, et al. Self-reported sitting time and markers of inflammation, insulin resistance, and adiposity. Am J Prev Med. 2012;42 (1):1–7. https://doi.org/10.1016/j.amepre.2011.09.022.
177. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. Eur Heart J. 2011;32(5):590–7. https://doi.org/10.1093/eurheartj/ehq451.
178. Stamatakis E, Hamer M, Dunstan DW. Screen-based entertainment time, all-cause mortality, and cardiovascular events: population-based study with ongoing mortality and hospital events follow-up. J Am Coll Cardiol. 2011;57(3):292–9. https://doi.org/10.1016/j.jacc.2010.05.065.
179. Loprinzi PD. Leisure-time screen-based sedentary behavior and leukocyte telomere length: implications for a new leisure-time screen-based sedentary behavior mechanism. Mayo Clin Proc. 2015;90(6):786–90. https://doi.org/10.1016/j.mayocp.2015.02.018.
180. Sjogren P, Fisher R, Kallings L, Svenson U, Roos G, Hellenius ML. Stand up for health--avoiding sedentary behaviour might lengthen your telomeres: secondary outcomes from a physical activity RCT in older people. Br J Sports Med. 2014;48(19):1407–9. https://doi.org/10.1136/bjsports-2013-093342.
181. Hamer M, Stamatakis E. The accumulative effects of modifiable risk factors on inflammation and haemostasis. Brain Behav Immun. 2008;22(7):1041–3. https://doi.org/10.1016/j.bbi.2008.03.003.
182. Wijndaele K, Healy GN, Dunstan DW, Barnett AG, Salmon J, Shaw JE, et al. Increased cardiometabolic risk is associated with increased TV viewing time. Med Sci Sports Exerc. 2010;42(8):1511–8. https://doi.org/10.1249/MSS.0b013e3181d322ac.
183. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. JAMA. 2003;289(14):1785–91. https://doi.org/10.1001/jama.289.14.1785.289/14/1785.
184. Ford ES, Kohl HW 3rd, Mokdad AH, Ajani UA. Sedentary behavior, physical activity, and the metabolic syndrome among U.S. adults. Obes Res. 2005;13(3):608–14. https://doi.org/10.1038/oby.2005.65.
185. Must A, Tybor DJ. Physical activity and sedentary behavior: a review of longitudinal studies of weight and adiposity in youth. Int J Obes (Lond). 2005;29(Suppl 2):S84–96.
186. Nelson MC, Casanova MP, Ball JR, Midence RD, Johnson TR, Martin B, et al. Effects of uninterrupted sitting: are there differences across sex in vascular and inflammatory bio-markers? Med Sci Sports Exerc. 2021;53(8S):81. https://doi.org/10.1249/01.mss.0000760060.63336.ad.
187. Chen YC, Betts JA, Walhin JP, Thompson D. Adipose tissue responses to breaking sitting in men and women with central adiposity. Med Sci Sports Exerc. 2018;50(10):2049–57. https://doi.org/10.1249/MSS.0000000000001654.

188. Wennberg P, Boraxbekk CJ, Wheeler M, Howard B, Dempsey PC, Lambert G, et al. Acute effects of breaking up prolonged sitting on fatigue and cognition: a pilot study. BMJ Open. 2016;6(2):e009630. https://doi.org/10.1136/bmjopen-2015-009630.
189. Pinto AJ, Meireles K, Pecanha T, Mazzolani BC, Smaira FI, Rezende D, et al. Acute cardiometabolic effects of brief active breaks in sitting for rheumatoid arthritis patients. Am J Physiol Endocrinol Metab. 2021;321(6):E782–94. https://doi.org/10.1152/ajpendo.00259.2021.
190. Karra E, Batterham RL. The role of gut hormones in the regulation of body weight and energy homeostasis. Molecular and cellular endocrinology. 2010;316(2):120–8. https://doi.org/10.1016/j.mce.2009.06.010.
191. Hussain SS, Bloom SR. The regulation of food intake by the gut-brain axis: implications for obesity. Int J Obes (Lond). 2013;37(5):625–33. https://doi.org/10.1038/ijo.2012.93.
192. Hazell TJ, Islam H, Townsend LK, Schmale MS, Copeland JL. Effects of exercise intensity on plasma concentrations of appetite-regulating hormones: potential mechanisms. Appetite. 2016;98:80–8. https://doi.org/10.1016/j.appet.2015.12.016.
193. Schubert MM, Desbrow B, Sabapathy S, Leveritt M. Acute exercise and subsequent energy intake. A meta-analysis. Appetite. 2013;63:92–104. https://doi.org/10.1016/j.appet.2012.12.010.
194. Chaput JP, Klingenberg L, Astrup A, Sjodin AM. Modern sedentary activities promote overconsumption of food in our current obesogenic environment. Obes Rev. 2011;12(5):e12–20. https://doi.org/10.1111/j.1467-789X.2010.00772.x.
195. Granados K, Stephens BR, Malin SK, Zderic TW, Hamilton MT, Braun B. Appetite regulation in response to sitting and energy imbalance. Appl Physiol Nutr Metab. 2012;37(2):323–33. https://doi.org/10.1139/h2012-002.
196. Stubbs RJ, Hughes DA, Johnstone AM, Horgan GW, King N, Blundell JE. A decrease in physical activity affects appetite, energy, and nutrient balance in lean men feeding ad libitum. Am J Clin Nutr. 2004;79(1):62–9.
197. Bergouignan A, Momken I, Schoeller DA, Normand S, Zahariev A, Lescure B, et al. Regulation of energy balance during long-term physical inactivity induced by bed rest with and without exercise training. J Clin Endocrinol Metab. 2010;95(3):1045–53. https://doi.org/10.1210/jc.2009-1005.
198. Bailey DP, Broom DR, Chrismas BC, Taylor L, Flynn E, Hough J. Breaking up prolonged sitting time with walking does not affect appetite or gut hormone concentrations but does induce an energy deficit and suppresses postprandial glycaemia in sedentary adults. Appl Physiol Nutr Metab. 2016;41(3):324–31. https://doi.org/10.1139/apnm-2015-0462.
199. Holmstrup ME, Fairchild TJ, Keslacy S, Weinstock RS, Kanaley JA. Satiety, but not total PYY, Is increased with continuous and intermittent exercise. Obesity (Silver Spring). 2013;21(10):2014–20. https://doi.org/10.1002/oby.20335.
200. Bergouignan A, Legget KT, De Jong N, Kealey E, Nikolovski J, Groppel JL, et al. Effect of frequent interruptions of prolonged sitting on self-perceived levels of energy, mood, food cravings and cognitive function. Int J Behav Nutr Phys Act. 2016;13(1):113. https://doi.org/10.1186/s12966-016-0437-z.
201. Mete EM, Perry TL, Haszard JJ, Homer AR, Fenemor SP, Rehrer NJ, et al. Interrupting prolonged sitting with regular activity breaks does not acutely influence appetite: a randomised controlled trial. Nutrients. 2018;10(2):125. https://doi.org/10.3390/nu10020125.
202. Dutta N, Koepp GA, Stovitz SD, Levine JA, Pereira MA. Using sit-stand workstations to decrease sedentary time in office workers: a randomized crossover trial. Int J Environ Res Public Health. 2014;11(7):6653–65. https://doi.org/10.3390/ijerph110706653.
203. Hagberg M, Tornqvist EW, Toomingas A. Self-reported reduced productivity due to musculoskeletal symptoms: associations with workplace and individual factors among white-collar computer users. J Occup Rehabil. 2002;12(3):151–62.

204. Wahlstrom J, Hagberg M, Toomingas A, Wigaeus TE. Perceived muscular tension, job strain, physical exposure, and associations with neck pain among VDU users; a prospective cohort study. Occup Environ Med. 2004;61(6):523–8.
205. Rocha LE, Glina DM, Marinho Mde F, Nakasato D. Risk factors for musculoskeletal symptoms among call center operators of a bank in Sao Paulo, Brazil. Ind Health. 2005;43 (4):637–46.
206. Korhonen T, Ketola R, Toivonen R, Luukkonen R, Hakkanen M, Viikari-Juntura E. Work related and individual predictors for incident neck pain among office employees working with video display units. Occup Environ Med. 2003;60(7):475–82.
207. Gerr F, Marcus M, Ensor C, Kleinbaum D, Cohen S, Edwards A, et al. A prospective study of computer users: I. Study design and incidence of musculoskeletal symptoms and disorders. Am J Ind Med. 2002;41(4):221–35.
208. Ekman A, Andersson A, Hagberg M, Hjelm EW. Gender differences in musculoskeletal health of computer and mouse users in the Swedish workforce. Occup Med (Lond). 2000;50 (8):608–13.
209. Al-Eisa E, Egan D, Deluzio K, Wassersug R. Effects of pelvic asymmetry and low back pain on trunk kinematics during sitting: a comparison with standing. Spine. 2006;31(5):E135–E43. https://doi.org/10.1097/01.brs.0000201325.89493.5 f.
210. Braun SI, Kim Y, Jetton AE, Kang M, Morgan DW. Prediction of bone mineral density and content from measures of physical activity and sedentary behavior in younger and older females. Prev Med Rep. 2015;2:300–5. https://doi.org/10.1016/j.pmedr.2015.04.012.
211. Pope MH, Goh KL, Magnusson ML. Spine ergonomics. Annu Rev Biomed Eng. 2002;4:49–68. https://doi.org/10.1146/annurev.bioeng.4.092101.122107.
212. Chen SM, Liu MF, Cook J, Bass S, Lo SK. Sedentary lifestyle as a risk factor for low back pain: a systematic review. Int Arch Occup Environ Health. 2009;82(7):797–806. https://doi.org/10.1007/s00420-009-0410-0.
213. Cote P, van der Velde G, Cassidy JD, Carroll LJ, Hogg-Johnson S, Holm LW, et al. The burden and determinants of neck pain in workers: results of the bone and joint decade 2000–2010 task force on neck pain and its associated disorders. J Manip Physiol Therap. 2009;32(2 Suppl):S70–86. https://doi.org/10.1016/j.jmpt.2008.11.012.
214. Ariens GA, van Mechelen W, Bongers PM, Bouter LM, van der Wal G. Physical risk factors for neck pain. Scand J Work Environ Health. 2000;26(1):7–19.
215. Bakker EW, Verhagen AP, van Trijffel E, Lucas C, Koes BW. Spinal mechanical load as a risk factor for low back pain: a systematic review of prospective cohort studies. Spine. 2009;34(8): E281–93. https://doi.org/10.1097/BRS.0b013e318195b257.
216. Waersted M, Hanvold TN, Veiersted KB. Computer work and musculoskeletal disorders of the neck and upper extremity: a systematic review. BMC Musculoskelet Disord. 2010;11:79. https://doi.org/10.1186/1471-2474-11-79.
217. Janwantanakul P, Sitthipornvorakul E, Paksaichol A. Risk factors for the onset of nonspecific low back pain in office workers: a systematic review of prospective cohort studies. J Manip Physiol Therap. 2012;35(7):568–77. https://doi.org/10.1016/j.jmpt.2012.07.008.
218. da Costa BR, Vieira ER. Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. Am J Ind Med. 2010;53(3):285–323. https://doi.org/10.1002/ajim.20750.
219. Messing K, Stock S, Cote J, Tissot F. Is sitting worse than static standing? How a gender analysis can move us toward understanding determinants and effects of occupational standing and walking. J Occup Environ Hyg. 2015;12(3):D11–7. https://doi.org/10.1080/15459624.2014.987388.
220. Roelofs A, Straker L. The experience of musculoskeletal discomfort amongst bank tellers who just sit, just stand or sit and stand at work. Ergonomics J South Afr. 2002;14(2):11–29.
221. Thorp AA, Kingwell BA, Owen N, Dunstan DW. Breaking up workplace sitting time with intermittent standing bouts improves fatigue and musculoskeletal discomfort in overweight/

obese office workers. Occup Environ Med. 2014;71(11):765–71. https://doi.org/10.1136/oemed-2014-102,348.

222. Coenen P, Parry S, Willenberg L, Shi JW, Romero L, Blackwood DM, et al. Associations of prolonged standing with musculoskeletal symptoms: a systematic review of laboratory studies. Gait Posture. 2017;58:310–8. https://doi.org/10.1016/j.gaitpost.2017.08.024.
223. Coenen P, Willenberg L, Parry S, Shi JW, Romero L, Blackwood DM, et al. Associations of occupational standing with musculoskeletal symptoms: a systematic review with meta-analysis. Br J Sports Med. 2018;52(3):176–83. https://doi.org/10.1136/bjsports-2016-096795.
224. Kowalsky RJ, Perdomo SJ, Taormina JM, Kline CE, Hergenroeder AL, Balzer JR, et al. Effect of Using a Sit-Stand Desk on Ratings of Discomfort, Fatigue, and Sleepiness Across a Simulated Workday in Overweight and Obese Adults. J Phys Act Health. 2018;15(10):788–94. https://doi.org/10.1123/jpah.2017-0639.
225. Benzo RM, Kruse NT, Hughes WE, Casey DP, Carr LJ. Acute effects of interrupting sitting on discomfort and alertness of office workers. J Occup Environ Med. 2018;60(9):804–9. https://doi.org/10.1097/JOM.0000000000001329.
226. Dempsey PC, Dunstan DW, Larsen RN, Lambert GW, Kingwell BA, Owen N. Prolonged uninterrupted sitting increases fatigue in type 2 diabetes. Diabetes Res Clin Pract. 2018;135:128–33. https://doi.org/10.1016/j.diabres.2017.11.001.
227. Chrismas BCR, Taylor L, Cherif A, Sayegh S, Bailey DP. Breaking up prolonged sitting with moderate-intensity walking improves attention and executive function in Qatari females. PLoS One. 2019;14(7):e0219565. https://doi.org/10.1371/journal.pone.0219565.
228. Jensen CS, Hasselbalch SG, Waldemar G, Simonsen AH. Biochemical markers of physical exercise on mild cognitive impairment and dementia: systematic review and perspectives. Front Neurol. 2015;6:187. https://doi.org/10.3389/fneur.2015.00187.
229. Zheng G, Xia R, Zhou W, Tao J, Chen L. Aerobic exercise ameliorates cognitive function in older adults with mild cognitive impairment: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 2016;50(23):1443–50. https://doi.org/10.1136/bjsports-2015-095699.
230. Falck RS, Davis JC, Best JR, Crockett RA, Liu-Ambrose T. Impact of exercise training on physical and cognitive function among older adults: a systematic review and meta-analysis. Neurobiol Aging. 2019;79:119–30. https://doi.org/10.1016/j.neurobiolaging.2019.03.007.
231. Falck RS, Davis JC, Liu-Ambrose T. What is the association between sedentary behaviour and cognitive function? A systematic review. Br J Sports Med. 2017;51(10):800–11. https://doi.org/10.1136/bjsports-2015-095551.
232. Rojer AGM, Ramsey KA, Amaral Gomes ES, D'Andrea L, Chen C, Szoeke C, et al. Objectively assessed physical activity and sedentary behavior and global cognitive function in older adults: a systematic review. Mech Ageing Dev. 2021;198:111524. https://doi.org/10.1016/j.mad.2021.111524.
233. Carter SE, Draijer R, Holder SM, Brown L, Thijssen DHJ, Hopkins ND. Regular walking breaks prevent the decline in cerebral blood flow associated with prolonged sitting. J Appl Physiol (1985). 2018;125(3):790–8. https://doi.org/10.1152/japplphysiol.00310.2018.
234. Wheeler MJ, Dunstan DW, Smith B, Smith KJ, Scheer A, Lewis J, et al. Morning exercise mitigates the impact of prolonged sitting on cerebral blood flow in older adults. J Appl Physiol (1985). 2019;126(4):1049–55. https://doi.org/10.1152/japplphysiol.00001.2019.
235. Yew B, Nation DA. Alzheimer's Disease Neuroimaging I. Cerebrovascular resistance: effects on cognitive decline, cortical atrophy, and progression to dementia. Brain. 2017;140(7):1987–2001. https://doi.org/10.1093/brain/awx112.
236. Wheeler MJ, Dempsey PC, Grace MS, Ellis KA, Gardiner PA, Green DJ, et al. Sedentary behavior as a risk factor for cognitive decline? A focus on the influence of glycemic control in brain health. Alzheimer's Dement (N Y). 2017;3(3):291–300. https://doi.org/10.1016/j.trci.2017.04.001.

237. Panza F, D'Introno A, Colacicco AM, Capurso C, Pichichero G, Capurso SA, et al. Lipid metabolism in cognitive decline and dementia. Brain Res Rev. 2006;51(2):275–92. https://doi.org/10.1016/j.brainresrev.2005.11.007.
238. Ruitenberg A, den Heijer T, Bakker SL, van Swieten JC, Koudstaal PJ, Hofman A, et al. Cerebral hypoperfusion and clinical onset of dementia: the Rotterdam Study. Ann Neurol. 2005;57(6):789–94. https://doi.org/10.1002/ana.20493.
239. Maasakkers CM, Melis RJF, Kessels RPC, Gardiner PA, Olde Rikkert MGM, Thijssen DHJ, et al. The short-term effects of sedentary behaviour on cerebral hemodynamics and cognitive performance in older adults: a cross-over design on the potential impact of mental and/or physical activity. Alzheimer's Res Ther. 2020;12(1):76. https://doi.org/10.1186/s13195-020-00644-z.
240. Bojsen-Moller E, Ekblom MM, Tarassova O, Dunstan DW, Ekblom O. The effect of breaking up prolonged sitting on paired associative stimulation-induced plasticity. Exp Brain Res. 2020;238(11):2497–506. https://doi.org/10.1007/s00221-020-05866-z.
241. Mullane SL, Buman MP, Zeigler ZS, Crespo NC, Gaesser GA. Acute effects on cognitive performance following bouts of standing and light-intensity physical activity in a simulated workplace environment. J Sci Med Sport. 2017;20(5):489–93. https://doi.org/10.1016/j.jsams.2016.09.015.
242. Wheeler MJ, Green DJ, Ellis KA, Cerin E, Heinonen I, Naylor LH, et al. Distinct effects of acute exercise and breaks in sitting on working memory and executive function in older adults: a three-arm, randomised cross-over trial to evaluate the effects of exercise with and without breaks in sitting on cognition. Br J Sports Med. 2020;54(13):776–81. https://doi.org/10.1136/bjsports-2018-100,168.
243. Wanders L, Cuijpers I, Kessels RPC, van de Rest O, Hopman MTE, Thijssen DHJ. Impact of prolonged sitting and physical activity breaks on cognitive performance, perceivable benefits, and cardiometabolic health in overweight/obese adults: The role of meal composition. Clin Nutr. 2021;40(4):2259–69. https://doi.org/10.1016/j.clnu.2020.10.006.
244. Charlett OP, Morari V, Bailey DP. Impaired postprandial glucose and no improvement in other cardiometabolic responses or cognitive function by breaking up sitting with bodyweight resistance exercises: a randomised crossover trial. J Sports Sci. 2021;39(7):792–800. https://doi.org/10.1080/02640414.2020.1847478.
245. Schwartz B, Kapellusch JM, Schrempf A, Probst K, Haller M, Baca A. Effect of alternating postures on cognitive performance for healthy people performing sedentary work. Ergonomics. 2018;61(6):778–95. https://doi.org/10.1080/00140139.2017.1417642.
246. Curran F, Blake C, Cunningham C, Perrotta C, van der Ploeg H, Matthews J, et al. Efficacy, characteristics, behavioural models and behaviour change strategies, of non-workplace interventions specifically targeting sedentary behaviour; a systematic review and meta-analysis of randomised control trials in healthy ambulatory adults. PLoS One. 2021;16(9):e0256828. https://doi.org/10.1371/journal.pone.0256828.
247. Shrestha N, Grgic J, Wiesner G, Parker A, Podnar H, Bennie JA, et al. Effectiveness of interventions for reducing non-occupational sedentary behaviour in adults and older adults: a systematic review and meta-analysis. Br J Sports Med. 2019;53(19):1206–13. https://doi.org/10.1136/bjsports-2017-098270.
248. Peachey MM, Richardson J, Tang AV, Dal-Bello Haas V, Gravesande J. Environmental, behavioural and multicomponent interventions to reduce adults' sitting time: a systematic review and meta-analysis. Br J Sports Med. 2020;54(6):315–25. https://doi.org/10.1136/bjsports-2017-098968.
249. Martin A, Fitzsimons C, Jepson R, Saunders DH, van der Ploeg HP, Teixeira PJ, et al. Interventions with potential to reduce sedentary time in adults: systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1056–63. https://doi.org/10.1136/bjsports-2014-094524.

250. Chu AH, Ng SH, Tan CS, Win AM, Koh D, Muller-Riemenschneider F. A systematic review and meta-analysis of workplace intervention strategies to reduce sedentary time in white-collar workers. Obes Rev. 2016;17(5):467–81. https://doi.org/10.1111/obr.12388.
251. Hadgraft NT, Winkler E, Climie RE, Grace MS, Romero L, Owen N, et al. Effects of sedentary behaviour interventions on biomarkers of cardiometabolic risk in adults: systematic review with meta-analyses. Br J Sports Med. 2021;55(3):144–54. https://doi.org/10.1136/bjsports-2019-101,154.
252. Nieste I, Franssen WMA, Spaas J, Bruckers L, Savelberg H, Eijnde BO. Lifestyle interventions to reduce sedentary behaviour in clinical populations: a systematic review and meta-analysis of different strategies and effects on cardiometabolic health. Prev Med. 2021;148: 106593. https://doi.org/10.1016/j.ypmed.2021.106593.
253. Hamilton MT. The role of skeletal muscle contractile duration throughout the whole day: reducing sedentary time and promoting universal physical activity in all people. J Physiol. 2018;596(8):1331–40. https://doi.org/10.1113/JP273284.
254. Akins JD, Crawford CK, Burton HM, Wolfe AS, Vardarli E, Coyle EF. Inactivity induces resistance to the metabolic benefits following acute exercise. J Appl Physiol (1985). 2019;126 (4):1088–94. https://doi.org/10.1152/japplphysiol.00968.2018.
255. Kim IY, Park S, Chou TH, Trombold JR, Coyle EF. Prolonged sitting negatively affects the postprandial plasma triglyceride-lowering effect of acute exercise. Am J Physiol Endocrinol Metab. 2016;311(5):E891–E8. https://doi.org/10.1152/ajpendo.00287.2016.
256. Hautala A, Martinmaki K, Kiviniemi A, Kinnunen H, Virtanen P, Jaatinen J, et al. Effects of habitual physical activity on response to endurance training. J Sports Sci. 2012;30(6):563–9. https://doi.org/10.1080/02640414.2012.658080.

Chapter 6
Genetics of Sedentariness

Yahua Zi, Hidde P. van der Ploeg, and Eco J. C. de Geus

Abstract This section will review the available literature on the genetics of sedentary behaviour. First, the classical twin design will be outlined, and the extant twin studies will be reviewed that decomposed the variance of sedentary behaviour into genetic and environmental variance. We conclude that sedentary behaviour is partly heritable (~30%) but can also be affected by the environment that is shared between siblings. Second, molecular genetic techniques will be introduced that aim to find the actual genetic variants that affect sedentary behaviour. We review the studies that have already provided a number of genetic markers reliably associated with sedentary behaviour, although substantial heritability is still missing. We end by demonstrating how behavioural and molecular genetic studies contribute to a better understanding of the consequences of sedentary behaviour by providing strong evidence for the causal effects of this behaviour on health outcomes, including obesity.

Y. Zi
School of Health and Exercise, Shanghai University of Sport, Shanghai, China

Department of Biological Psychology, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
e-mail: y.zi@vu.nl

H. P. van der Ploeg
Department of Public and Occupational Health, AmsterdamUMC, Vrije Universiteit, Amsterdam, The Netherlands

Amsterdam Public Health Research Institute, Amsterdam, The Netherlands
e-mail: hp.vanderploeg@amsterdamumc.nl

E. J. C. de Geus (✉)
Department of Biological Psychology, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

Amsterdam Public Health Research Institute, Amsterdam, The Netherlands
e-mail: eco.de.geus@vu.nl

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_6

What Is New?

- Recent studies in twins, some using accelerometers, have further confirmed the significant contribution of genetics to individual differences in sedentary behaviour.
- Genome-wide association studies have identified part of the actual variants involved in sedentary behaviours, with polygenetic risk scores explaining up to 15% of variance in sedentary behaviour.
- Mendelian Randomisation studies leveraging the identified genetic variants have reported a causal role of sedentary behaviours in obesity and cardiovascular disease risk.

6.1 Introduction

Sedentary behaviour has been associated with premature mortality and the development of a range of non-communicable diseases, including cardiovascular disease and type 2 diabetes [1–4]. Sedentary behaviour is defined as behaviour characterised by energy expenditure no more than 1.5 metabolic equivalents in sitting, reclining or lying position during waking time [5]. This is distinctly different from physical inactivity, which is defined as the lack of moderate to vigorous physical activity [6], and is poorly correlated with physical inactivity [7].

Both in light of its high prevalence and its detrimental effects on health, changing sedentary behaviour patterns on a population level is a major public health priority [8]. In order to develop interventions that decrease sedentary time, a better understanding of its underlying determinants is needed. The majority of studies that have been conducted to date have focused on cross-sectional associations [9, 10], and it is usually ignored that even under identical circumstances, some individuals are – due to their genetic material – more likely to pursue a sedentary lifestyle than others. Research on these innate differences is of utmost importance.

6.2 Heritability

Innate individual differences in a trait are suggested if smaller within-family variation is observed compared to the between-family variation. A few studies that were based on nuclear families (e.g. parental, spousal and sibling resemblance) [11–14] and a three-generation study [14] have shown familial aggregation of total sedentary time as objectively measured by accelerometers [11, 12] and subjectively assessed with self-reported computer use [13], television viewing [13, 14] and sitting time [13, 14] by questionnaire, diary and interview. However, this chapter focuses on twin studies to estimate heritability for two reasons: first, when comparing two twins of a pair, in contrast to, for instance, comparing parents and their offspring, generation-specific effects are taken into account. Second, compared to parent-offspring studies, twin studies allow the disentanglement of familial resemblance into genetic ('nature') and shared environmental ('nurture') effects [15]. Furthermore, when the shared environment does not play a large role, genetic effects can be further decomposed into additive and non-additive genetic effects.

Core to establishing the relative contribution of genetic and environmental effects is the comparison of the resemblance of monozygotic (MZ) twin pairs to the resemblance of dizygotic (DZ) twin pairs on a given phenotype (i.e. a trait, behaviour or characteristic). MZ twins originate from the same fertilised egg, meaning that they are (nearly) genetically identical, whereas DZ twins share on average 50% of their segregating additive genetic variation and 25% of their non-additive genetic variation. Environmental effects on the phenotype are expected to be equal for MZ and DZ twins, meaning that if the phenotypic correlation between MZ twins is larger than the correlation between DZ twins, this must be due to genetic influences. Under an additive genetic model, the MZ correlations are twice as large as those of the DZ twins reflecting the 100% versus 50% sharing of genetic variation. If the phenotypic correlation between MZ twins is much larger than twice the DZ correlation, then this points to additional non-additive genetic influences, which are shared to a much larger extend by MZ (100%) than DZ (25%) twins. If, alternatively, the MZ correlation is much less than twice the DZ correlation, this points towards shared environmental influences that make DZ twins more similar to each other than what would be expected based on their genes alone. These could be factors related to growing up in the same family and neighbourhood.

Finally, there is a part of the environment that two twins of a pair do not share and that therefore makes them different from each other. Non-shared environmental influences can be inferred from MZ twin correlations that are smaller than one, as MZ twins share 100% of both their genetic material and (by definition) all of their shared environment. These non-shared environmental influences could be twin-specific peer groups, work or life events. Measurement error would also be estimated as part of these non-shared environmental influences, because this random fluctuation would make twins of a pair more different from each other. A summary of virtually all existing twin studies of the past 50 years yields an average heritability of 49% across a range of human phenotypes, the majority of which are consistent with a simple and parsimonious model where twin resemblance is solely due to additive genetic variation [16].

Figure 6.1 depicts the path diagram of a basic twin model. The rectangles depict the measured phenotypes (in this case sedentary behaviour) of twin 1 and twin 2, respectively. The circles contain the unmeasured, latent factors 'A' (additive genetic effects), D ('non-additive genetic effects, also called dominant'), 'C' (shared, or common, environmental effects) and 'E' (non-shared environmental effects). The latent A-components have a correlation of 1.0 for MZ twins (meaning that they share 100% of their genetic material), whereas the correlation is 0.5 for DZ twins. The latent D-components have a correlation of one for MZ twins, whereas the correlation is 0.25 for DZ twins. By definition, the shared environmental factors have a correlation of 1.0 and the non-shared environmental factors are uncorrelated for

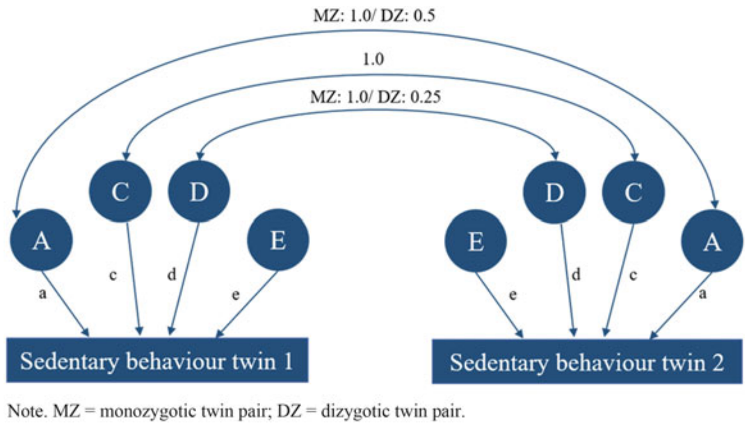

Fig. 6.1 Path diagram of a basic twin model depicting additive genetic factors ('A'), non-additive genetic factors ('D'), shared environmental factors ('C') and non-shared environmental factors ("E")

both types of twins. Based on maximum likelihood estimation, structural equation software aims to find the path coefficients (a, d, c, e) that, given the imposed model, fit the data best. The *absolute* variance that is explained by A, D, C and E, is obtained by squaring the path coefficients (a^2, d^2, c^2, e^2). Their *relative* contribution is obtained by dividing the result by the total variance [e.g. $a^2/(a^2 + d^2 + c^2 + e^2)$]. The relative contribution of the additive genetic factors to the total variance is the narrow-sense heritability. The relative contribution of both additive and non-additive genetic factors together is the broad-sense heritability. The observed variance-covariance matrix does not contain sufficient information to estimate the effect of all four latent factors (A, D, C, E) simultaneously, unless, the phenotype is observed in additional relatives, for example in the parents. In studies with twins only, C and D cannot both be estimated, and a choice is made for either an ACE or ADE model guided by the pattern of MZ and DZ twin correlations.

6.2.1 Heritability of Sedentary Behaviour

Table 6.1 depicts an overview of twin studies on the heritability of sedentary behaviour. The available studies have assessed a wide variation of sedentary behaviour outcomes based on self-report, namely leisure screen time [18, 20], 'passive activities' during leisure time [23], sedentary work [17, 24] and total sitting time [22, 24], whereas two studies have objectively assessed total sedentary time, occupational sedentary time, non-occupational sedentary time with accelerometers [19, 24] or an activity monitor combining heart rate and accelerometer sensors [21]. It is usually tested whether the structural equation model that includes all possible parameters can be reduced to a model that includes fewer parameters

Table 6.1 Overview of twin studies on the heritability of sedentary behaviour under free-living conditions, age > 5 years old, published in English, ordered by publication date

Reference	Sample	Age range (year)	Sedentary behaviour phenotype	Percentage variance in sedentary behaviour explained by A, C and E
Kujala et al. 2002 [17]	The older Finnish twin cohort; $N = 15{,}904$ twins (5663 complete pairs; 49% male)	24–60	Self-reported sedentary work, dichotomised as 'mainly sedentary work, which requires very little physical activity' versus more active categories	A = 50; C = 0; E = 50 (derived from twin correlations, rMZ = 31, rDZ = 52)
Nelson et al. 2006 [18]	USA; National Longitudinal Study of adolescent health (add health); $N = 4782$ siblings that shared households in youth at baseline, 50% male; the sample included 1440 twin pairs of which some live together in adulthood and others live apart	16.5 ± 1.7 22.4 ± 1.8	Leisure screen time based on survey items assessing hours per week watching television/videos and/or playing video/computer games	Adolescence: A = 0; C = 36; E = 60 (derived from twin correlations, rMZ = 32, rDZ = 40) Adulthood: Live together: A = 0; C = 16; E = 84 (derived from twin correlations, rMZ = 16, rDZ = 16) Live apart: (derived from twin correlations, rMZ = 40, rDZ = 9) A = 40; C = 0; E = 60
Fisher et al. 2010 [19]	UK; twins early development study (TEDS); N = 234 twins (117 complete pairs, 46% male)	9–12	Total sedentary time measured with Actigraph accelerometers (<100 counts per minute)	A = 24, C = 37, E = 39
van der Aa et al. 2012 [20]	The Netherlands twin register (NTR); $N = 5090$ twins (2367 complete pairs) and 980 siblings, 44% male)	12–20	Leisure screen time, based on survey items assessing weekly frequency of television viewing, playing electronic games, and personal computer/internet use	Males age 12: A = 35, C = 29, E = 36 Males age 20: A = 48, C = 0, E = 52; Females age 12: A = 19, C = 48, E = 34 Females age 20: A = 34, C = 0, E = 66

(continued)

Table 6.1 (continued)

Reference	Sample	Age range (year)	Sedentary behaviour phenotype	Percentage variance in sedentary behaviour explained by A, C and E
den Hoed et al. 2013 [21]	Twins UK registry; N = 1654 twins (772 complete pairs, 2% male)	17–82	Total sedentary time (≤1.5 metabolic equivalents of task) as derived from a combined heart rate and movement sensor (Actiheart)	Full model: A = 31, C = 15, E = 55
Piirtola et al. 2014 [22]	The older Finnish twin cohort; N = 6713 twins (1940 complete pairs, 46% male)	53–67	Total sitting time, summed over survey items on sitting time (min/d) (1) in office or similar places, (2) at home watching television or videos, (3) at home at the computer, (4) in a vehicle and (5) elsewhere	A = 35, C = 1, E = 64 (derived from twin correlations, rMZ = 36.4, rDZ = 18.8)
Haberstick et al. 2014 [23]	USA; MacArthur longitudinal twin study (MALTS) and the Colorado twin registry (CTR); *N* = 2847 twins (1418 complete pairs); 48% male; mean age ± SD: 15.1 ± 2.2 years	15.1 ± 2.2	Self-reported 'passive activities' during leisure time, consisting of 'total hours watching television – weekday plus weekend', 'sitting around doing nothing' and 'sitting and listening to music'	Males: A = 3, C = 21, E = 76 Females: A = 30, C = 23, E = 46.
Schutte et al., 2020 [24]	The Netherlands twin register; *N* = 800, 73.9% female)	32.63 ± 8	Total, occupational and non-occupational sedentary time derived from both self-reported sitting time using IPAQ-SF and Actigraph accelerometer (<100 counts/min) during waking hours for 7 consecutive days, except during water-based activities	Objective sedentary time: A = 56, C = 0, E = 44 Self-reported sitting time: A = 26, C = 0, E = 74 Objective occupational sedentary time: A = 45, C = 0, E = 55 Objective non-occupational sedentary time: A = 28, C = 0, E = 72

Note. A = additive genetic effects; C = shared environmental effects; E = non-shared environmental effects; rMZ = monozygotic twin correlation; rDZ = dizygotic twin correlation without a significant deterioration of the model fit. If available, both results of the full model and the results of the best-fitting model are reported. Two studies [17, 22] relied on manual calculations of variance components based on the MZ and DZ twin correlations

The large diversity of studies makes it difficult to draw overall conclusions. Based on the available evidence, it seems that up till adolescence, both shared environmental and genetic factors play a role. For instance, Nelson and colleagues [18] reported twin correlations on leisure screen time for adolescent pairs living together, as well as for young adult pairs that kept living together and pairs that separated. In general, they find higher congruence between MZ and DZ twins that are living together, favouring the environment as the source of twin resemblance, whereas the MZ correlations are higher than the DZ correlations when they are living apart, showing an additional genetic cause of twin resemblance. Across all studies, the relative role of the shared environment decreases from childhood to adulthood, whereas heritability remains fairly stable. The larger contribution of the shared environment in childhood may be due to parental influences, the availability of screen-viewing opportunities at home and/or the influence of the school environment. In adults, the determinants of sedentary behaviour during leisure time, a time of free behavioural choices, are likely different from those of sedentary behaviour at work, a time governed by type of job and job-specific tasks.

The estimates in Table 6.1 differ rather widely, and it is unclear whether this is due to age differences or due to the large variety of sedentary behaviour measures. In the current literature, including twin studies, sedentary behaviour is sometimes mistaken for inactivity, which is a distinct behaviour, and both behaviours should be studied adjacent to each other or separately. More high-quality data are needed from large twin cohorts with objective as well as domain-specific self-report measurements of sedentary behaviour that allow the analysis of sex- and age-specific effects. Apart from studying the heritability of different types of sedentary behaviour, we also need to understand the distinctiveness and overlap between the variance components that affect these different types. Once we have a clearer picture of the relative contribution of genes and the environment to individual differences in sedentary behaviour, we need to focus on the underlying mechanisms.

6.3 Genetic Variants Influencing Sedentary Behaviour

Heritability of complex behavioural phenotypes derives from the summed effects of allelic variants at hundreds or thousands of loci. In the past two decades, mapping of the human genome and rapid technological advances have made it feasible to identify these specific variants. Once that specific genetic variants for sedentary behaviour are found, it becomes feasible to identify their function and to understand how they could affect sedentariness [25]. This would be helpful to delineate the biological pathways contributing to individual differences in sedentary behaviour.

There are two main approaches to study the effects of allelic variation on a phenotype such as sedentary behaviour: *linkage studies* and *association studies*. Linkage studies are used to identify a given genetic variant (a marker) by usage of observations of related individuals. If individuals share a greater proportion of alleles identical by descent (IBD) on the marker and they are also more similar to each other on a given phenotype, it is concluded that there is linkage between the marker and the phenotype. Nevertheless, the main limitation of linkage studies is that they do not identify actual DNA variation related to a phenotype, and subsequent fine mapping by association testing is needed to identify the allelic variants causing the linkage signal. Association studies compare variation in a phenotype across groups of people with different combinations of alleles in *specific* genetic variants. The variants to be tested are either selected based on a priori hypotheses (candidate gene study), or hundreds of thousands of variants are tested simultaneously without any hypotheses (genome-wide association study).

Table 6.2 depicts an overview of gene finding studies for sedentary behaviour. Three studies were based on a combined measure of sedentary behaviour and physical inactivity as assessed from a three-day activity diary in French Canadian parents and their offspring from the Québec Family Study [26–28]. Simonen and colleagues first did a linkage analysis [26] and next [27] investigated a polymorphism in the *DRD2 (dopamine receptor D2)*gene ($n = 712$) and found no association with the phenotype. Based on the same study, Loos and colleagues [28] investigated nine polymorphisms in seven genes coding for neuropeptides and receptors of the arcuate and paraventricular nucleus of the hypothalamus and molecules in downstream pathways ($n = 669$) and found an association with between physical inactivity score (inactivity represented by the sum of activities from class 1 to 4 out of nine-class activity category) and a variant of the *MC4R (melanocortin 4 receptor)* gene, which has previously been related to feeding behaviour and energy homeostasis. However, they did not correct for multiple testing. In general, stringent alpha levels and replication are of outmost importance with this kind of studies as significant associations are often found by mere chance or due to confounding [32]. The candidate gene study on sedentary behaviour best addressing this concern was that of Klimentidis and colleagues [29]. They found a significant association between a variant in the *FTO (fat mass and obesity associated)* gene and self-reported time spent sitting (number of hours a day) in participants of the Framingham Heart Study (FHS, $n = 7318$, mean age 45 years, 48% males), but only a trend was found in their replication sample that was derived from the Women's Health Initiative (WHI, $n = 4756$, mean age 61 years, females only). The *FTO* gene has been frequently related to body-mass index in previous research.

The current state-of-the-art gene findings are genome-wide association studies (GWAS) that allow a hypothesis-free, exploratory approach to the detection of relevant DNA markers as hundreds of thousands of variants covering most of the common genetic variation across the genome are tested simultaneously [33]. The main challenge of a GWAS is that very small *p*-values (e.g. $\alpha = 5 \times 10^{-8}$) need to be handled to correct for multiple testing. Most behavioural phenotypes, including sedentary behaviour, are thought to be influenced by many genetic variants with

Table 6.2 Overview of molecular genetics studies on the heritability of sedentary behaviour under free-living conditions, age > 5 years old, published in English, ordered by publication date

References	Sample	Country	Genetic marker	Locus	Sedentary behaviour phenotype	p	Heritability (%)
Simonen et al., 2003 [26]	The Québec family study; $N = 767$ subjects (offspring aged 30.0 ± 9.3 years and parents aged 53.9 ± 7.5 years) from 207 nuclear families	Canada	D2S2347	2p22-p16	Inactivity phenotype derived from 3-day activity diary (category number ranged from 1 to 9, inactivity derived from 1 to 4) and a PA questionnaire during the last year	$p < 0.0012$	
			D2S2305	7p11.2		$p < 0.0019$	
			IGFBP1	20q13.1		$p < 0.0046$	
			PLC1	4q28-q31		$p < 0.0074$	
Simonen et al., 2003 [27]	The Quebec family study (QFS), $N = 721$ participants from 161 family	Canada	DRD2		Inactivity phenotype derived from 3-day activity diary (category number ranged from 1 to 9, inactivity derived from 1 to 4) and a PA questionnaire during the last year	QFS Men: $p = 0.903$, women: $p = 0.754$	
Loos et al., 2005 [28]	The Québec family study; $N = 669$ subjects (parents aged 52 ± 3.4 years, offspring aged 28 ± 8.7 years) from 200 families	Canada	MC4R	C-2745 T	Inactivity phenotype derived from 3-day activity diary, including one weekend day (category number ranged from 1 to 9, inactivity derived from class 1 to 4) and a PA questionnaire during the last year	$p = 0.01$	
Klimentidis et al., 2016 [29]	The Framingham heart study (FHS); $N = 7318$ (3430 offspring and 3888 third generation), aged 45.4 ± 10.9 years The Women's health initiative (WHI); N = 4756, aged 61.0 ± 7 years	USA	FTO	rs9939609	Time spent sitting (TSS) derived from a single-item question 'number of hours typically sitting in a typical day?' In FHS and 'during a usual day and night, about how many hours do you spend sitting? Include the time	FHS: $p = 9.9 \times 10^{-4}$ WHI: $p = 0.08$	

(continued)

Table 6.2 (continued)

References	Sample	Country	Genetic marker	Locus	Sedentary behaviour phenotype	p	Heritability (%)
					you spend sitting at work, sitting at the table eating, driving or riding in a car or bus, and sitting up watching TV or talking.' In WHI. TSS was recorded as one of eight categories (from <4 h to >16 h, with the rest in 1-hour increments) in WHI		
Doherty et al., 2018 [30]	The UK biobank; N = 91,105 individuals; age range 18–91 years	UK	MEF2C-AS2	rs26579	Total sedentary time (MET ≤1.5) derived from 7-day wrist-worn accelerometer and wearable cameras to create a reference set of labels for sedentary time	$p = 2.6 \times 10^{-9}$	Males: A = 15; Females: A = 18
			EFNA5	rs25981		$p = 3.0 \times 10^{-9}$	
			LOC105377146	rs1858242		$p = 3.1 \times 10^{-9}$	
			CALN1	rs34858520		$p = 4.2 \times 10^{-9}$	
Vegte et al., 2020 [31]	The UK biobank; $N = 408{,}815$ (57.4 ± 8.0 years), ranging 40 to 69 years, 45.7% male	UK	Genome-wide scan	145 loci	Leisure television watching time derived from a single-item question 'in a typical DAY, how many hours do you spend watching TV'?	$p = 0.5 \times 10^{-8}$	A = 16.1
				36 loci	Leisure computer use derived from a single-item question 'in a typical DAY, how many hours do you spend using the computer? (do not include using a computer at work)'	$p = 0.5 \times 10^{-8}$	A = 9.3
				4 loci	Driving time derived from a single-item question 'in a typical DAY, how many hours do you spend driving'?	$p = 0.5 \times 10^{-8}$	A = 4.4

very small effects. This means that to identify associations, very large samples are needed that have collected and genotyped DNA data of hundreds of thousands of individuals, in parallel to taking measures of sedentary behaviour. For any single research group, this is still an expensive undertaking, and furthermore, any significant effects need to be confirmed in independent samples to make sure that they do not represent chance findings. Therefore, large-scale projects have been started like the UK Biobank [30, 31] and the Kadoorie Biobank [34, 35] that collect data in over half a million individuals.

Vegte and colleagues assessed self-reported leisure television watching, leisure computer use and driving behaviour in the UK Biobank and identified 145, 36 and 4 genetic loci associated with these traits, respectively, at genome-wide significance ($P < 1 \times 10^{-8}$), that is, taking the risk for false positives in the millions of genetic tests done into account [31]. The amount of heritability that could be explained by all of the single nucleotide polymorphisms (SNPs) tested was highest for television watching (SNP-$h^2 = 16\%$), followed by leisure computer use (SNP-$h^2 = 9\%$) and car driving (SNP-$h^2 = 4.4\%$). In addition, Doherty et al. [30] reported objectively measured sedentary behaviour by seven-day wrist-worn accelerometer and wearable cameras to create a reference set of labels for sedentary time in 91,105 UK Biobank participants. The heritability of sedentary behaviour was estimated to be 18% and 15% for women and men, respectively, and four novel genetic loci were identified to be associated with sedentary time ($P < 1 \times 10^{-9}$) [30]. Compared to heritability estimates from twin studies, this suggests that a large part of the genetic variants still remain to be detected in future GWAS. Pathway analyses and tissue enrichment on the genes implied by the detected genetic variants implicated the nervous system as the most important source of the genetic effects on sedentary time. Of note, the three genes previously implicated by candidate gene studies (*FTO*, *DRD2* and *MC4R*) were not replicated by this GWAS.

In addition to large initiatives like the UK Biobank, existing long-running cohort studies have created collaborative consortia that pool their data in meta-analysis, such as the **G**enome **W**ide **A**ssociation on **P**hysical **A**ctivity (**GWAPA**) consortium [36]. The GWAPA consortium has recently pooled the UK Biobank data with data of over more than 50 studies that had measured both genome-wide DNA and self-reported sedentary behaviours (leisure screen time, sitting at work, sedentary commuting) to perform a multi-ancestry meta-analysis of GWAS in 703,901 individuals. A total of 104 independent SNPs in 99 loci were detected that influenced leisure screen time. Of these, 42 new loci were not previously reported in the earlier UK Biobank study [31]. Individuals at the highest decile of the polygenetic risk score for leisure screen time were also 26% less likely to spend more than 20 minutes per week on moderate-to-vigorous physical activity in a separate cohort than individuals at the fifth decile (mean). This suggests that the genetic variants for sedentary behaviour and physical activity in part overlap. Only four (previously found) variants achieved genome-wide significance for sitting at work and none for sedentary commuting. This could point to a lower heritability of these potentially more task and environmentally determined sedentary behaviours but alternatively reflect a larger imprecision in subjective recall, compared to leisure screen time.

6.4 Health Effects of Sedentary Behaviour: Causality or Genetic Pleiotropy?

The main reasons for the current interest in sedentary behaviour are well documented detrimental health effects of too much sitting. Genetically informative studies can contribute to a better understanding of these as they can explicitly test the hypothesis of causality between two phenotypes. What is often interpreted as a negative causal effect of sedentary behaviour on health might partly be explained by underlying factors that influence both phenotypes in the absence of causality.

6.4.1 Causal Hypothesis Testing in Twins

Causality can be supported (but not proven) or falsified by using (1) bivariate twin models that decompose genetic and environmental effects on the covariance between two phenotypes [37, 38] and (2) the MZ twin intra-pair differences design [37]. The rationale behind causality testing based on bivariate genetic models is that if sedentary behaviour causally influences a health outcome, then everything that influences sedentary behaviour will also, through the causal chain, influence the health outcome (if 1 causes 2, and 2 causes 3, then 1 causes 3). Let us assume that sedentary behaviour is affected by genetic effects (A), shared environmental effects (C) and non-shared environmental effects (E). Under the hypothesis of causality, the effects of A, C and E on sedentary behaviour also need to affect the health outcome. This can be tested by calculating the genetic and environmental cross-trait correlations between sedentary behaviour and the health outcome in a bivariate twin model. Figure 6.2 depicts the path diagram of such a model [39]. As before, the measured phenotypes are depicted in rectangles, whereas the unmeasured latent factors are depicted in circles. The genetic, shared environmental and non-shared environmental (co-)variances are decomposed into (1) effects on sedentary behaviour (a11, c11, e11), (2) effects on the health outcome that are not shared with sedentary behaviour

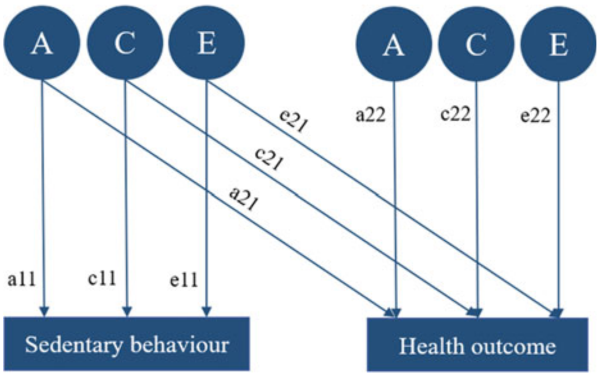

Fig. 6.2 Path diagram of a bivariate twin model with only one of the twins depicted, for clarity. Failure of tests of significance for e21 > 0, c21 > 0, and a21 > 0 falsify the causal effect of sedentary behaviour

(a22, c22, e22) and (3) effects that overlap between the two phenotypes (a21, c21, e21). According to the rationale that was outlined before, a21, c21 and e21 – given sufficient power – all need to be significantly different from zero. If, for instance, only a21 was significantly different from zero and c21 and e21 were not, this would point towards underlying genetic effects that affect both phenotypes (‘genetic pleiotropy’) in the absence of causality. The power of this test can be increased by using repeated measures or multiple indicators of sedentary behaviour and the health outcome.

The MZ twin intra-pair differences design is based on the assumption that if there is a negative causal association between sedentary behaviour and a health outcome, the twin who is more sedentary should have a worse health compared to the genetically identical co-twin who is less sedentary. As MZ twins are perfectly matched for age, genetic background and for their shared environment, no difference in the health outcome would imply that some of these underlying factors explain the association that is only found on a population level. If the negative causal association between sedentary behaviour and a health outcome is observed when regressing the MZ twin intra-pair differences for these traits, then this increases our confidence in the causal hypothesis, as genetic background and shared childhood and adolescent environment are now accounted for.

The outlined designs have been frequently applied to regular exercise behaviour, particularly in connection to its effects on mental health [40]. Unfortunately, applications to sedentary behaviour are scarce. Kujala and colleagues [17] investigated the effect of persistent discordance in sedentary work on mortality in both adult MZ and DZ twins. Sedentary workers had a lower mortality risk than non-sedentary workers. However, the effect was attenuated when controlling for income level, education, smoking, heavy use of alcohol and participation in vigorous leisure physical activity. There was no difference between MZ and DZ twins, supporting a causal association between sedentary work and mortality. The National Aeronautics and Space Administration (NASA) Johnson Space Center conducted two 30-day bed rest studies with MZ twins, where one of the pairs served as sedentary control and the other performed exercises to counteract bed rest-induced bone loss [41, 42]. They concluded that the exercises counteracted bone resorption, especially in men. These kinds of interventions offer stronger support for causality than experiments with non-twin individuals as treatment effects are less confounded due to better matching of experimental and control group. However, bed rest is an extreme form of sedentary behaviour that rarely occurs in daily life, especially not for prolonged periods of time. Studies on sedentary phenotypes more relevant to daily life that employ the power of causality testing based on twin data are called for.

6.4.2 *Causal Hypothesis Testing Using Mendelian Randomisation*

The test of causality based on bivariate genetic twin models that was outlined before can also be performed with measured genetic variants instead of latent genetic variance components, using a technique called Mendelian randomisation (MR). MR is a method that uses genetic variants that are strongly associated with modifiable exposures to detect causal effects and provide an unbiased estimation of their magnitude [43]. An easy way to understand MR is by analogy with randomised controlled trials (RCTs). In an RCT, the participants are randomly allocated to one treatment or control group (without any intervention/treatment), avoiding potential confounding effects between treatment and outcome, and causal inference is unambiguous. In MR, study participants are similarly randomised to the possession of alleles that are known to increase the risk for exposure, in our case sedentary behaviour. No active dice throwing on the part of the experimenter is needed, however, because during meiosis participants get random combinations of their parental genotypes. If a particular allele is sufficiently strongly related to the exposure (here sedentary behaviour) and the exposure truly causes the outcome, then the alleles influencing the exposure should be significant predictors of the outcome also. As in any statistical method, a number of assumptions need to be met, and meta-analysis across multiple SNPs as well as triangulation across a large number of sensitivity analyses is now common practice in MR [44].

Vegte and colleagues applied MR to the 185 loci detected for self-reported leisure television watching, leisure computer use and car driving behaviour in the UK Biobank [31]. They found high correlations between the genetic variants influencing these sedentary behaviours and health outcomes [31]. A causal effect between television watching and coronary artery disease (CAD; OR = 1.44, $P = 5.63 \times 10^{-7}$) was estimated with MR analysis, as well as between driving and CAD (OR 2.65, $P = 4.46 \times 10^{-3}$). However, this was not true for leisure computer use (OR 0.81, $P = 0.07$). Whereas the relationship between driving and CAD was not consistent across sensitivity analyses, television watching remained significantly associated with CAD.

The causal effect of sedentary behaviour on body mass index (BMI) shown by Vegte et al. [31] was recently replicated and extended by the study of the GWAPA consortium (personal communication, den Hoed). Using genetic variants for both sedentary time and BMI in bidirectional MR, they fully confirmed the causal effects of sedentary time on BMI but also showed a reverse effect of BMI on sedentary time. The effect size of sedentary time on BMI, however, was three times as large as the reverse causal effect of BMI on sedentary time. Also, this effect survived correction for potential confounding by educational attainment, which is known to be associated with high BMI and sedentary time. Taken together, these MR studies provide a strong rationale for interventions targeting sedentary time to reduce obesity and coronary artery disease risk.

6.5 Summary

Although genetic epidemiology has tackled many behavioural and health phenotypes [16], sedentary behaviour, a relative 'newcomer', has not been widely studied. The available evidence from family and twin studies does suggest, based on both subjective and device-based data, that sedentary behaviour is partly heritable across the life span (~30%), and the first genetic markers have been associated with this phenotype through the GWAS approach. The environment that is shared between siblings plays an important role in childhood and adolescence, but its influence seems to wane in adulthood. In the present chapter, we have outlined genetically informative designs that could be applied to test the causal effects of sedentary behaviour on health outcomes. Bigger twin- and family-based datasets that use better measurement instruments for sedentary behaviour, as well as enrichment of existing cohorts that already have good sedentary behaviour measures with molecular genetic marker data will further help to advance this field of research.

References

1. de Rezende LFM, Rodrigues Lopes M, Rey-López JP, Matsudo VKR, Luiz OC. Sedentary behavior and health outcomes: an overview of systematic reviews. PLoS One. 2014;9(8):e105620.
2. Patterson R, McNamara E, Tainio M, de Sá TH, Smith AD, Sharp SJ, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. Eur J Epidemiol. 2018;33(9):811–29.
3. Ekelund U, Brown WJ, Steene-Johannessen J, Fagerland MW, Owen N, Powell KE, et al. Do the associations of sedentary behaviour with cardiovascular disease mortality and cancer mortality differ by physical activity level? A systematic review and harmonised meta-analysis of data from 850 060 participants. Br J Sports Med. 2019;53(14):886.
4. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54(24):1451.
5. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary behavior research network (SBRN) - terminology consensus project process and outcome. Int J Behav Nutr Phys Act. 2017;14(1):75.
6. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U. Global physical activity levels: surveillance progress, pitfalls, and prospects. Lancet. 2012;380(9838):247–57.
7. van der Ploeg HP, Hillsdon M. Is sedentary behaviour just physical inactivity by another name? Int J Behav Nutr Phys Act. 2017;14(1):142.
8. Dempsey PC, Biddle SJH, Buman MP, Chastin S, Ekelund U, Friedenreich CM, et al. New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. Int J Behav Nutr Phys Act. 2020;17(1):151.
9. Rhodes RE, Mark RS, Temmel CP. Adult sedentary behavior: a systematic review. Am J Prev Med. 2012;42(3):e3–e28.
10. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. Am J Prev Med. 2011;41(2):189–96.

11. Cai G, Cole SA, Butte N, Bacino C, Diego V, Tan K, et al. A quantitative trait locus on chromosome 18q for physical activity and dietary intake in Hispanic children. Obesity (Silver Spring). 2006;14(9):1596–604.
12. Butte NF, Cai G, Cole SA, Comuzzie AG. Viva la Familia study: genetic and environmental contributions to childhood obesity and its comorbidities in the Hispanic population. Am J Clin Nutr. 2006;84(3):646–54.
13. Santos DM, Katzmarzyk PT, Diego VP, Blangero J, Souza MC, Freitas DL, et al. Genotype by sex and genotype by age interactions with sedentary behavior: the Portuguese Healthy Family Study. PLoS One. 2014;9(10):e110025.
14. Diego VP, de Chaves RN, Blangero J, de Souza MC, Santos D, Gomes TN, et al. Sex-specific genetic effects in physical activity: results from a quantitative genetic analysis. BMC Med Genet. 2015;16:58.
15. Falconer DS, Mackay TFC. Introduction to quantitative genetics. 4th ed. Essex, UK: Pearson Education; 1996. p. 280.
16. Polderman TJ, Benyamin B, de Leeuw CA, Sullivan PF, van Bochoven A, Visscher PM, et al. Meta-analysis of the heritability of human traits based on fifty years of twin studies. Nat Genet. 2015;47(7):702–9.
17. Kujala UM, Kaprio J, Koskenvuo M. Modifiable risk factors as predictors of all-cause mortality: the roles of genetics and childhood environment. Am J Epidemiol. 2002;156(11):985–93.
18. Nelson MC, Gordon-Larsen P, North KE, Adair LS. Body mass index gain, fast food, and physical activity: effects of shared environments over time. Obesity (Silver Spring). 2006;14(4):701–9.
19. Fisher A, van Jaarsveld CH, Llewellyn CH, Wardle J. Environmental influences on children's physical activity: quantitative estimates using a twin design. PLoS One. 2010;5(4):e10110.
20. van der Aa N, Bartels M, te Velde SJ, Boomsma DI, de Geus EJ, Brug J. Genetic and environmental influences on individual differences in sedentary behavior during adolescence: a twin-family study. Arch Pediatr Adolesc Med. 2012;166(6):509–14.
21. den Hoed M, Brage S, Zhao JH, Westgate K, Nessa A, Ekelund U, et al. Heritability of objectively assessed daily physical activity and sedentary behavior. Am J Clin Nutr. 2013;98(5):1317–25.
22. Piirtola M, Kaprio J, Ropponen A. A study of sedentary behaviour in the older Finnish twin cohort: a cross sectional analysis. Biomed Res Int. 2014;2014:2019140.
23. Haberstick BC, Zeiger JS, Corley RP. Genetic and environmental influences on the allocation of adolescent leisure time activities. Biomed Res Int. 2014;2014:805476.
24. Schutte NM, Huppertz C, Doornweerd S, Bartels M, de Geus EJC, van der Ploeg HP. Heritability of objectively assessed and self-reported sedentary behavior. Scand J Med Sci Sports. 2020;30(7):1237–47.
25. van Dongen J, Slagboom PE, Draisma HHM, Martin NG, Boomsma DI. The continuing value of twin studies in the omics era. Nat Rev Genet. 2012;13(9):640–53.
26. Simonen RL, Rankinen T, Perusse L, Rice T, Rao DC, Chagnon Y, et al. Genome-wide linkage scan for physical activity levels in the Quebec family study. Med Sci Sports Exerc. 2003;35(8):1355–9.
27. Simonen RL, Rankinen T, Pérusse L, Leon AS, Skinner JS, Wilmore JH, et al. A dopamine D2 receptor gene polymorphism and physical activity in two family studies. Physiol Behav. 2003;78(4):751–7.
28. Loos RJ, Rankinen T, Tremblay A, Perusse L, Chagnon Y, Bouchard C. Melanocortin-4 receptor gene and physical activity in the Quebec Family Study. Int J Obes. 2005;29(4):420–8.
29. Klimentidis YC, Arora A, Chougule A, Zhou J, Raichlen DA. FTO association and interaction with time spent sitting. Int J Obes. 2016;40(3):411–6.
30. Doherty A, Smith-Byrne K, Ferreira T, Holmes MV, Holmes C, Pulit SL, et al. GWAS identifies 14 loci for device-measured physical activity and sleep duration. Nat Commun. 2018;9(1):5257.

31. van de Vegte YJ, Said MA, Rienstra M, van der Harst P, Verweij N. Genome-wide association studies and Mendelian randomization analyses for leisure sedentary behaviours. Nat Commun. 2020;11(1):1770.
32. Tabor HK, Risch NJ, Myers RM. Candidate-gene approaches for studying complex genetic traits: practical considerations. Nat Rev Genet. 2002;3(5):391–7.
33. Pearson TA, Manolio TA. How to interpret a genome-wide association study. JAMA. 2008;299 (11):1335–44.
34. Chen Z, Chen J, Collins R, Guo Y, Peto R, Wu F, et al. China Kadoorie biobank of 0.5 million people: survey methods, baseline characteristics and long-term follow-up. Int J Epidemiol. 2011;40(6):1652–66.
35. Li X, Zhou T, Ma H, Liang Z, Fonseca VA, Qi L. Replacement of sedentary behavior by various daily-life physical activities and structured exercises: genetic risk and incident type 2 diabetes. Diabetes Care. 2021;44(10):2403–10.
36. Wang Z, Emmerich A, Pillon NJ, Moore T, Hemerich D, Cornelis MC, et al. Genome-wide association analyses of physical activity and sedentary behavior provide insights into underlying mechanisms and roles in disease prevention. Nat Genet. 2022.;in press;54:1332.
37. De Moor MH, Boomsma DI, Stubbe JH, Willemsen G, de Geus EJ. Testing causality in the association between regular exercise and symptoms of anxiety and depression. Arch Gen Psychiatry. 2008;65(8):897–905.
38. Huppertz C, Bartels M, Jansen IE, Boomsma DI, Willemsen G, de Moor MH, et al. A twin-sibling study on the relationship between exercise attitudes and exercise behavior. Behav Genet. 2014;44(1):45–55.
39. Neale MC, Boker SM, Xie G, Maes HH. Mx: statistical modeling. 7th ed. Richmond: Department of Psychiatry, Virginia Commonwealth University; 2006.
40. de Geus EJC. A genetic perspective on the association between exercise and mental health in the era of genome-wide association studies. Ment Health Phys Act. 2021;20:1–14.
41. Smith SM, Davis-Street JE, Fesperman JV, Calkins DS, Bawa M, Macias BR, et al. Evaluation of treadmill exercise in a lower body negative pressure chamber as a countermeasure for weightlessness-induced bone loss: a bed rest study with identical twins. J Bone Miner Res. 2003;18(12):2223–30.
42. Zwart SR, Hargens AR, Lee SM, Macias BR, Watenpaugh DE, Tse K, et al. Lower body negative pressure treadmill exercise as a countermeasure for bed rest-induced bone loss in female identical twins. Bone. 2007;40(2):529–37.
43. Davey Smith G, Hemani G. Mendelian randomization: genetic anchors for causal inference in epidemiological studies. Hum Mol Genet. 2014;23(R1):R89–98.
44. Hemani G, Zheng J, Elsworth B, Wade KH, Haberland V, Baird D, et al. The MR-base platform supports systematic causal inference across the human phenome. Elife. 2018;7:7.

Chapter 7
Sedentary Behaviour, Diabetes and the Metabolic Syndrome

Joseph Henson, Charlotte L. Edwardson, Paddy C. Dempsey, Melanie J. Davies, and Thomas Yates

Abstract Given the increasing global prevalence of type 2 diabetes (T2DM) and the metabolic syndrome, prevention and management strategies are of the utmost importance. Lifestyle interventions that target increasing levels of physical activity and reductions in sedentary behaviour have the potential to yield a substantial public health impact and inform future policies on the optimal approaches to reducing prolonged sitting time. This is epitomised by the incorporation of new evidence-based recommendations on sedentary behaviour within the 2020 World Health Organisation guidelines. Since the publication of the 1st edition of 'Sedentary Behaviour Epidemiology', several meta-analyses have highlighted the dose-response relationship between sitting time and the incidence of T2DM. Moreover, epidemiological and experimental data continue to reinforce the message that the intensity of the activity replacing sedentary behaviour may be less important than the decision of whether to be active at all (i.e. 'any movement counts'). Novel analytical approaches have seen a shift away from separate public health guidelines for individual movement behaviours, with an increasing recognition to consider movement behaviours (sleep, sedentary behaviour, light activity and moderate-to-vigorous physical activity) as co-dependent. The co-existence of two global pandemics

J. Henson (✉) · C. L. Edwardson · M. J. Davies · T. Yates
Institute for Physical Activity and Nutrition (IPAN), School of Exercise and Nutrition Sciences, Deakin University, Geelong, Victoria, Australia

Diabetes Research Centre, University of Leicester, Leicester, UK
e-mail: jjh18@leicester.ac.uk; ce95@leicester.ac.uk; melanie.davies@uhl-tr.nhs.uk; ty20@leicester.ac.uk

P. C. Dempsey
MRC Epidemiology Unit, Institute of Metabolic Science, University of Cambridge, Cambridge Biomedical Campus, Cambridge, UK

Diabetes Research Centre, University of Leicester, Leicester, UK

Baker Heart and Diabetes Institute, Melbourne, VIC, Australia

Institute for Physical Activity and Nutrition (IPAN), School of Exercise and Nutrition Sciences, Deakin University, Geelong, Victoria, Australia
e-mail: pcd5@leicester.ac.uk

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_7

(T2DM and COVID-19) has reinforced the notion that reducing sedentary behaviour and maintaining a physically active lifestyle is no longer a hobby of a few, but a necessity for all.

What Is New?

- Nearly half a billion adults worldwide (aged 20–79 years) now have type 2 diabetes mellitus (T2DM).
- Meta-analyses have demonstrated a dose-response relationship between higher levels of total sitting time and TV viewing time with the incidence of T2DM. Compared to other morbidity and mortality outcomes, the results are stronger and most consistent for T2DM.
- Epidemiological and experimental data reinforce the message that the intensity of the activity replacing sedentary behaviour may be less important than the decision of whether to be active at all (i.e. 'any movement counts').
- There is an increasing recognition to consider movement behaviours (sleep, sedentary behaviour, light activity and moderate-to-vigorous physical activity) as co-dependent.
- Predictors of the postprandial response may inform future individualised tailored interventions in high-risk participants, for whom breaking prolonged sitting time could be a viable and effective prevention or treatment strategy.

This chapter will principally focus on the role of sedentary behaviour on type 2 diabetes mellitus (T2DM) and metabolic syndrome and the common mechanism underpinning both conditions. In the first instance, an overview of the prevalence, economic burden and prevention strategies will be discussed. Although the metabolic syndrome includes a clustering of metabolic risk factors (e.g. lipids, hypertension and obesity), the role of sedentary behaviour on these markers is discussed in detail in other chapters. Consideration will also be given to the epidemiological and experimental data and the potential impact of sedentary behaviour on other risk factors associated with T2DM (e.g. physical function). We also discuss the impact of COVID-19 in exacerbating sedentary behaviour in those with T2DM and what effect this potentially has on the risk of adverse COVID-19 outcomes.

7.1 Type 2 Diabetes Mellitus: Prevalence, Economic Burden and Prevention Strategies

In 2019, the global prevalence of T2DM was estimated to be nearly half a billion (463 million), representing 9.3% of the total adult population aged 20–79 years [1]. This figure has increased by 62% compared to 2009 and 9% since the publication of the first edition of 'Sedentary Behaviour Epidemiology' in 2018 [1]. The rising trend can be partly attributed to earlier diagnosis and better management (leading to greater life-expectancy), particularly in younger adults and a rapid increase in urbanisation and obesogenic environments (partly driven by physical inactivity and sedentary behaviour). If this trend continues unabated, the prevalence of T2DM is likely to rise to 700 million by 2045, representing 10.4% of the total adult population aged 20–79 years [1].

Therefore, there is an urgent need to develop and implement coordinated and multi-sectoral strategies to reduce the incidence of T2DM. In response, the World Health Organisation (WHO) and the United Nations have set global targets to encourage action to improve care and reinforce healthcare systems [2, 3]. These actions include reducing premature death from non-communicable diseases (NCDs), including diabetes (30% by 2030), whilst establishing national diabetes plans (see below) and achieving universal health coverage [2, 3]. Similarly, the Lancet commission on diabetes recently provided a blueprint for reducing gaps in diabetes prevention, ongoing care and professional knowledge. In particular, the use of data-driven modelling could avert up to 800,000 premature deaths in the top 10 low- to middle-income countries with the highest populations of people with T2DM [4].

Due to its adverse effect on people's health, T2DM also imposes an extensive economic burden. The most comprehensive analysis to date concludes that the cost of diabetes to the National Health Service (NHS) in the United Kingdom is £9.8bn in direct costs in 2010/11, with £8.8bn for T2DM [5]. Around 80% is spent on complications, with treatment and intervention costs dominated by the costs of primary care and prescriptions. If the costs of treating a patient with T2DM stay the same, the overall costs are set to account for 17% of the entire NHS budget over the next 20 years. From a global perspective, assuming past trends continue, the economic burden of T2DM in 2030 will exceed 2015 levels by 88% [6]. Importantly, even if countries meet the sustainable development goals of decreasing mortality from T2DM by one-third [2], the economic burden in 2030 will still be 61% higher than in 2015 [6].

The evidence base for the prevention of T2DM has developed exponentially over the last two decades, from efficacy trials through to real-world translational studies. As reported in the first edition of 'Sedentary Behaviour Epidemiology', lifestyle interventions that target overall consumption of food and increasing levels of physical activity reduce the risk of T2DM by 30–60% in those with impaired glucose tolerance [7]. Importantly, such programmes have also been shown to still yield benefits well after the cessation of the intervention. For example, 30 year results

(24 years after the intervention ended) from the Da Qing Diabetes Prevention Study (DQDPS) demonstrated that the combined intervention group (diet plus exercise) had a median delay in diabetes onset of ~4 years, fewer cardiovascular disease events, fewer cardiovascular disease and all-cause deaths and an average increase in life expectancy of ~1.5 years, compared to the control group [8]. It is likely that the success of such prevention programmes is largely underpinned by reductions in body weight and increasing levels of physical activity. That said, in some instances, attention must also be given to recommendations for pharmacological therapy or surgery in order to yield long-term societal benefits.

7.1.1 Real-World Example from the United Kingdom

Clinical trials have shown what is possible (efficacy), but not what is feasible or scalable (effectiveness) in a primary care or community setting. In response, 2016 saw the establishment of The Healthier You: NHS Diabetes Prevention Programme (NHS DPP) in England [9]. Universal population coverage now means that >750,000 people have been referred into the programme. The main aim of the NHS DPP is to prevent or delay the onset of T2DM in adults with non-diabetic hyperglycaemia (defined as: HbA_{1c} 42–47 mmol/mol [6·0–6·4%] or impaired fasting glycaemia 5·5–6·9 mmol/L), through a structured lifestyle intervention [10]. Programme content includes weight loss or the maintenance of a healthy weight, achievement of UK dietary recommendations [11] and achievement of the UK physical activity recommendations [12]. Importantly, the latter also includes recommendations to minimise the amount of time spent sedentary, and although there are no specific recommendations for light activity, it is recommended as an option to break up prolonged periods of inactivity/sedentary behaviour [12].

This national programme to provide behavioural support to people with non-diabetic hyperglycaemia in England was modelled on National Institute for Health and Care Excellence (NICE) Public Health Guidance on Type 2 Diabetes: Prevention in People at High Risk (NICE PH38) [13], with the design informed by a Public Health England–commissioned systematic review and meta-analysis assessing the effectiveness of pragmatic lifestyle interventions [14]. This found a reduction of 26% in the incidence of T2DM vs. usual care (over 12–18 months). A more recent global systematic review and network meta-analysis of pragmatic DPP studies also demonstrated a similar relative risk reduction (29%) [15].

Preliminary results from a service evaluation assessing UK DPP effectiveness (using data from the first 2.5 years) demonstrated a significant reduction in weight and HbA_{1c}. There was a clear dose-response relationship, and people who attended more sessions experienced greater reductions. For example, those that completed the programme (attended >60% of the 13 intervention sessions) demonstrated a mean weight loss of 3.3 kg and a HbA_{1c} reduction of 2.04 mmol/mol [16]. These results are comparable to the US DPP, where a mean percentage weight reduction of 4.2% was reported [17] (4% in the UK DPP). The absolute weight differences also broadly mirror those reported in the Finnish DPP (1.3 kg in men and 1.1 kg in women) [18] and the Australian DPP (2.5 kg) [19]. In summary, these results provide optimism that this lifestyle programme may lead to a reduced incidence of T2DM among high-risk participants.

7.2 Metabolic Syndrome: Definition and Prevalence

The metabolic syndrome is considered to be one of the most important risk factors for the epidemic of T2DM [20] and is associated with an approximate fivefold increased risk [21]. Obesity has been recognised as one of the leading causes for the metabolic syndrome since it is strongly associated with all metabolic risk factors [22], but its development can also be accelerated by a sedentary/inactive lifestyle [23]. The reported prevalence varies, depending on the definition used, sex, age, socioeconomic status and the ethnic background of study cohorts. However, it is estimated that approximately one adult in every four or five, depending on the country, has metabolic syndrome [24]. The incidence also increases with age, with estimates suggesting ~30% of the European population over the age of 50 has metabolic syndrome [25].

Although it is unclear whether there is a unifying pathogenic mechanism that could decipher the pathophysiology of the metabolic syndrome, it is highly likely that abdominal obesity and insulin resistance play a central role in promoting the development of the metabolic syndrome [26]. Therefore, as with T2DM, lifestyle modification and weight loss should be considered as primary preventative measures. Although the traditional definitions of the metabolic syndrome and individual outcome measures are still frequently reported in the sedentary behaviour literature, the combination of such components has received added prominence in the form of clustered cardiometabolic risk or continuous cardiometabolic risk scores (discussed in more detail below).

7.3 Epidemiological Evidence

As previously reported in the first edition of ‘Sedentary Behaviour Epidemiology’, multiple meta-analyses have estimated the independent associations of sedentary behaviour on the incidence of chronic disease(s) and markers of health, including those associated with T2DM [27–30]. Despite the increasing prominence of sedentary behaviour in current physical activity recommendations, the message remains generic (‘sit less’) [12, 31], with the exception of American Diabetes Association guidelines [32]. That said, the incorporation of new evidence-based recommendations on sedentary behaviour within the 2020 WHO guidelines [31] still marks an important step forward [33].

In order to inform the evidence surrounding the frequency and/or duration of bouts or breaks in sedentary behaviour (and future guidelines) [33], there is a need to determine whether there is a marked increase in risk of T2DM at specific sedentary thresholds. In 2018, a meta-analysis including >1,000,000 participants and data from 11 prospective studies demonstrated a dose-response relationship between higher levels of total sitting time and TV viewing time with the incidence of T2DM [34]. The results were independent of physical activity and are consistent with previous meta-analyses, where the strongest and most consistent associations are seen for T2DM (when compared to the increased risk for all-cause and cardio-vascular disease (CVD) mortality) [28]. For example, 29% of T2DM incidence was estimated to be related to TV viewing, compared to 5% for cancer and CVD mortality [34]. For all-cause and CVD mortality, a threshold of 6–8 hours per day of total sitting and 3–4 hours per day of TV viewing was identified, above which the risk is increased [34]. However, the larger increases in the risk of T2DM were seen below 4 hours per day. This corroborates previous experimental and epidemiological data suggesting that for T2DM, any reductions in sitting time are likely to be beneficial [35–40].

Similarly, a 2019 dose-response meta-analysis (n = 1,071,967; 13 cohort, 10 cross-sectional) examining the association of total sedentary behaviour and TV viewing time with the risk of T2DM demonstrated a linear association. For each 1-hour day increase in total sedentary time or TV viewing, the risk of T2DM increased by 5% and 8%, respectively [41]. Again, the associations with TV viewing were stronger than those for total sedentary behaviour for all outcomes, which may in part be partly driven by the association with a clustering of unhealthy behaviours (e.g. snacking) [42, 43]. When focusing specifically on sitting (as opposed to TV viewing), Bailey et al. found an increase in CVD (HR = 1.14, 95% CI = 1.04, 1.23, $p < 0.001$)) and diabetes risk (HR = 1.11, 95% CI = 1.01, 1.19, $p < 0.001$), which remained after adjustment for physical activity [44].

At present, there is limited evidence from device-based measures of sedentary behaviour or sitting per se [33]. In order to adequately quantify time spent in sedentary behaviours and their potential influence upon markers of cardiometabolic health, there is a need to develop and incorporate better field-based measurements.

7.3.1 Are the Associations of Sedentary Behaviour Moderated by Fitness?

When examining the relationships between sedentary behaviour and markers of cardio-metabolic health, it is important to consider the mediating role of cardiore-spiratory fitness (CRF), that is, each outcome should not necessarily be considered in isolation. For example, previous studies have shown an inverse association between sedentary time and CRF [45, 46], and mediation analyses have shown that CRF explains 73% of the associations between MVPA and clustered metabolic risk [47].

A cross-sectional analysis in 1933 adults [average age = 57.9 ± 8.1 years, body mass index (BMI) = 26.7 ± 4.3 kg/m^2, CRF = 30.1 ± 6.2 ml·min^{-1}·kg^{-1}, ~40% with impaired glucose regulation and 36% with metabolic syndrome] [48] demonstrated that the highest odds for the metabolic syndrome were seen in the low fitness and high sedentary time group (odds ratio [OR] and 95% confidence interval [CI]: OR 9.22 [CI = 5.74, 14.80]). Interestingly, those with high CRF and high sedentary time also had greater odds for the metabolic syndrome (OR 2.93 [1.72, 4.99]) compared to the reference group (high CRF, low sedentary time). The results for T2DM followed a similar pattern, where the highest ORs were seen in the low CRF and high sedentary time group (OR 8.38 [4.83, 14.55]). Further, people with high CRF and high sedentary time displayed greater ORs (OR 2.21 [1.17, 4.17]) [48]. This study highlights an important topic of debate. Given that high sedentary time was associated with the metabolic syndrome and T2DM, even in those with relatively high fitness levels, does fitness offer any degree of protection for cardiometabolic health in those with high levels of sedentary behaviour?

The importance of CRF as one of the most important determinants of health was highlighted in a population-based study of 425 adults (baseline values: average age = 46.1 ± 9.5 years, CRF = 34.6 ± 8.3 ml·min^{-1}·kg^{-1}, 35% female) who were followed prospectively for ~10 years [47]. Results demonstrated that a decrease in CRF was associated with a greater increase in clustered cardiometabolic risk (with the associations being almost twice as strong compared to sedentary behaviour and MVPA). Importantly, the associations for change in sedentary behaviour and MVPA with change in clustered cardiometabolic risk were mediated through changes in CRF.

These findings are broadly similar to an acute, experimental study involving 34 younger adults (average age = 40 ± 9 years, BMI = 24.5 ± 3.0 kg/m^2, CRF = 41.3 ± 18.9 ml·min^{-1}·kg^{-1}). This trial investigated whether fitness modified the postprandial response to prolonged sitting and determined the potential influence of fitness on the benefits of interrupting postprandial sitting time with light activity breaks [49]. Each participant undertook two 7.5-h experimental conditions in a cross-over design: (1) prolonged sitting and (2) sitting interspersed with 5 minutes light walking bouts every 30 minutes. Despite the results showing that interrupting prolonged sitting with regular light walking breaks reduced postprandial glucose and insulin (both −35%), CRF modified the response. Those individuals with lower fitness levels displayed incrementally greater reductions in postprandial glucose. For example, the average response for a male with a VO_2 peak of 42.5 ml·min^{-1}·kg^{-1} (25th centile) would be a 48.6% reduction in postprandial levels when performing regular light walking breaks, compared to prolonged sitting. In contrast, the average response for a man at the 75th centile of fitness (VO_2 peak of 60.5 ml·min^{-1}·kg^{-1}) only reduced this by a further 11% through using regular light walking breaks [49]. The concept that fitter individuals may gain less pronounced health benefits from lower levels of sitting time is supported by cross-sectional research that has stratified data by habitual MVPA levels, reporting that individuals with higher MVPA levels display significantly weaker associations between sedentary time, HbA1c [50] and MRI-derived measures of adiposity [51].

Future research examining how much the cardiometabolic benefits from fitness across the continuum are offset by sedentary time is warranted. This is particularly pertinent when you factor in age, existence of comorbidities and potential interactions with medications.

7.4 Isotemporal Substitution and Compositional Data Analysis Studies

As previously mentioned, there has been an increase in the number of epidemiological studies assessing physical behaviours together. There has been a notable shift away from separate public health guidelines for individual movement behaviours and a growing body of evidence linking health to the movement behaviour composition, emphasising the importance of the whole, 24-h day. This has informed the development of the Canadian 24-Hour Movement Guidelines [52].

Two statistical approaches can be used in order to model the effects of replacing time in one physical behaviour with time in another: isotemporal substitution modelling (ISM) and compositional isotemporal modelling (CISM). Both approaches have shown beneficial associations with markers of cardiometabolic health when time is reallocated from sedentary behaviour to active, non-sedentary behaviours [53–66]. To discuss the strengths and weaknesses of each approach is beyond the scope of this chapter, particularly as this has been discussed in detail elsewhere [67, 68]. However, a recent study found that reallocating time from sitting to standing or from sitting to stepping showed beneficial associations with BMI, waist circumference, triglycerides, high-density lipoprotein (HDL) cholesterol and a clustered cardiometabolic risk score (with and without adiposity). Importantly, the direction and magnitude of associations with markers of cardiometabolic health were broadly similar when using both approaches [69].

Recent work has extended these cross-sectional findings by utilising prospective change data, where behavioural reallocation has actually occurred. In a group of individuals at high risk of T2DM, reallocating 30 minutes from sedentary into light activity was associated with a reduction in waist circumference, 2-h glucose, triglycerides and a clustered cardiometabolic risk score [70]. Results also demonstrated a dose-response relationship, as each 30 minutes of reallocation from sedentary behaviour to MVPA was associated with a 1.23 cm reduction in waist circumference, 0.23 mmol/l reduction in 2-h glucose and a 0.04 mmol/L reduction in triglycerides [70]. Therefore, over 12 months, reallocating time away from sedentary behaviour into light activity was associated with improved cardiometabolic health, but the greatest benefits were observed when reallocating from sedentary behaviour to MVPA.

These findings also extend to a younger, healthier population in a workplace setting. Compositional data analysis using 12-month data from the *Stand Up Victoria* intervention demonstrated that improvements in several cardiometabolic health risk biomarkers (cardiometabolic risk score, insulin, triglycerides, total/HDL cholesterol ratio) were significantly associated with reductions in sitting time [71]. The greatest degree and/or widest range of cardiometabolic benefits appeared to occur when increasing ambulatory activities. However, replacing sitting time with standing was still associated with improvements in the clustered cardiometabolic risk score at 12 months.

7.5 Acute, Chronic and Free-Living Interventions

Over recent years, epidemiological research has been complemented by acute experimental studies showing that breaking up bouts of prolonged sitting with standing or light-intensity activity (including resistance exercises) elicits significant benefits on markers of metabolic health [36, 38, 39, 72–74]. This also includes some alternative strategies that do not involve upright activity for breaking up prolonged sitting. For example, seated arm ergometry (5 minutes every 30 minutes) has been shown to acutely lower glucose and insulin levels by 57% and 20%, respectively, when compared to prolonged sitting [39]. This is pertinent for those with weight-bearing difficulties especially those with chronic disease, are wheelchair bound or may present severe peripheral neuropathy. Similarly, pedal desks in a workplace setting have shown potential in reducing postprandial insulin concentrations, without affecting work skills [75]. With such a low attainment of current physical activity guidelines, particularly in those with T2DM and metabolic syndrome [76], focusing on light-intensity physical activity as a feasible means of increasing daily energy expenditure in different contexts (e.g. workplace, home-based) seems practical.

In order to quantify the acute and chronic effect of light-intensity physical activity on markers of cardiometabolic health, Chastin et al. performed a meta-analysis that included 27 experimental studies [40]. The findings demonstrated that when compared to prolonged sitting, short, frequent bouts of light-intensity activity reduced postprandial glucose by 17.5% and insulin levels by 25.1% [40]. However, given the heterogeneity, there appears to be considerable inter-individual variability in the effectiveness of such interventions. Therefore, in order to ensure future prevention and management strategies are stratified and targeted at those who could derive the greatest benefit, it is necessary to determine the factors that may predict a favourable response to breaking up prolonged sitting with a low-intensity intervention. The importance of this was further highlighted in a recent systematic review and meta-analysis (n of studies = 42), where the use of physical activity breaks during sitting moderately attenuated post-prandial glucose and insulin with greater glycaemic attenuation observed in people with a higher BMI [77]. Exploratory analysis of the *Stand and Move at Work* intervention, a multilevel intervention targeting reduction in sedentary time, along with sit-stand workstations, also showed differences in the effect size, depending on the underlying degree of cardiometabolic dysfunction [78]. For example, although the intervention was effective for large reductions in sitting time at 12 months for the whole cohort (n = 487), when examining only those with non-diabetic hyperglycaemia or T2DM ($n = 95$), the reductions in glucose, HbA1c, body weight and body fat were considerably larger and clinically meaningful [78].

The inter-individual variability has also been shown in pooled analyses of cross-over laboratory-based trials. For example, Dempsey et al. showed that the magnitude of differences in postprandial glucose and insulin responses between two conditions (prolonged sitting and prolonged sitting interrupted with regular activity breaks) was significantly exacerbated with poorer baseline levels of fasting glucose, insulin and/or surrogate markers of β-cell function and insulin resistance [79]. Similarly, our group recently conducted a pooled analysis of four acute, randomised, experimental trials ($n = 129$, South Asian = 31.0%; high risk of T2DM = 27.1%) examining the postprandial glucose and insulin response to three treatment conditions: prolonged sitting (6.5 h) or prolonged sitting broken-up with either standing or light-intensity physical activity (5 minutes every 30 minutes) [80]. The results demonstrated that reductions in postprandial insulin were more pronounced if individuals were South Asian compared with white European (−23.5% vs. -9.3%), female compared to male (−21.2% vs. -17.6%) or had a BMI ≥27.2 kg/m^2 (−22.9% vs. -18.2%) (Fig. 7.1). Being female (−6.8% vs. -1.7%)) or having a BMI ≥27.2 kg/m^2 (−6.7% vs. -3.4%) modified the postprandial glucose response.

In terms of ethnicity, it has been well established that South Asians have a higher risk of cardiometabolic disease than white Europeans [81, 82] and develop T2DM at a lower BMI level, up to 12 years earlier than white Europeans. Nevertheless, despite South Asians having greater metabolic dysfunction, this analysis suggests that they are likely to receive the greater absolute benefit per dose of light activity. This finding was first highlighted in our experimental work (that was also included in the above pooled analysis) examining the postprandial response to breaking up prolonged sitting (7.5 h) with standing or light intensity walking (5 minutes every 30 minutes) in South Asians and white European older adults (65–79 years). The results demonstrated that when compared to the prolonged sitting condition, walking breaks reduced postprandial insulin area under the curve to a greater extent in South Asians (22.4 mU/l·h vs. 10.3 mU/l·h) [38].

As such, these results may be used to guide future individualised tailored interventions in high-risk participants for whom breaking prolonged sitting time could be a viable and effective prevention or treatment strategy. A reasonable goal may be to first break up sitting time with informal/light-intensity physical activity, which may also be more culturally acceptable to high-risk groups (e.g. South Asian women) [83], before progressing onto higher-intensity activities.

The promising results from acute, experimental studies have yet to be replicated in chronic, free-living interventions. Although the primary focus of chronic sedentary behaviour studies so far has been on the behavioural efficacy of the proposed interventions, some studies have also focused on the impact of reducing sedentary time for health-related outcomes. For example, a recent systematic review and meta-analysis reported that although interventions (≥7 days) targeting sedentary behaviour yielded significant reductions in markers of cardiometabolic health, the differences were minimal and arguably not clinically significant (weight (−0.6 kg),

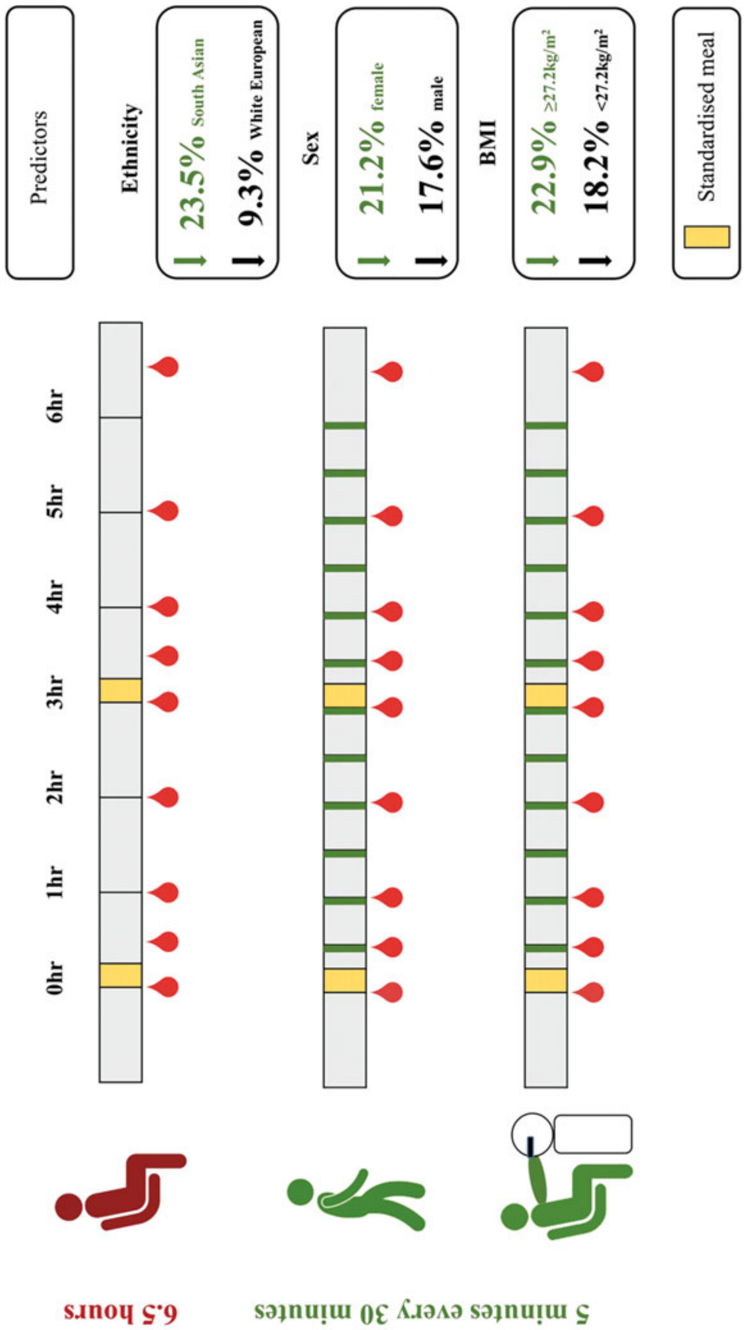

Fig. 7.1 Predictors of the postprandial insulin response to breaking up prolonged sitting with light activity

waist circumference (−0.7 cm), percentage body fat (−0.3%), systolic blood pressure (−1.1 mm Hg), insulin (−1.4 pmol/L) [84]. This is likely to be a reflection of the relatively small number of studies available and the lack of diversity regarding ethnicity, age and underlying degree of insulin resistance. That said, a systematic review and meta-analysis including 18 studies, confined to a clinical population (overweight/obesity, type 2 diabetes, cardiovascular, neurological/cognitive and musculoskeletal diseases), demonstrated that behavioural lifestyle interventions reduce sedentary behaviour by ~90 minutes per day and improve markers of cardiometabolic health to a greater extent (HbA1c (−0.17%), percentage body fat (−0.66%) and waist circumference (−1.52 cm) [85]. The differences may be driven by the higher absolute baseline values.

7.6 Broadening Targeted Activity Options and Looking Beyond Cardiometabolic Health

Given the inter-individual variability in the postprandial response, it is necessary to continue exploring the modification effect of key demographic, social, cardiometabolic and anthropometric characteristics (e.g. sex, age, ethnicity, multimorbidity, level of deprivation, glucose, insulin HbA1c, adiposity and cardiorespiratory fitness) to breaking up prolonged sitting. Moreover, in order to inform future sedentary behaviour guidelines and provide insight into the optimal method to replace sitting time, future interventions (ideally RCTs) should encompass the full 24-hour range of behaviours (e.g. sleep, sedentary time, light-intensity physical activity and MVPA).

It is also important to reiterate that T2DM has far reaching implications that extend beyond traditional markers of cardiometabolic health. For example, T2DM reflects a powerful physiological model of accelerated biological ageing that influences whole body health and function [86]. Our previous work has shown that ~30% of 635 adults (median age = 66 years, average BMI = 30.8 ± 5.0 kg/m^2, 34% female) with T2DM have impaired physical function, with their ability to carry out functional tasks of daily living similar to those without diabetes who are over a decade older [87]. Moreover, the group with impaired physical function spent more time in prolonged sedentary behaviour (600.7 vs 572.5 minutes per day) and showed stronger inverse associations with markers of physical function (sit-to-stand repetitions (−15% vs. 2%) and Duke Activity Status Index (DASI) score (−16% vs. 1%)).

As T2DM is a risk factor for the development of both frailty and sarcopenia [88], international expert consensus statements now recommend routine physical function assessments and reiterate the need for interventions to prevent diabetes-related disabling outcomes [89, 90]. It is therefore important to translate the concept of sedentary breaks from a focus on cardiometabolic health into the broader arena of ageing, frailty and functional decline. Whilst recent observational evidence supports the hypothesis that greater sedentary time exacerbates the symptoms of frailty in older adults [91–93] and that replacing sedentary behaviour with movement is associated with better physical function [93–96], interventional research is largely lacking.

7.7 COVID-19

As the global COVID-19 pandemic highlighted, the interplay between COVID-19 and T2DM entails a complex pathophysiology. COVID-19 outcomes are known to be more severe in people with T2DM and metabolic dysfunction [97]. As well as being a pivotal therapeutic interventions and the prevention and management of T2DM [32], physical activity is also known to enhance immunity (immune activation, immunosenescence and vaccination efficacy) [98]. Indeed, adoption of physically active lifestyles can delay the aging of the immune system and minimise the risk of contracting communicable and non-communicable diseases [99].

COVID-19 has undoubtedly changed patterns of daily life for many (Chap. 27). This is particularly important in those with T2DM, who are known to engage in less physical activity and more sedentary pursuits than those without the condition [76]. Observational research from 165 participants with T2DM (median + interquartile range [IQR] for age = 66 [59,70] years, BMI = 30.8 [27.3,35.9] kg/m^2, 45% female) has shown that during COVID-19 restrictions, overall physical activity was lower by ~800 steps/day and inactive/sedentary time was higher by over 20 minutes per day [100]. Further analysis also demonstrated that higher BMI and/or being female were consistent predictors of lower physical activity and/or higher inactive/sedentary time. Similarly, being older and/or from ethnic minority groups was associated with higher inactive/sedentary time [100].

The overarching importance of physical activity was further demonstrated by Rowlands et al., where accelerometer data from 82,253 UK Biobank participants showed that the odds of severe COVID-19 were approximately 25% lower per standard deviation (∼30 minutes/day) of MVPA [101], with a greater proportion of vigorous activity also associated with lower odds of severe and non-severe infections. In terms of reducing sedentary behaviour (and thus increasing physical activity), a recent study including 48,440 participants demonstrated that the risk of adverse COVID-19 outcomes (hospitalisation, admission to intensive care, death) associated with being physically inactive was higher than that of smoking and most chronic conditions (obesity, diabetes mellitus, hypertension, CVD and cancer) [102]. Although meeting current physical guidelines was associated with substantial benefit (only met by 6.4%), even those doing some physical activity had lower risks for severe COVID-19 outcomes versus those who were consistently inactive. Thus, these results show the critical role of reducing sedentary behaviours and promoting habitual physical activity to lower COVID-19 illness severity. Importantly, it appears that the intensity of the activity is less important than the decision of whether to be active at all.

7.8 Conclusion

Exorbitant sitting now resides as the default setting for the large majority of individuals. Over recent years, epidemiological research has been complemented by acute experimental and chronic intervention studies showing that breaking up bouts of prolonged sitting elicits significant benefits on markers of metabolic health. As sedentary behaviour research continues to mature, future translational work is likely to have a substantial public health impact. It is also likely to inform future policies on the optimal approaches to reducing prolonged sitting time as part of integrated lifestyle promotion pathways. Indeed, sedentary behaviour is already present in international guidelines and national diabetes prevention programmes.

Recently, the use of telehealth and home-based exercise programmes have become increasingly visible. Harnessing such technology may improve continuity of care, promote participation (through flexible scheduling) and help to guide individualised tailored interventions in high-risk participants for whom breaking prolonged sitting time could be a viable and effective prevention/management strategy. The co-existence of two global pandemics (T2DM and COVID-19) has reinforced the notion that reducing sedentary behaviour and maintaining a physically active lifestyle are no longer a hobby of a few, but a necessity for all.

References

1. International Diabetes Federation. Diabetes Atlas, 9th Edition. 2019. http://www.idf.org/diabetesatlas. Accessed June 2020.
2. United Nations. Transforming our world: the 2030 Agenda for Sustainable Development. 2015. https://sdgs.un.org/2030agenda, 2021.
3. World Health Organisation. Global action plan for the prevention and control of noncommunicable diseases 2013–2020; 2013. https://apps.who.int/iris/handle/10665/94384
4. Chan JCN, Lim LL, Wareham NJ, Shaw JE, Orchard TJ, Zhang P, et al. The Lancet Commission on diabetes: using data to transform diabetes care and patient lives. Lancet. 2021 Dec 19;396(10267):2019–82.
5. Hex N, Bartlett C, Wright D, Taylor M, Varley D. Estimating the current and future costs of Type 1 and Type 2 diabetes in the UK, including direct health costs and indirect societal and productivity costs. Diabet Med. 2012 Jul;29(7):855–62.
6. Bommer C, Sagalova V, Heesemann E, Manne-Goehler J, Atun R, Barnighausen T, et al. Global economic burden of diabetes in adults: projections from 2015 to 2030. Diabetes Care. 2018 May;41(5):963–70.
7. Gillies CL, Abrams KR, Lambert PC, Cooper NJ, Sutton AJ, Hsu RT, et al. Pharmacological and lifestyle interventions to prevent or delay type 2 diabetes in people with impaired glucose tolerance: systematic review and meta-analysis. BMJ. 2007 Feb 10;334(7588):299.
8. Gong Q, Zhang P, Wang J, Ma J, An Y, Chen Y, et al. Morbidity and mortality after lifestyle intervention for people with impaired glucose tolerance: 30-year results of the Da Qing Diabetes Prevention Outcome Study. Lancet Diabetes Endocrinol. 2019 Jun;7(6):452–61.
9. NHS England. NHS Diabetes Prevention Programme (NHS DPP). 2020. https://www.england.nhs.uk/diabetes/diabetes-prevention/, 2021.

10. Barron E, Clark R, Hewings R, Smith J, Valabhji J. Progress of the healthier you: NHS Diabetes Prevention Programme: referrals, uptake and participant characteristics. Diabet Med. 2018 Apr;35(4):513–8.
11. Public Health England. The Eatwell guide. 2018. https://www.gov.uk/government/publications/the-eatwell-guide, 2021.
12. Department of Health & Social Care. UK Chief Medical Officers' Physical Activity Guidelines. 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/832868/uk-chief-medical-officers-physical-activity-guidelines.pdf. Accessed December 2020.
13. National Institute for Health and Care Excellence. Preventing type 2 diabetes: risk identification and interventions for individuals at high risk; 2012. https://www.nice.org.uk/guidance/ph38. Accessed February 2015.
14. Public Health England. A systematic review and meta-analysis assessing the effectiveness of pragmatic lifestyle interventions for the prevention of type 2 diabetes mellitus in routine practice; 2015.
15. Galaviz KI, Weber MB, Straus A, Haw JS, Narayan KMV, Ali MK. Global diabetes prevention interventions: a systematic review and network meta-analysis of the real-world impact on incidence, weight, and glucose. Diabetes Care. 2018 Jul;41(7):1526–34.
16. Valabhji J, Barron E, Bradley D, Bakhai C, Fagg J, O'Neill S, et al. Early outcomes from the English National Health Service Diabetes Prevention Programme. Diabetes Care. 2020 Jan;43(1):152–60.
17. Ely EK, Gruss SM, Luman ET, Gregg EW, Ali MK, Nhim K, et al. a national effort to prevent type 2 diabetes: participant-level evaluation of CDC's National Diabetes Prevention Program. Diabetes Care. 2017 Oct;40(10):1331–41.
18. Saaristo T, Moilanen L, Korpi-Hyovalti E, Vanhala M, Saltevo J, Niskanen L, et al. Lifestyle intervention for prevention of type 2 diabetes in primary health care: one-year follow-up of the Finnish National Diabetes Prevention Program (FIN-D2D). Diabetes Care. 2010 Oct;33(10):2146–51.
19. Dunbar JA, Jayawardena A, Johnson G, Roger K, Timoshanko A, Versace VL, et al. Scaling up diabetes prevention in Victoria, Australia: policy development, implementation, and evaluation. Diabetes Care. 2014 Apr;37(4):934–42.
20. Wilson PW, D'Agostino RB, Parise H, Sullivan L, Meigs JB. Metabolic syndrome as a precursor of cardiovascular disease and type 2 diabetes mellitus. Circulation. 2005 Nov 15;112(20):3066–72.
21. Shin JA, Lee JH, Lim SY, Ha HS, Kwon HS, Park YM, et al. Metabolic syndrome as a predictor of type 2 diabetes, and its clinical interpretations and usefulness. J Diabetes Investig. 2013 Jul 8;4(4):334–43.
22. Ritchie SA, Connell JM. The link between abdominal obesity, metabolic syndrome and cardiovascular disease. Nutr Metab Cardiovasc Dis. 2007 May;17(4):319–26.
23. Pietilainen KH, Kaprio J, Borg P, Plasqui G, Yki-Jarvinen H, Kujala UM, et al. Physical inactivity and obesity: a vicious circle. Obesity (Silver Spring). 2008 Feb;16(2):409–14.
24. Saklayen MG. The global epidemic of the metabolic syndrome. Curr Hypertens Rep. 2018 Feb 26;20(2):12.
25. Scuteri A, Laurent S, Cucca F, Cockcroft J, Cunha PG, Manas LR, et al. Metabolic syndrome across Europe: different clusters of risk factors. Eur J Prev Cardiol. 2015 Apr;22(4):486–91.
26. Kahn R, Buse J, Ferrannini E, Stern M. The metabolic syndrome: time for a critical appraisal. Joint statement from the American Diabetes Association and the European Association for the Study of Diabetes. Diabetologia. 2005 Sep;48(9):1684–99.
27. Edwardson CL, Gorely T, Davies MJ, Gray LJ, Khunti K, Wilmot EG, et al. Association of sedentary behaviour with metabolic syndrome: a meta-analysis. PLoS One. 2012;7(4):e34916.
28. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012 Nov;55(11):2895–905.

29. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015 Jan 20;162(2):123–32.
30. Grontved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. JAMA. 2011 Jun 15;305(23):2448–55.
31. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020 Dec;54(24):1451–62.
32. Colberg SR, Sigal RJ, Yardley JE, Riddell MC, Dunstan DW, Dempsey PC, et al. Physical activity/exercise and diabetes: a position statement of the American Diabetes Association. Diabetes Care. 2016 Nov;39(11):2065–79.
33. Dempsey PC, Biddle SJH, Buman MP, Chastin S, Ekelund U, Friedenreich CM, et al. New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. Int J Behav Nutr Phys Act. 2020 Nov 26;17(1):151.
34. Patterson R, McNamara E, Tainio M, de Sa TH, Smith AD, Sharp SJ, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. Eur J Epidemiol. 2018 Sep;33(9):811–29.
35. Henson J, Dunstan DW, Davies MJ, Yates T. Sedentary behaviour as a new behavioural target in the prevention and treatment of type 2 diabetes. Diabetes Metab Res Rev. 2016 Jan;32 (Suppl 1):213–20.
36. Henson J, Davies MJ, Bodicoat DH, Edwardson CL, Gill JM, Stensel DJ, et al. Breaking up prolonged sitting with standing or walking attenuates the postprandial metabolic response in postmenopausal women: a randomized acute study. Diabetes Care. 2016 Jan;39(1):130–8.
37. Henson J, Yates T, Edwardson CL, Khunti K, Talbot D, Gray LJ, et al. Sedentary time and markers of chronic low-grade inflammation in a high risk population. PLoS One. 2013 Oct 29;8(10):e78350.
38. Yates T, Edwardson CL, Celis-Morales C, Biddle SJH, Bodicoat D, Davies MJ, et al. Metabolic effects of breaking prolonged sitting with standing or light walking in older South Asians and White Europeans: a randomized acute study. J Gerontol A Biol Sci Med Sci. 2018 Nov 7;75(1):139–46.
39. McCarthy M, Edwardson CL, Davies MJ, Henson J, Rowlands A, King J, et al. Breaking up sedentary time with seated upper body activity can regulate metabolic health in obese high risk adults: a randomised crossover trial. Diabetes Obes Metab. 2017 May 23;19(12):1732–9.
40. Chastin SFM, De Craemer M, De Cocker K, Powell L, Van Cauwenberg J, Dall P, et al. How does light-intensity physical activity associate with adult cardiometabolic health and mortality? Systematic review with meta-analysis of experimental and observational studies. Br J Sports Med. 2019 Mar;53(6):370–6.
41. Guo C, Zhou Q, Zhang D, Qin P, Li Q, Tian G, et al. Association of total sedentary behaviour and television viewing with risk of overweight/obesity, type 2 diabetes and hypertension: A dose-response meta-analysis. Diabetes Obes Metab. 2020 Jan;22(1):79–90.
42. Bowman SA. Television-viewing characteristics of adults: correlations to eating practices and overweight and health status. Prev Chronic Dis. 2006 Apr;3(2):A38.
43. Hobbs M, Pearson N, Foster PJ, Biddle SJ. Sedentary behaviour and diet across the lifespan: an updated systematic review. Br J Sports Med. 2015 Sep;49(18):1179–88.
44. Bailey DP, Hewson DJ, Champion RB, Sayegh SM. Sitting time and risk of cardiovascular disease and diabetes: a systematic review and meta-analysis. Am J Prev Med. 2019 Sep;57(3): 408–16.
45. Kulinski JP, Khera A, Ayers CR, Das SR, de Lemos JA, Blair SN, et al. Association between cardiorespiratory fitness and accelerometer-derived physical activity and sedentary time in the general population. Mayo Clin Proc. 2014 Aug;89(8):1063–71.

46. van der Velde JHPM, Koster A, van der Berg JD, SJS S, van der Kallen CJH, Dagnelie PC, et al. Sedentary Behavior, Physical Activity, and Fitness-The Maastricht Study. Med Sci Sports Exerc. 2017 Aug;49(8):1583–91.
47. Knaeps S, Bourgois JG, Charlier R, Mertens E, Lefevre J, Wijndaele K. Ten-year change in sedentary behaviour, moderate-to-vigorous physical activity, cardiorespiratory fitness and cardiometabolic risk: independent associations and mediation analysis. Br J Sports Med. 2018 Aug;52(16):1063–8.
48. van der Velde JHPM, Schaper NC, Stehouwer CDA, van der Kallen CJH, Sep SJS, Schram MT, et al. Which is more important for cardiometabolic health: sedentary time, higher intensity physical activity or cardiorespiratory fitness? The Maastricht Study. Diabetologia. 2018 Dec;61(12):2561–9.
49. McCarthy M, Edwardson CL, Davies MJ, Henson J, Bodicoat DH, Khunti K, et al. Fitness moderates glycemic responses to sitting and light activity breaks. Med Sci Sports Exerc. 2017 Jun 8;49(11):2216–22.
50. Bakrania K, Edwardson CL, Bodicoat DH, Esliger DW, Gill JM, Kazi A, et al. Associations of mutually exclusive categories of physical activity and sedentary time with markers of cardiometabolic health in English adults: a cross-sectional analysis of the Health Survey for England. BMC Public Health. 2016 Jan 12;16(1):25.
51. Henson J, Edwardson CL, Morgan B, Horsfield MA, Khunti K, Davies MJ, et al. Sedentary time and MRI-derived measures of adiposity in active versus inactive individuals. Obesity (Silver Spring). 2018 Jan;26(1):29–36.
52. Ross R, Chaput JP, Giangregorio LM, Janssen I, Saunders TJ, Kho ME, et al. Canadian 24-hour movement guidelines for adults aged 18–64 years and adults aged 65 years or older: an integration of physical activity, sedentary behaviour, and sleep. Appl Physiol Nutr Metab. 2020 Oct;45(10):S57–S102.
53. Buman MP, Winkler EA, Kurka JM, Hekler EB, Baldwin CM, Owen N, et al. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. Am J Epidemiol. 2014 Feb 1;179(3):323–34.
54. Edwardson CL, Henson J, Bodicoat DH, Bakrania K, Khunti K, Davies MJ, et al. Associations of reallocating sitting time into standing or stepping with glucose, insulin and insulin sensitivity: a cross-sectional analysis of adults at risk of type 2 diabetes. BMJ Open. 2017 Jan 13;7 (1):e014267.
55. Falconer CL, Page AS, Andrews RC, Cooper AR. the potential impact of displacing sedentary time in adults with type 2 diabetes. Med Sci Sports Exerc. 2015 Oct;47(10):2070–5.
56. Hamer M, Stamatakis E, Steptoe A. Effects of substituting sedentary time with physical activity on metabolic risk. Med Sci Sports Exerc. 2014 Oct;46(10):1946–50.
57. Henson J, Edwardson CL, Bodicoat DH, Bakrania K, Davies MJ, Khunti K, et al. Reallocating sitting time to standing or stepping through isotemporal analysis: associations with markers of chronic low-grade inflammation. J Sports Sci. 2018 Jul;36(14):1586–93.
58. Yates T, Henson J, Edwardson C, Dunstan D, Bodicoat DH, Khunti K, et al. Objectively measured sedentary time and associations with insulin sensitivity: Importance of reallocating sedentary time to physical activity. Prev Med. 2015 Jul;76:79–83.
59. Dumuid D, Stanford TE, Martin-Fernandez JA, Pedisic Z, Maher CA, Lewis LK, et al. Compositional data analysis for physical activity, sedentary time and sleep research. Stat Methods Med Res. 2017 Jan 01;27(12):3726–38.
60. Dumuid D, Pedisic Z, Stanford TE, Martin-Fernandez JA, Hron K, Maher CA, et al. The compositional isotemporal substitution model: a method for estimating changes in a health outcome for reallocation of time between sleep, physical activity and sedentary behaviour. Stat Methods Med Res. 2019 Mar;28(3):846–57.
61. Biddle GJH, Edwardson CL, Henson J, Davies MJ, Khunti K, Rowlands AV, et al. Associations of physical behaviours and behavioural reallocations with markers of metabolic health: a compositional data analysis. Int J Environ Res Public Health. 2018 Oct 17;15(10):2280. https://doi.org/10.3390/ijerph15102280.

62. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. PLoS One. 2015 Oct 15;10(10): e0139984.
63. Grgic J, Dumuid D, Bengoechea EG, Shrestha N, Bauman A, Olds T, et al. Health outcomes associated with reallocations of time between sleep, sedentary behaviour, and physical activity: a systematic scoping review of isotemporal substitution studies. Int J Behav Nutr Phys Act. 2018 Jul 13;15(1):69.
64. Janssen I, Clarke AE, Carson V, Chaput JP, Giangregorio LM, Kho ME, et al. A systematic review of compositional data analysis studies examining associations between sleep, sedentary behaviour, and physical activity with health outcomes in adults. Appl Physiol Nutr Metab. 2020 Oct;45(10):S248–57.
65. Powell C, Browne LD, Carson BP, Dowd KP, Perry IJ, Kearney PM, et al. Use of compositional data analysis to show estimated changes in cardiometabolic health by reallocating time to light-intensity physical activity in older adults. Sports Med. 2020 Jan;50(1):205–17.
66. Healy GN, Winkler EA, Owen N, Anuradha S, Dunstan DW. Replacing sitting time with standing or stepping: associations with cardio-metabolic risk biomarkers. Eur Heart J. 2015 Jul 30;36(39):2643–9.
67. Biddle GJH, Edwardson CL, Henson J, Rowlands AV, Yates T. Reply to Mekary, R.A.; Ding, E.L. Isotemporal substitution as the gold standard model for physical activity epidemiology: why it is the most appropriate for activity time research. Int. J. Environ. Res. Public Health 2019, 16, 797. Int J Environ Res Public Health. 2019 Aug 12;16(16):2885. https://doi.org/10.3390/ijerph16162885.
68. Mekary RA, Ding EL. Isotemporal substitution as the gold standard model for physical activity epidemiology: why it is the most appropriate for activity time research. Int J Environ Res Public Health. 2019 Mar 5;16(5):797. https://doi.org/10.3390/ijerph16050797.
69. Biddle GJH, Henson J, Biddle SJH, Davies MJ, Khunti K, Rowlands AV, et al. Modelling the reallocation of time spent sitting into physical activity: isotemporal substitution vs. compositional isotemporal substitution. Int J Environ Res Public Health. 2021 Jun 8;18(12):6210. https://doi.org/10.3390/ijerph18126210.
70. Yates T, Edwardson CL, Henson J, Zaccardi F, Khunti K, Davies MJ. Prospectively reallocating sedentary time: associations with cardiometabolic health. Med Sci Sports Exerc. 2020 Apr;52(4):844–50.
71. Winkler EAH, Chastin S, Eakin EG, Owen N, Lamontagne AD, Moodie M, et al. Cardiometabolic impact of changing sitting, standing, and stepping in the workplace. Med Sci Sports Exerc. 2018 Mar;50(3):516–24.
72. Dempsey PC, Larsen RN, Sethi P, Sacre JW, Straznicky NE, Cohen ND, et al. Benefits for type 2 diabetes of interrupting prolonged sitting with brief bouts of light walking or simple resistance activities. Diabetes Care. 2016 Jun;39(6):964–72.
73. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. Am J Clin Nutr. 2013;98(2):358–66.
74. Dunstan DW, Kingwell BA, Larsen R, Healy GN, Cerin E, Hamilton MT, et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes Care. 2012 Feb 28;35(5):976–83.
75. Han HO, Lim J, Viskochil R, Aguiar EJ, Tudor-Locke C, Chipkin SR. Pilot study of impact of a pedal desk on postprandial responses in sedentary workers. Med Sci Sports Exerc. 2018 Oct;50(10):2156–63.
76. Kennerly AM, Kirk A. Physical activity and sedentary behaviour of adults with type 2 diabetes: a systematic review. Pract Diabetes. 2018;35(3):86–9.
77. Loh R, Stamatakis E, Folkerts D, Allgrove JE, Moir HJ. Effects of interrupting prolonged sitting with physical activity breaks on blood glucose, insulin and triacylglycerol measures: a systematic review and meta-analysis. Sports Med. 2020 Feb;50(2):295–330.

78. Pereira MA, Mullane SL, Toledo MJL, Larouche ML, Rydell SA, Vuong B, et al. Efficacy of the 'stand and move at work' multicomponent workplace intervention to reduce sedentary time and improve cardiometabolic risk: a group randomized clinical trial. Int J Behav Nutr Phys Act. 2020 Oct 27;17(1):133.
79. Dempsey PC, Larsen RN, Winkler EAH, Owen N, Kingwell BA, Dunstan DW. Prolonged uninterrupted sitting elevates postprandial hyperglycaemia proportional to degree of insulin resistance. Diabetes Obes Metab. 2018 Jun;20(6):1526–30.
80. Henson J, Edwardson CL, Celis-Morales CA, Davies MJ, Dunstan DW, Esliger DW, et al. Predictors of the acute postprandial response to breaking up prolonged sitting. Med Sci Sports Exerc. 2020 Jun;52(6):1385–93.
81. Gholap N, Davies M, Patel K, Sattar N, Khunti K. Type 2 diabetes and cardiovascular disease in South Asians. Prim Care Diabetes. 2011 Apr;5(1):45–56.
82. Barnett AH, Dixon AN, Bellary S, Hanif MW, O'Hare JP, Raymond NT, et al. Type 2 diabetes and cardiovascular risk in the UK south Asian community. Diabetologia. 2006 Oct;49(10): 2234–46.
83. Lucas A, Murray E, Kinra S. Heath beliefs of UK South Asians related to lifestyle diseases: a review of qualitative literature. J Obes. 2013;2013:827674.
84. Hadgraft NT, Winkler E, Climie RE, Grace MS, Romero L, Owen N, et al. Effects of sedentary behaviour interventions on biomarkers of cardiometabolic risk in adults: systematic review with meta-analyses. Br J Sports Med. 2021 Feb;55(3):144–54.
85. Nieste I, Franssen WMA, Spaas J, Bruckers L, Savelberg HHCM, Eijnde BO. Lifestyle interventions to reduce sedentary behaviour in clinical populations: a systematic review and meta-analysis of different strategies and effects on cardiometabolic health. Prev Med. 2021 Jul;148:106593.
86. Bianchi L, Volpato S. Muscle dysfunction in type 2 diabetes: a major threat to patient's mobility and independence. Acta Diabetol. 2016 Dec;53(6):879–89.
87. Mickute M, Henson J, Rowlands AV, Sargeant JA, Webb D, Hall AP, et al. Device-measured physical activity and its association with physical function in adults with type 2 diabetes mellitus. Diabet Med. 2020 Aug;26:e14393.
88. Sinclair A, Morley J. Frailty and diabetes. Lancet. 2013 Oct 26;382(9902):1386–7.
89. Sinclair AJ, Abdelhafiz A, Dunning T, Izquierdo M, Rodriguez Manas L, Bourdel-Marchasson I, et al. An international position statement on the management of frailty in diabetes mellitus: summary of recommendations 2017. J Frailty Aging. 2018;7(1):10–20.
90. Strain WD, Hope SV, Green A, Kar P, Valabhji J, Sinclair AJ. Type 2 diabetes mellitus in older people: a brief statement of key principles of modern day management including the assessment of frailty. A national collaborative stakeholder initiative. Diabet Med. 2018 Jul;35 (7):838–45.
91. da Silva CR, de Queiroz BM, Oliveira DS, das Merces MC, Oliveira Carneiro JA, Pereira R, et al. Cross-sectional relationships between sedentary behavior and frailty in older adults. J Sports Med Phys Fitness. 2017 Jun;57(6):825–30.
92. Blodgett J, Theou O, Kirkland S, Andreou P, Rockwood K. The association between sedentary behaviour, moderate-vigorous physical activity and frailty in NHANES cohorts. Maturitas. 2015 Feb;80(2):187–91.
93. Kehler DS, Hay JL, Stammers AN, Hamm NC, Kimber DE, Schultz ASH, et al. A systematic review of the association between sedentary behaviors with frailty. Exp Gerontol. 2018 Dec;114:1–12.
94. Sardinha LB, Ekelund U, dos Santos L, Cyrino ES, Silva AM, Santos DA. Breaking-up sedentary time is associated with impairment in activities of daily living. Exp Gerontol. 2015 Dec;72:278.
95. Lerma NL, Cho CC, Swartz AM, Miller NE, Keenan KG, Strath SJ. Isotemporal substitution of sedentary behavior and physical activity on function. Med Sci Sports Exerc. 2018 Apr;50 (4):792–800.

96. Nagai K, Tamaki K, Kusunoki H, Wada Y, Tsuji S, Ito M, et al. Isotemporal substitution of sedentary time with physical activity and its associations with frailty status. Clin Interv Aging. 2018 Sep;25(13):1831–6.
97. Hartmann-Boyce J, Rees K, Perring JC, Kerneis SA, Morris EM, Goyder C, et al. Risks of and from SARS-CoV-2 infection and COVID-19 in people with diabetes: a systematic review of reviews. Diabetes Care. 2021 Oct 28;44(12):2790–811.
98. Chastin SFM, Abaraogu U, Bourgois JG, Dall PM, Darnborough J, Duncan E, et al. Effects of regular physical activity on the immune system, vaccination and risk of community-acquired infectious disease in the general population: systematic review and meta-analysis. Sports Med. 2021 Aug;51(8):1673–86.
99. Campbell JP, Turner JE. Debunking the myth of exercise-induced immune suppression: redefining the impact of exercise on immunological health across the lifespan. Front Immunol. 2018 Apr;16(9):648.
100. Rowlands AV, Henson JJ, Coull NA, Edwardson CL, Brady E, Hall A, et al. The impact of COVID-19 restrictions on accelerometer-assessed physical activity and sleep in individuals with type 2 diabetes. Diabet Med. 2021 Mar;1:e14549.
101. Rowlands AV, Dempsey PC, Gillies C, Kloecker DE, Razieh C, Chudasama Y, et al. Association Between Accelerometer-Assessed Physical Activity and Severity of COVID-19 in UK Biobank. Mayo Clin Proc Innov Qual Outcomes. 2021 Dec;5(6):997–1007.
102. Sallis R, Young DR, Tartof SY, Sallis JF, Sall J, Li Q, et al. Physical inactivity is associated with a higher risk for severe COVID-19 outcomes: a study in 48,440 adult patients. Br J Sports Med. 2021 Oct;55(19):1099–105.

Chapter 8
Sedentary Behaviour and Cardiovascular Disease

Emmanuel Stamatakis, Leandro F. M. Rezende, and Juan Pablo Rey-López

Abstract Sedentary behaviour is ubiquitous in high-income countries and increasingly so in low- to middle-income countries. Sedentary behaviour research has made substantial progress in the last 15 years, including a consensus on the definition of sedentary behaviour, the development and standardisation of methods that acknowledge displacement effects and a plethora of mechanistic studies. Despite such progress, our understanding of the independent effects of sedentary behaviour on cardiovascular health and cardiovascular disease occurrence is still incomplete. Multiple methodological and interpretational issues hinder a confident translation of available research into interventions and guidelines aimed at the primary prevention of cardiovascular disease. Such issues include a paucity of prospective longitudinal studies measuring actual posture, the influence of pre-existing illness and reverse causation, the dependence of sedentary behaviour effects on physical activity levels, the exaggerated benefits of replacing siting with standing and the causal interpretations of poor sedentary behaviour markers such as television viewing. In young people, the overwhelming majority of the evidence examining the links between objectively assessed sedentary behaviour and surrogate markers of cardiovascular health is cross-sectional and the few prospective studies point towards no associations. The best available epidemiological evidence on self-reported sitting time in adults suggests that the risk for incident cardiovascular disease is elevated at around 10 h/day and over. Considering that self-reported measures underestimate

E. Stamatakis (✉)
Mackenzie Wearables Research Hub, Charles Perkins Centre, University of Sydney, Sydney, Australia
e-mail: emmanuel.stamatakis@sydney.edu.au

L. F. M. Rezende
Escola Paulista de Medicina, Departamento de Medicina Preventiva, Universidade Federal de São Paulo, Sao Paulo, SP, Brazil
e-mail: leandro.rezende@unifesp.br

J. P. Rey-López
Faculty of Health Sciences, Valencian International University, Valencia, Spain

Faculty of Sports, UCAM, Murcia, Spain

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_8

actual sitting times considerably, it is likely that the 'true' threshold is higher. The causality of sitting time and cardiovascular disease is far from established. Besides, the biological mechanisms that would explain any 'independent' effect of sitting time are not proven in humans, despite a plethora of proposed hypotheses (e.g. endothelial damage, lipoprotein lipase activation). The association between high sedentary time and cardiovascular disease appears to be modified by physical activity; equivalents of approximately 45–60 minutes of moderate intensity activity per day appear to largely offset cardiovascular events risk. Since such an amount of daily physical activity may be beyond the reach of large parts of the population, advocates of the sedentary behaviour paradigm recommend to replace sitting with physical activity of any intensity for cardiovascular health benefits, particularly among the most physically inactive middle aged and older population groups and those who are likely to be resistant or unable to increase physical activity of moderate-to-vigorous intensity. Further research efforts are warranted for optimising the device-based measurement of sedentary behaviour in large-scale observational studies and consortia, for understanding better its independent cardiovascular effects and mechanisms of action – if any such mechanisms exist.

What Is New?

- The cardiovascular health consequences on high sedentary behaviour times are a relatively new but established field of research.
- Based on best available self-reported evidence, approximately 10 h of sitting or more per day is associated with elevated cardiovascular disease risk.
- Based on best available self-reported evidence, 45–60 minutes of moderate-to-vigorous physical activity per day attenuate (substantially) the associations of sitting time with cardiovascular disease.
- It is uncertain if the associations of sedentary behaviour and cardiovascular disease-related outcomes are causal.
- Emerging observational studies and consortia utilising robust designs and measurements of actual posture are likely to advance the field of sedentary behaviour and cardiovascular health in the years to come.

8.1 Introduction

Modern lifestyle has brought innumerable advantages in terms of increasing humans' lifespan. However, it is undisputable that human biology is mismatched to a myriad of exposures common in modern societies. Although daily time spent in non-ambulatory postures by modern humans has not changed relative to hunter-gatherer times, our evolutionary ancestors practiced 'active rest' involving muscle-engaging postures like squatting and sitting on the floor [1]. Excessive chair-sitting in modern times, on the other hand, leads to minimal muscle contractions and compromised muscle metabolic function. Another one of many mismatches has occurred in the occupational domain, where rapid advances in technology (computers, robotics, etc.) elicit lower physical activity-related energy expenditure (including more sitting time) at workplaces compared with prior decades [2, 3]. In a similar way, sitting time today may be more prevalent in most regions around the world due to the wide use of motorised ways of transport (e.g. cars) and the nature of the predominant leisure time activities (e.g. screen-based activities) [4].

In 2019, ischaemic heart disease and stroke were the leading causes of disease burden worldwide for adults aged 50 years and over [5]. Since 2013, cardiovascular disease has also become the main cause of death and disability-adjusted life years in developing countries too, overcoming deaths due to infection and neonatal disorders [6]. In the coming decades, the burden of cardiovascular disease is expected to rise sharply in both the developed and developing countries due to the population ageing and the upward trajectory increase in the prevalence of several cardiovascular disease risk factors, such as ultra-processed food consumption [7] and obesity [8]. In the United States, for example, cardiovascular disease prevalence has been projected to rise by 10% between 2010 and 2030 [9]. The importance of moderate-to-vigorous physical activity for preventing and treating cardiovascular disease is well established, and this is reflected by the consistent and prominent inclusion of quantitative physical activity guidance in position statements or treatment/prevention recommendations put forward by major cardiovascular health authorities around the world, such as the American Heart Association [10, 11], the Joint British Societies [12] and the Brazilian Society of Cardiology [13]. For more information on existing recommendations on sedentary behaviour please refer to Sect. 1.3. This is not surprising given that the question of whether sedentary behaviour is a promising target for preventing cardiovascular disease *in its own right* has been posed relatively recently and remains unanswered, as we shall see in the following sections. For many decades, both cardiovascular medicine and health promotion were concerned with structured aerobic exercise of a given dose and intensity, but this unilateral approach was abandoned in the years that followed the publication and dissemination of the US Surgeon General's report on 'Physical Activity and Health', which had incidental moderate intensity physical activity at its very core [14]. The main attraction of targeting solely sedentary behaviour as a health intervention (as opposed to promoting moderate-to-vigorous physical activity) is the widespread perception that many of the barriers commonly encountered in starting and adhering to a physical activity programme (e.g. lack of time, affordability, need for supervision by a trained expert, poor access to exercise facilities, deconditioning and inadequate skills and fitness levels) are less relevant for interventions aiming to minimise sedentary behaviour. In other words, it is only a relatively small part of the adult population who can and are willing to engage in physical activity, but it is well within everyone's capacity to sit less (see Fig. 8.1).

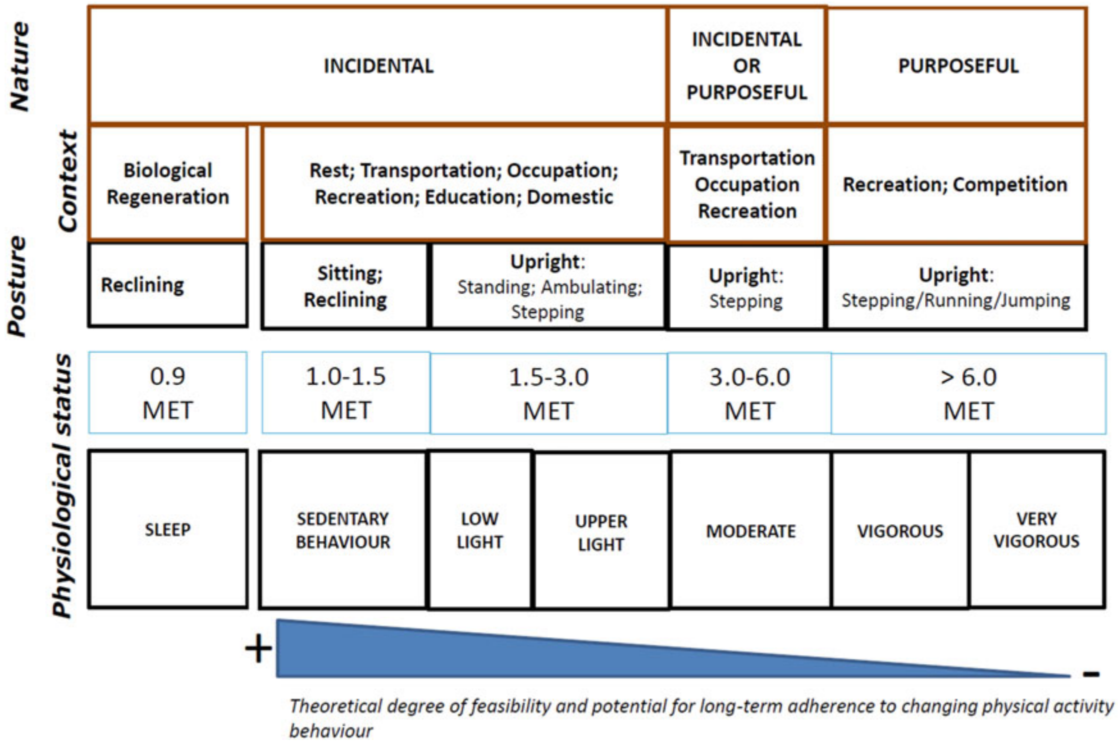

Fig. 8.1 A simplified representation of the *24-hour physical activity and sleep continuum* according to (from bottom to top): physiological status, posture, context and nature. The sedentary behaviour paradigm is primarily concerned with replacing time spent sitting (<1.5 MET) with an upright posture of low light and upper light activities of daily living, an approach that is assumed to be more feasible than the historical focus of public health and cardiovascular clinical practice on moderate and vigorous intensity physical activity and structured exercise

8.1.1 Defining Sedentary Behaviour

Historically, the term ‘sedentary’ had been used interchangeably with the term ‘physically inactive’ to denote low or no engagement in physical activities. One of the first attempts to delineate a unique definition was published in 2008 and involved only the physiological (energy expenditure-related) aspects of sedentary behaviour, that is, an energy expenditure rate of <1.5 metabolic equivalents (METs) [15]. The uptake of this definition was relatively modest, and no universal consensus had been reached during the first 10–15 years of sedentary behaviour research [16]. In 2017, the Sedentary Behaviour Research Network filled this gap with the Terminology Consensus Project [17], a systematically developed comprehensive definition framework for relevant terms (including physical inactivity, stationary behaviour and sedentary behaviour). The 2017 definition for ‘sedentary behaviour’ (an energy expenditure rate < 1.5 METs in a sitting or reclining posture during waking times) was essentially identical to a 2013 Sedentary Behaviour Research Network definition proposed in a letter-to-the editor [18] (Sect. 1.1). Although the existence of a systematically developed terminology framework is invaluable, there are areas for further improvement in the 2017 definition of ‘sedentary behaviour’. For example, the inclusion of reclining in the latter definition may have questionable public health relevance as daytime reclining is a rather unusual behaviour in most contexts (e.g. work, transportation, socialising). As previously noted [19], the tabled MET values for common types of sitting range from 1 to 2 METs [20] and therefore do not strictly conform with this definition. Additionally, this definition does not readily define the societal, and operational context of sedentary behaviour (see Fig. 8.1). For epidemiologic studies with cardiovascular disease endpoints (or any other major health outcome), the context where sedentary behaviour takes place is important because, for example, every domain has its own (measured, unmeasured or unmeasurable) confounders that may obscure our understanding of its links with health outcomes and because understanding of the context is necessary for designing targeted interventions.

8.1.2 Historical Context of Sedentary Behaviour as a Cardiovascular Risk Factor

The first study that provided indirect and unintentional evidence on sedentary behaviour and cardiovascular health was Jerry Morris’ (1953) seminal epidemiological study among 31,000 employees of London Transport aged 35–64 years [21]. Although the study was not specifically designed to disentangle the cardiovascular benefits of physical activity from the risks of sitting, the main finding was that the largely sedentary bus drivers had almost double the age-adjusted rate of fatal coronary heart disease when compared with conductors who spent much of their workday climbing stairs, walking and standing. Morris’ work is also the very first example of a study where the context of bus drivers' sitting was not fully accounted for, that is, the fact that, contrary to bus conductors, bus drivers had limited or no opportunity for potentially cardiovascular health promoting social interactions [22] during the work day. Nevertheless, in the following decades, other studies that compared cardiovascular disease risk between sedentary and routinely active occupations confirmed Morris' findings. But for almost 50 years following Morris' publication, sedentary behaviour received hardly any explicit attention as a distinct behavioural cardiovascular health risk factor. The precursors of the field of sedentary behaviour as distinct from physical activity can be traced back to two high-profile publications at the turn of the century [16, 23, 24] that coined the term 'non-exercise activity thermogenesis' (NEAT), a term describing incidental movement and non-structured low-intensity physical activity such as fidgeting, standing, ambulating and incidental walking. The core NEAT proposition was that as structured exercise makes up a very small proportion of daily physical activity energy expenditure, obesity can be tackled by energy expenditure increases through incidental movement, fidgeting and less sitting. It was not until the turn of the millennium when the first epidemiologic studies of TV viewing and obesity [25–27] or broader cardiometabolic risk [27, 28] contextualised sedentary behaviour as a distinct behavioural cardiovascular disease risk factor that may not simply be the inverse of moderate-to-vigorous physical activity. The eloquent review of Hamilton et al. [29] gave further momentum to the field by proposing a widely cited physiological and mechanistic framework for the cardiometabolic effects of sedentary behaviour that was distinct from the pathways through which physical activity exerted its beneficial effects on the cardiovascular system. Hamilton's proposition, which was enthusiastically promoted by mass media, defined the initially epidemiological framework for examining the links between sedentary behaviour and physical activity and cardiovascular health (Fig. 8.2). There were calls to introduce public health guidelines on sitting as early as 2008 [30]. The response to a relatively small volume of accumulated research in this area has been the inclusion of sedentary behaviour related messages in several national physical activity guidelines aimed at adults and children, including the United Kingdom in 2011 [31], Australia [32], New Zealand [33], Canada [34], Germany [35], Norway [36] (see Table 8.1) and in statements of eminent scientific authorities [37]. A set of quantitative workplace-specific sedentary behaviour guidelines [38] recommended reducing worktime sitting by up to 4 h/day. Calls for developing population-wide quantitative sitting guidance continued apace, and they were eventually actioned by the 2020 Canadian 24-hour movement guidelines, which included a specific threshold for limiting daily sitting to under <8 h, as well as recommendations for increasing number of 'sedentary breaks' and standing more [39]. The sedentary behaviour-centric Canadian 2020 guidelines, which to some extend were derived using cross-sectional evidence [40], are an exception rather than the rule. Both the World Health Organization Guidelines Development Group (WHOGDG) in 2020 and the Physical Activity Guidelines for Americans Committee (PAGAC) in 2018, which reviewed roughly the same evidence base reviewed by the Canadian guidelines, were considerably more conservative in their handling of sedentary behaviour recommendations.

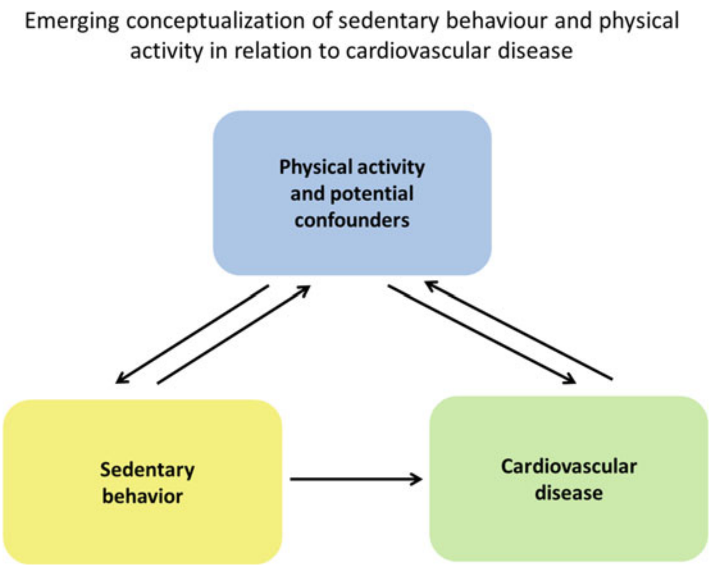

Fig. 8.2 A nearly conceptualisation of the relationships between sedentary behaviour, physical activity and cardiovascular outcomes

For example, WHOGDG included one generic recommendation on limiting sedentary time [41], and PAGAC [42] did acknowledge sedentary behaviour but provided no specific recommendation. Please refer to Sect. 1.3 for more information on existing recommendations on sedentary behaviour.

8.1.3 Prevalence of Sitting

Among other reasons, understanding the prevalence of sedentary behaviour in the population is important because of the likely 'threshold effect' characterising the association between sitting and cardiovascular disease, as elaborated in the sections below. That is, a threshold of daily amounts of sitting below which we do not observe elevated cardiovascular disease risks at the population level, such as the threshold that has been described for sitting and all-cause mortality [43]. There is a plethora of studies describing the distribution of sedentary behaviour in a variety of settings and populations. A comparative study of over 49,000 adults in 20 countries [44] reported a median of 5 h of self-reported sitting a day but also considerable between-country variation, with daily medians ranging from 3 h or less (Portugal, Brazil and Colombia) to 6 h or more (Taiwan, Norway, Hong Kong, Saudi Arabia and Japan). This median of about 5 h/day is concordant with a study of over 27,000 adults from 32 European countries where the median across all countries was 5 h/day

Table 8.1 Examples of the first countries that released official sedentary behaviour public health recommendations for adults

Country, year, issuing body	Sedentary behaviour guideline component 1	Sedentary behaviour guideline component 2
Australia, 2014, Department of Health	Minimise the amount of time spent in prolonged sitting[a]	Break up long periods of sitting as often as possible[a]
Germany, 2017, German Federal Ministry of Health	Adults and older adults should avoid long periods of sitting[b]	Adults and older adults should break up sitting time by physical activity whenever possible[b]
New Zealand, 2015, New Zealand Ministry of Health	Sit less[c]	Break up long periods of sitting[c]
Norway, 2014, Norwegian Directorate of Health	Sedentary time should be reduced[a]	Long periods of sedentary behaviour should be interrupted with activity breaks[a]
UK, 2011, Department of Health/ The Four Home Countries' Chief Medical Officers	All adults should minimise the amount of time spent being sedentary (sitting) for extended periods[d]	Taking regular breaks at work; breaking up sedentary time such as swapping a long bus or car journey for walking part of the way[d]

[a]The two components appear in the same sentence/as one recommendation

[b]The two components appear as separate recommendations

[c]The two components appear as one recommendation but in different sentences

[d]In the UK guidelines, sedentary breaks appear as an example of how to minimise sedentary behaviour. In the full guidelines document explanatory notes, it is stated that "*Based on the current evidence, reducing total sedentary time and breaking up extended periods of sitting is strongly recommended*"

[45] and self-reported US data [19]. A more recent comprehensive scoping review of country-level questionnaire data representing 47% of the global adult population found that the median of mean daily sitting times was 4.7 (interquartile range (IQR): 3.5–5.1) hours across all countries. Sitting time was higher in high-income countries compared to lower-income countries (4.9 vs 2.7 h) [46].

On the other hand, it is not clear whether total sitting has changed in the recent decades. A review estimated that mean occupational energy expenditure in US men has decreased by some 140 calories/day over the period from 1960 to 2006 [3]. In contrast, a study on trends of total sitting from 27 European countries found that the prevalence of self-reported high sitting (>7.5 h/day) decreased steadily from 23.1% in 2002 to 21.8% in 2005 and 17.8% in 2013 [47].

National surveillance studies that used waist-worn accelerometers to estimate the prevalence of sedentary behaviour reported much higher daily averages than the self-reported studies cited above, for example, 7.5–8 h/day for working age adults in the United States [48] and 9.5 h/day for working age adults in England in 2008 [49]. Waist-worn devices used in the above national US and UK accelerometry studies have numerous limitations as a sedentary behaviour prevalence monitoring tool, including their innate inability to differentiate between sitting and standing, the incomplete recording times as they are typically worn for approximately 80–85% of waking time around or an average of about 13–14 h/day [48, 49], with the remaining 15–20% (3–4 h/day) being unclassified. Interestingly, in a large population study of over 200,000 Australians aged 45 years and over [50], the sum of self-reported sitting and standing was 9.1 h/day (5 h/day sitting plus 4.1 h/day standing). These averages of self-reported sedentary time are roughly comparable with the waist accelerometry estimates of the English study above [49] but are well below the sitting times reported in studies that used thigh-worn accelerometers (which are the only devices that can specifically differentiate time spent sitting/reclining, standing and stepping) [51–54]. Although such studies were not sampled to be nationally representative and vary considerably in scope/geographical context/age range, they have reported remarkably consistent average postural allocation times. For example, the Australian Diabetes, Obesity, and Lifestyle Study (AusDiab) of 700 participants aged 35 years and over recorded an average of 8.9 h/day of sitting [51], the Maastricht Study of approximately 2500 Dutch participants aged 40–75 recorded 9.4 h of sitting/day [52] and the 1970 British Cohort study that recorded an average of 9.3 h/day in a sample of adults aged 43–46 years [53, 54]. While the diverse populations studied make it difficult to make direct comparisons, the possibility that questionnaires largely underestimate sitting time by almost 50% is very high. Such a likely overestimation may have consequences when interpreting studies on the dose response of sitting and cardiovascular outcomes, as discussed in Sect. 8.2.2 below. For further information on the prevalence of sedentary behaviour, please refer to Chap. 2.

8.1.4 Television Viewing and Other Recreational Screen Time

Much of the sedentary behaviour literature, in particular in the early days [25–27], was consumed with the study of the associations of screen time, in particular television (TV) viewing, and cardiovascular disease [55, 56]. While this literature was very valuable in that it brought scientific, policy and public attention to an important issue and unarguably propelled the sedentary behaviour field of research, it offers poor information on the links between excessive sitting, which is the core behavioural problem, and cardiovascular health. At face value, such a focus is justified because screen media is a major *discretionary* component of total sedentary behaviour, with national surveys showing that adults spend some 2.5–4 h/day watching TV. Although TV time has historically been the largest component of screen time, this is rapidly changing due to the advent and popularisation of multiple screen devices that are owned by large parts of the population. But, overall, TV is a poor indicator of overall sedentary behaviour [57, 58] that is largely confounded by factors that are not fully accounted for in epidemiologic studies, such as socioeconomic status [59, 60], dietary intake [61] and mental health [62]. Recent UK Biobank analyses involving accidental causes of death as negative controls concluded that the association of TV time and ischaemic heart disease mortality are likely due to confounding [63]. Aspects of TV and screen media other than the sitting posture such as programme content, excessive exposure to advertising (and development of potentially unfulfilled needs to consume) or the exposure to excessive amounts of negative messages that may act as chronic psychological cardiovascular stressors [64] have hardly been acknowledged by the sedentary behaviour field and therefore represent universal residual confounders in the literature.

With all these considerations in mind, this chapter will place prominence on the prospective epidemiologic literature of self-reported sitting and on device-assessed sedentary behaviour and to a lesser extent on TV and other screen media.

8.2 Sedentary Behaviour and Cardiovascular Disease Across the Life Course

Age is unarguably the most important cause of cardiovascular disease [65]. For instance, in 2019, the Global Burden of Disease study estimated that cardiovascular disease incidence rates (per 100,000 inhabitants) at 15–49, 50–69 and 70 or more years were 215, 1750 and 5566, respectively [66]. In high-income countries, the median age of cardiovascular disease events and deaths are much higher than in low- to middle-income countries [7]. Much of cardiovascular disease occurrence could be prevented or postponed by addressing the major behavioural risk factors, socioeconomic, political and environmental factors predisposing to the disease. None of these risk factors emerge suddenly in adulthood, and there is an imperative to consider the development of cardiovascular disease and the different exposures that influence it, including unhealthy behaviours, in the context of the life course (gestation, infancy, childhood, adolescence, young adulthood, midlife and older age) (see Fig. 8.3) [67]. The majority of the evidence about these early life and adulthood cardiovascular disease risk factors is mostly concerned with high blood pressure, dyslipidaemias, impaired glucose tolerance, height, obesity and certain unhealthy behaviours, such as tobacco smoking, physical inactivity and unhealthy diet [67–70]. Nonetheless, unhealthy behaviours during middle age and later in life have shown to increase the risk of cardiovascular disease, regardless of the behaviours you had early in life. For instance, the seminal study published by Paffenbarger and colleagues examined the association of changes in unhealthy behaviours and cardiovascular disease mortality in middle-aged and older men [71]. After more than a decade, men who increased their physical activity level had 41% lower risk of deaths from coronary heart disease than those who remained physically inactive [71]. These results support the idea that changes in unhealthy behaviours later in life have a

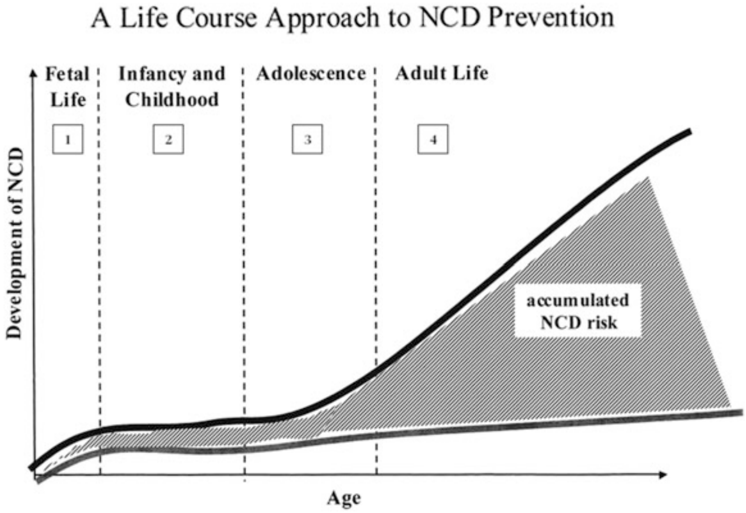

Fig. 8.3 A life course approach to the development of non-communicable disease (NCD) including cardiovascular disease. Multiple risk factors (including physical activity and perhaps sedentary behaviour) act cumulatively or synergistically from early life, and risk is rising steeply from early mid-life. *Copyright free material, reproduced: from Aboderin, I., Kalache, A., Ben-Shlomo, Y., Lynch, J.W., Yajnik, C.S., Kuh, D., Yach, D. (2002) Life Course Perspectives on Coronary Heart Disease, Stroke and Diabetes: Key Issues and Implications for Policy and Research. Geneva, World Health Organization*

profound impact on cardiovascular disease outcomes. For more details on cardiovascular disease mortality, please refer to Chap. 14.

The life course epidemiology of sedentary behaviour is a new research area, and as we shall see in the next section, there are many uncertainties around its cumulative and acute role in cardiovascular disease development. The majority of the evidence is based on middle-aged and older populations, which limits understanding of lifetime risk of sedentary behaviour on cardiovascular health. Therefore, many questions need further clarification regarding the role of sedentary behaviour across the life course for cardiovascular disease development, such as the following:

- Is there a critical period of life in which sedentary behaviour impacts physical or structural functions resulting in cardiovascular disease later on?
- Do later life behaviours modify the effect of early exposures to sedentary behaviour (including during critical periods) on cardiovascular disease?
- Is there a synergistic effect of sedentary behaviour with other risk factors at each stage of life that raise cardiovascular disease risk?
- Can adequate moderate-to-vigorous activity offset the acute or cumulative cardiovascular risks associated with sedentary behaviour across the life course?
- How socioeconomic and broader life circumstances across the life course influence the cardiovascular effects of sedentary behaviour?

Many of these questions could not be answered with confidence even if they referred to moderate-and-vigorous physical activity and other unhealthy behaviours that are much more mature as areas of research than sedentary behaviour. Nevertheless, the plethora of large birth cohorts around the world that may conclude in our lifetime and are increasingly using sophisticated technologies to measure posture and other lifestyle factors offer much promise for understanding better the cardiovascular properties of sedentary behaviour.

8.2.1 Sedentary Behaviour in Youth in Relation to Cardiovascular Health

Compared to adults, youth in Western countries spend lower amounts of time being sedentary; for example, the average (waist) accelerometry-estimated sedentary time of 5–15 years old in England is 7–8 h/day [72]. Since no studies with mortality or cardiovascular 'hard endpoints' can be carried out in children, the literature is only concerned with surrogate cardiovascular markers. A sizeable body of mostly cross-sectional studies suggests that children and adolescents participating in moderate-to-vigorous physical activity have better cardiometabolic risk factor profiles than their inactive peers [73, 74]. The sedentary behaviour literature on the same topic is also emerging, but there is an apparent paucity of prospective studies. Cross-sectional studies have consistently shown that TV (but not all other kinds of screen time) is associated with adverse levels of a range of cardiovascular risk factors in youth [75–77]. However, TV viewing is a complex exposure, and one cannot confidently attribute any observed effects on the sitting that TV viewing entails, as discussed earlier in this chapter.

The largest objective study of total sedentary behaviour and cardiovascular risk markers was a pooled analysis of the International Children's Accelerometry Database comprising 14 studies carried out between 1998 and 2009 that included a total of 20,871 children and adolescents (aged 4–18 years) that wore waist-worn accelerometers [78]. Sedentary time was not associated with any cross-sectional outcomes, but moderate-to-vigorous physical activity was inversely associated with triglycerides, high-density lipoprotein (HDL) cholesterol and blood pressure independently of sedentary time. Baseline sedentary time did not predict waist circumference in a sub-sample of almost 6500 participants, but baseline waist circumference predicted sedentary time over an average follow up of 2.1 years [78]. This finding is in line with a cross-sectional accelerometry study of about 5400 twelve years old that found no associations between sedentary time and dual energy X-ray absorptiometry (DXA) assessed body fat mass or body mass index (BMI) [79].

The prospective study in the field with the longest follow-up to date is an analysis of the Avon Longitudinal Study of Parents and Children (ALSPAC) cohort that examined the associations between objectively assessed sedentary behaviour (waist-worn accelerometers) with broad cardiovascular risk profiles (systolic and diastolic blood pressure, fasting triglycerides, total, low density lipoprotein (LDL) and HDL cholesterol, glucose, insulin, c-reactive protein, a clustered standardised cardiometabolic risk score, and three adiposity markers including percentage body fat) over a follow-up of approximately 3.5 years [80]. Device-assessed daily sedentary time was not prospectively associated with any outcomes, but moderate-to-vigorous physical activity was beneficially associated with percent body fat, insulin, HDL cholesterol and clustered cardiometabolic score.

The 1993 Pelotas (Brazil) Birth Cohort Study leveraged a cohort of 3613 participants to examine the association of physical activity and screen time with indicators of cardiometabolic risk during adolescence. Physical activity and screen time were measured at ages 11, 15 and 18 years. Indicators of cardio-metabolic risk (fat mass index, waist circumference, triglycerides, blood glucose, non-HDL cholesterol and resting diastolic blood pressure) were measured at 18 years. There were no statistically significant association between physical activity and sedentary behaviour at 11 and 15 years with cardiometabolic outcomes at 18 years [81].

Another small ($n = 723$), very short-term (<7 months of follow-up) prospective study [82] of children aged 8–11 years looking at objectively measured sedentary time in relation to a range of cardiometabolic outcomes (blood pressure, homeostatic model assessment of insulin resistance (HOMA-IR), triglycerides and HDL cholesterol) also reported null associations.

A population Dutch birth cohort including 1447 adolescents followed over 1 year found that screen time at 11 years of age was positively associated with adiposity and cardiometabolic markers (total-to-high-density lipoprotein cholesterol (TC/HDLC) ratio, blood pressure, glycated haemoglobin) at 12 years. Of note, the association between screen time and cardiometabolic risk was almost completely mediated by adiposity, suggesting no direct association of screen time with TC/HDLC [83].

Collectively, the literature summarised above casts doubt on the idea that sitting merits attention as a stand-alone (separate to moderate-to-vigorous physical activity) target for cardiovascular health-related interventions in young people, and this is consistent with the totality of the evidence on sedentary behaviour in youth in relation to broader developmental and health outcomes [84]. But, as alluded to above, it is worth considering that the lack of association between sedentary behaviour in youth and surrogate cardiovascular endpoints could be due to the long latency to develop a non-communicable disease (Fig. 8.3). In middle-aged adults, for example, the cardiometabolic harms associated with any chronic poor lifestyle habit, including excessive sedentary behaviour, will be accumulated over several decades and will follow a sequence of natural disease progression stages – that is, subclinical (raised biological risk factors with no symptoms) – clinical (diagnosed disease through an event) and fatal event trajectory. In children and adolescents, the pathogenesis associated with lifestyle-related exposure such as sitting may not have been acting long enough to progress to subclinical and clinical expressions of the disease. If this lifetime risk accumulation assumption is proved to be correct, interventions targeting sedentary time alongside physical activity in childhood/adolescence would still be important despite the null findings in the few available longitudinal studies. Nevertheless, this assumption can only be tested using long-term life course studies with repeated measures of device-assessed sedentary time and cardiovascular health markers. Since physically active children and adolescents have been shown to be more likely to be active as adults [85], limiting sedentary behaviour in youth could also be approached from the habit formation point of view and to a lesser extent in expectation of immediate measurable cardiovascular health benefits. Although other lifestyle exposures such as diet and low moderate-to-vigorous physical activity are associated with cardiovascular risk endpoints [86], such endpoints may be less responsive to a subtle exposure like sedentary behaviour. Of course, we cannot preclude the possibility that the lack of association in prospective epidemiological studies simply indicates that higher sedentary behaviour *in its own right* (i.e. independently of physical activity) does not cause deterioration of cardiovascular risk profiles in young age.

8.2.2 Sedentary Behaviour and Cardiovascular Disease in Adults and Older Adults

Meta-Analyses of Prospective Studies of Sedentary Behaviour and Cardiovascular Disease

There have been at least seven major meta-analyses of (mostly prospective) epidemiological studies synthesising the associations between sedentary behaviour and incident cardiovascular disease [87–93]. Grontved and Hu reviewed studies of TV and screen time and reported a pooled relative risk (RR) of 1.15 (95% confidence interval (95% CI): 1.06–1.23) for fatal or nonfatal cardiovascular disease per 2 h of TV per day [87]. Biswas and colleagues considered a non-specific mixture of TV studies and sitting studies and reported pooled RRs comparing low versus high levels of sedentary behaviour exposure of 1.18 (95% CI: 1.11–1.26) for cardiovascular death and 1.14 (95% CI: 1.00–1.73) for cardiovascular events [88]. Wilmot and colleagues also considered a non-specific mixture of TV studies and sitting studies and reported RRs of 1.90 (95% Credible Interval (95% CrI): 1.36–2.66) for cardiovascular death and 2.47 (95% CrI: 1.44–4.24) for cardiovascular events [90]. Ahmad and colleagues found that greater sedentary time was associated with increased risk of cardiometabolic diseases among the South Asian adults. Compared to those reporting <70 min/day of sedentary time, adults reporting ≥ 250 min/day of sedentary time had a 58% higher risk of myocardial infarction (RR 1.58; 95% CI: 1.05–2.36) [93]. In a systematic review of five cohort studies, covering adults aged 44–64 years and mean follow-up ranging from 2.7 to 13 years, Bailey et al. found that higher total daily sitting time was associated with significantly higher risk of cardiovascular diseases ((hazard ratio) HR 1.29; 95% CI: 1.27–1.30). After adjusting for physical activity, the association was attenuated (HR 1.14; 95% CI: 1.04–1.23) but remained statistically significant [91]. The meta-analysis by Patterson and colleagues found a non-linear dose response of total sedentary behaviour for cardiovascular disease mortality among 667,524 participants from six non-physical activity adjusted and five physical activity-adjusted studies, with weaker evidence for an association for ≤6 h of sitting per day (RR per additional sedentary behaviour hour 1.01; 95% CI: 0.99–1.02) than >6 h/day (RR 1.04; 95% CI: 1.03–1.04) [92].

One of the few dose-response meta-analyses on sitting (i.e. excluding TV studies) and incident cardiovascular disease or cardiovascular disease mortality to date, Pandey et al. [89] identified nine prospective studies and reported a pooled RR of 1.14 (95% CI: 1.09–1.19) for highest (median: 12.5 h/day) versus lowest (median: 2.5 h/day) sitting categories. There was no evidence for differences in risk between the lowest and intermediate sitting category (median: 7.5 h/day) (pooled HR: 1.02; 95% CI: 0.96–1.08) [89]. The key studies included in this systematic review are briefly summarised here.

One of the first epidemiologic studies in the field was that of Katzmarzyk et al. [94], and it found an increased risk of cardiovascular disease in those who reported sitting almost all the time versus almost none of the time (HR: 1.54; 95% CI: 1.09–2.17). In Finland, sitting more than 10 h/day showed weak evidence of an association with higher cardiovascular disease risk versus sitting ≤10 h/day (HR: 1.45; 95% CI: 0.91–2.29) [95]. In the United States, Kim et al. found an increased risk of cardiovascular disease in women (total self-reported sitting >10 h/day) 1.19 (95% CI: 1.06–1.34) but not in men (HR: 1.06; 95% CI: 0.96–1.18) [96]. Conversely, in a sample of 6154 Australian women, no association was found in those who self-reported more than 8.4 h/day sitting versus less than 2.7 h/day (HR 0.90; 95% CI: 0.62–1.32) [97]. A similar finding was reported in Denmark [98], where no associations between sitting time and coronary heart disease (HR: 1.06; 95% CI: 0.88–1.28) or myocardial infarction (HR: 1.13; 95% CI: 0.78–1.64) were found during a 5-year follow-up. Finally, in a recent US study [99], self-reported sitting of more than 12 h/day versus less than 5.8 h/day was associated with an increased risk of cardiovascular disease in a white population but not in the black population. Patel et al. [100] evaluated the effect of non-occupational sedentary time on cardiovascular disease mortality during a follow-up of 14 years in a large sample of 123,216 men and women (57% women). Self-reported sitting >6 h/day (versus <3 h/day) was significantly associated with increased cardiovascular mortality risk (RR in women: 1.33; 95% CI: 1.17–1.52; RR in men: 1.18; 95% CI: 1.08–1.30). Similarly, in 240,819 US participants (44% women), Matthews et al. [58] found that total sedentary time > 9 daily hours (versus >3 h/day) increased the risk of cardiovascular disease mortality (HR 1.16; 95% CI: 1.02–1.30). In 71,018 US women [101], sitting ≥10 h/day was associated with increased cardiovascular disease risk (HR:1.15; 95% CI: 1.05–1.25) versus ≤5 h/day.

Dose-Response Relationship Between Sitting Time and Cardiovascular Disease The meta-analysis by Pandey et al. [89] was the only review to specifically examine the dose-response element of the examined associations with regard to cardiovascular disease risk. Similarly to meta-analytical work on sitting and all-cause mortality risk [43], Pandey et al. found a non-linear association between sitting time and risk for cardiovascular disease with an increased risk only for sitting more than 10 h/day

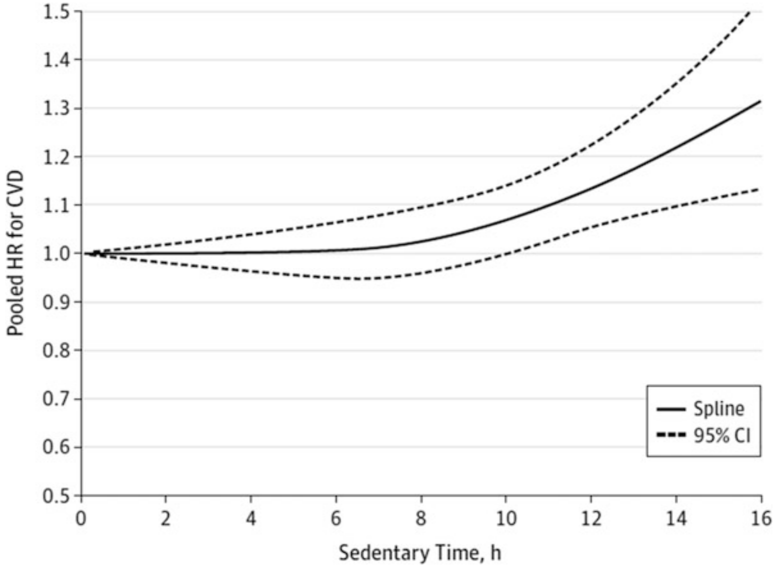

Fig. 8.4 Dose-response association between total sedentary duration and risk for incident cardiovascular disease. The graph here shows spline (smoothed fit) and 95% confidence interval of pooled hazard ratio of cardiovascular disease by hour. *Reproduced with permission from: Pandey A, Salahuddin U, Garg S, Ayers C, Kulinski J, Anand V, Mayo H, Kumbhani DJ, de Lemos J, Berry JD. Continuous Dose-Response Association Between Sedentary Time and Risk for Cardiovascular Disease: A Meta-analysis. JAMA Cardiol. 2016 Aug 1;1(5):575–83*

(see Fig. 8.4). Specifically, there was no association with cardiovascular events at sedentary times >6.8 h/day (pooled HR, 1.01; 95% CI: 0.95–1.08), but there was an association at times higher than 10.04 h/day (pooled HR:1.08; 95% CI: 1.00–1.14). Considering that all included studies used questionnaires to quantify sitting, such a threshold is very high as it corresponds to almost twice the average of self-reported sitting reported by international prevalence studies [44, 45] or studies that examined cardiovascular effects of siting [97]. Studies that measured sitting using inclinometers, on the other hand, consistently report daily sitting times in the region of 9–9.5 h [51, 52]. If this large discrepancy between objective and self-report daily sitting estimates is due to systematic under-reporting of sitting in questionnaire-based studies, there is a possibility that the 10 h/day threshold identified by Pandey et al. [89] may be even higher. These measurement-related considerations and other limitations of the literature, such as the large heterogeneity of the methods used among studies, impede a definitive determination of the theoretical curve and exact effect threshold between sitting time and cardiovascular risk.

Sedentary Breaks

A widely discussed concept is that of 'sedentary breaks', that is, the introduction of frequent and regular interruptions of continuous bouts of sitting that has been proposed to confer cardiovascular and metabolic benefits even when total sitting time is held constant [102]. Different variations of such interruptions are included in the guidance of several countries [31–33, 35, 36, 39], and in the case of the New Zealand guidelines [33], 'Sit less, breaking sedentary time' appears before the physical activity recommendation.

To date, no prospective study has shown associations between sedentary breaks and cardiovascular outcomes. Baseline sedentary breaks did not predict any of five surrogate cardiometabolic outcomes at 6-month follow-up in a study of 582 patients with type 2 diabetes mellitus [103] and were not associated with all-cause mortality over 5 years of follow-up in a recent study of 1655 older British men [104]. Even the cross-sectional evidence base presents an unclear picture that often also point towards no associations. In the study of about 170 Australian participants aged 30–87 years that first introduced the concept of sedentary breaks, the number of breaks measured by a waist-worn accelerometer was inversely associated with triglycerides and to a lesser extent with adiposity surrogate markers and 2-hour plasma glucose [102]. A larger investigation by the same group using accelerometry data among 4757 US adults aged 20 years and over [105] reported inverse associations of breaks only with C-reactive protein (CRP) and waist circumference but no associations with the remaining six examined cardiometabolic risk factors (that included blood pressure, HDL-cholesterol and fasting triglycerides). Thus far, the largest cross-sectional study that used inclinometers to examine the associations between sedentary breaks and metabolic outcomes (glucose metabolism) among 2497 Dutch middle-aged adults found no association between the two. Overall, there is little evidence to suggest that sedentary breaks have an effect on lipidaemia and that sedentary breaks consisting of lower light intensity activity such as standing can produce favourable responses of cardiovascular markers [106, 107]. To maximise the public health relevance research investment in this area, future efforts will benefit from tighter definition to clarify whether sedentary breaks refer to interruptions of sitting with any upright activity, in particular standing, or a 're-branded' version of interrupting sitting time with frequent *ambulatory* light- or moderate-intensity physical activity. Currently, the evidence points towards the latter possibility. Also, the cardioprotective effects of light-intensity physical activity (that is often considered the opposite of sedentary time) is largely under-researched [37].

Beyond the limited support of observational studies, several laboratory-based trials have consistently shown beneficial acute effects of interrupting continuous sitting with physical activity on postprandial cardiometabolic markers [108]. Such studies have demonstrated effects of frequent interruptions of continued sitting (e.g. 2–3 minutes of light-intensity activity every 20–30 minutes over several hours) on postprandial glucose and insulin and to a lesser extent on classical cardiovascular biomarkers such as triglycerides and cholesterol [106]. While such studies provide important mechanistic insights, there are several issues that complicate their translation into *sitting-specific* population guidance. First, it is unclear if the cardiometabolic benefits of sedentary breaks are due to (a) higher energy expended during the light-intensity activity bouts, (b) the muscular contraction occurring during the transition from sitting to standing (and vice versa), or (c) by the change in posture (which is what the sedentary breaks hypothesis mostly postulates). The finding that *standing* breaks appear to have an effect among metabolically compromised (e.g. dysglycemia or type 2 diabetes mellitus patients [109] but not healthy adults support interpretation a or b: even subtle muscular contraction during the sitting to standing transition generates measurable improvements among those with impaired levels of metabolic markers. Second, there is currently no indication that such acute and relatively subtle beneficial responses to interrupting sitting translate into improved long-term outcomes. This is an important aspect of the interpretation of these small laboratory-based studies given that the link between surrogate type 2 diabetes mellitus outcomes and long-term cardiovascular implications is not always clear [110, 111]. For example, evidence from pharmacological trials suggests that even intensive glycaemic control often does not translate into better cardiovascular disease mortality and morbidity outcomes [110, 112]. In the absence of any degree of congruence between mechanistic and prospective evidence, the use of such laboratory-based evidence to develop conclusive public health guidance may be less appropriate. Despite the paucity of evidence outlined above, sedentary breaks were included in the public health guidelines of at least four countries [32, 33, 35, 39] in the last 10 years. The more comprehensive evidence evaluation by the 2018 Physical Activity Guidelines for Americans Advisory Committee Scientific Report concluded that there was insufficient evidence for sedentary breaks across all examined health outcomes [113].

Occupational Sitting and Cardiovascular Disease

Sedentary time occurs in the domestic, transport, occupational and leisure time domains (see Fig. 8.1). Despite the limited number of studies examining the impact of each domain of sitting time on health outcomes, to examine the effect of prolonged sitting at work is particularly important for public health because most current work environments impose prolonged sitting. An early systematic review [114] found no consistent associations between occupational sitting and cardiovascular disease. Such inconsistency in results is perhaps a sign of the complexities of disentangling the independent health effects of occupational sitting. A possible explanation is that higher social status linked with sedentary occupations [59] might offset any adverse effects linked with the sedentary nature of these occupations. This is a likely interpretation for the absence of association of occupational sitting and cardiovascular mortality in men, found in England and Scotland [115]. Also, the presence or absence of other cardio-metabolic risk factors can influence the risk of cardiovascular mortality. A Norwegian study [116] with a median follow-up of 12 years examining the physical labour demands of different occupations found no associations with cardiovascular mortality among those without metabolic syndrome. In people with metabolic syndrome, both physically demanding and sedentary jobs were associated with higher cardiovascular mortality risk. In a study of 7320 Canadian workers aged 35–74 years who were followed up for 12 years, occupations involving predominately standing were associated with an approximately twofold risk of incident cardiovascular disease, compare to occupations involving predominately sitting (HR for standing compared to referent sitting 1.97; 95% CI: 0.99–3.90) [117].

8.3 Perspectives on the Evidence Linking Sedentary Behaviour and Cardiovascular Disease Risk

8.3.1 Biological Mechanisms

Despite the plethora of candidate mechanisms [118], no established and broadly replicated biological pathway linking sedentary behaviour and cardiovascular disease currently exists. A rodent model-based hypothesis suggested that prolonged sitting causes dramatic reductions of lipase lipoprotein enzyme activity compared to standing up or ambulating regimes [119]. Although this hypothesis was put forward over 15 years ago, it has yet to be replicated in humans. Human studies that manipulated sitting experimentally indirectly refute this hypothesis as there appears to be no effect from replacing sitting with standing on blood lipids [106, 120–122]. More recently, prolonged sitting has been implicated in endothelial cell dysfunction caused by reduction in leg blood flow-induced shear stress [123]. This is a coherent mechanistic framework, but it does not support independent effects of sitting as it acknowledges that endothelial dysfunction is prevented if sitting is preceded by an exercise bout [123]. Please refer to Sect. 5.6 for more details on the effects of sedentary behaviour on cardiovascular function and to Sect. 7.4 for more details on the experimental evidence linking sedentary behaviour with cardiometabolic markers and outcomes. Other proposed biological mechanisms include the lower expression of endothelial nitric oxide synthase (i.e. related to increased vascular oxidative stress) and reduction of glucose transporter type 2 and glucose uptake [30, 124].

In summary, some published cross-sectional and prospective studies suggest that sitting has detrimental associations with cardiovascular surrogate markers and cardiovascular disease incidence and mortality. The epidemiologic evidence on the effects of sedentary breaks on classic cardiovascular risk is very weak. An emerging body of mechanistic studies shows that frequent interruptions of sitting with light-intensity activity induces favourable glycaemic responses and endothelial function, although it is unknown if such acute responses translate into any longer-term cardiovascular benefits. The literature on the associations of occupational sitting with cardiovascular disease outcomes is largely inconclusive.

8.3.2 Appraisal of the Evidence: Are Associations between Sitting Time and Cardiovascular Disease Causal?

Whether associations found in epidemiological studies reflect causality is, to some extent, a philosophical endeavour based on the available information from a combination of theory, different methodological designs and triangulation of research evidence [125]. To this aim, in 1965, Sir Bradford Hill provided the widely publicised 'nine viewpoints' [126] to offer a guidance framework for studying associations before declaring causation. It is important to highlight that, as Hill himself stated, none of these points should be required as sine qua non for judging causality. The relevance of these causality criteria to contemporary science has been questioned [127].

Here, we provide a brief summary of the literature on sitting time and cardiovascular disease based on some of the core 'Bradford Hill' viewpoints. We based our appraisal mostly on the studies included in the recent Pandey et al. meta-analysis [89]. Evidence of 'temporality', that is, 'cause precedes the disease occurrence', has been observed in prospective studies, albeit some cohorts still present short average lengths of follow-up; thus, reverse causality cannot be ruled out [128]. The 'strength' (of the association) is relatively small, suggesting an 8% increased risk of cardiovascular diseases comparing ≥10 h/day versus <2.5 h/day, leaving open the possibility of residual confounding (e.g. dietary intake). There is evidence of a non-linear 'biological gradient' (dose-response relationship) between sitting time and cardiovascular disease, suggesting a high threshold (10 h/day) above which there is an increment in risk of cardiovascular diseases. Lack of clear (biological) 'plausibility' has been highlighted in the previous section. 'Consistency' of positive association between sitting time and cardiovascular diseases has been observed in five out of nice prospective cohort studies.

More recently, theory of causal inference has grown substantially and offered additional insights and assumptions for distinguishing association and causation [129]. Here, we present some basic reflections and definitions on whether sitting is causally linked with cardiovascular disease based on some of these concepts of causal inference. For pedagogic reasons, we ignored random error attributable to sampling variability, assuming that we have retrieved data from a very large (hypothetically infinite) population. For simplicity, we considered a dichotomous exposure variable A (1: ≥10 h/day of sitting time; 0: <10 h/day of sitting time) and a dichotomous outcome variable Y (1: cardiovascular disease; 0: no cardiovascular disease). Let $Pr[Y^{a=1}]$ be the risk (probability) of the cardiovascular disease that would have been observed in the population under the exposure $a = 1$, and $Pr[Y^{a=0}]$ be the risk of the cardiovascular disease that would have been observed in the same population, but now under the exposure $a = 0$. We now can formally define that sitting time has an average causal effect on cardiovascular disease if $Pr[Y^{a=1}] \neq Pr[Y^{a=0}]$. That is, the risk of cardiovascular disease if everybody had been exposed to ≥10 h/day of sitting time would be different (likely higher) than the risk of cardiovascular disease if everybody had been exposed to <10 h/day of sitting time. For instance, the causal risk ratio (or causal relative risk) could be calculated as $Pr[Y^{a=1}] / Pr[Y^{a=0}]$. Because these outcomes would have been observed in a situation that did not actually happen (i.e. individuals are either exposed ($A = 1$) or not exposed ($A = 0$); one situation is factual, and the other is in counter to the fact situation), we say that average causal effect could be computed by comparing counterfactual outcomes – *the effect measures*.

In real-life epidemiological studies, however, we are not able to compute the risk of outcome Y in the same population under different values/versions of exposure A ($A = 1$; $A = 0$), the counterfactual outcomes. Alternatively, we compare the risk of outcome Y in individuals with higher sitting time Pr[Y = 1 | A = 1] versus the risk of Y in individuals with lower sitting time Pr[Y = 1 | A = 0]. Thus, we compared different groups to compute associations, that is, differences in the risk of disease between groups – *the association measures*. For instance, the associational risk ratio (or associational RR) could be calculated as Pr[Y = 1 | A = 1] / Pr[Y = 1 | A = 0]. When association measures (associational risk ratio) differ from effect measures (causal risk ratio), we say that there is bias or confounding.

Causal inference has formally defined the sources of bias, as well as developed methods to identify causal effects from epidemiological studies – the identifiability conditions. The theory of causal diagrams or directed acyclic graphs (DAGs) is a useful tool for presenting and analysing these sources of bias and uncertainty in the results of epidemiological studies. DAGs are graphical, hypothetical and qualitative representations of the causal processes that ultimately give rise to the data and associations observed in the studies. These diagrams are built from prior knowledge of the relationships between the variables and, therefore, are important for the formalisation of hypotheses and assumptions in which associations observed in the data refer to causality or biases. Several methodological articles and book chapters have addressed the theory of DAGs in detail [129–131]. Herein, we briefly described and used DAGs to illustrate potential sources of bias/confounding that may explain, at least partially, the associations between sedentary behaviour and cardiovascular disease in epidemiologic studies.

Confounding The presence of a common cause of exposure A and outcome Y, we expect to find an association between A and Y even under the situation of null average causal effect. In randomised experiments (randomised controlled trials), if a sufficiently large number of participants is enroller, we expect to have the observed and unobserved common causes of A and Y equally distributed between A = 0 and A = 1, thus eliminating/mitigating confounding. In causal language, we say randomisation produces exchangeability between that A = 0 and A = 1 groups, that is, they are comparable. In observational studies, on the other hand, the common causes of A and Y are not evenly distributed between A = 0 and A = 1, and thus, association between and A and Y may be due, at least partially, due to residual confounding (Fig. 8.5a).

Regarding residual confounding, despite all studies included in Pandey et al. meta-analysis [89] adjusted for the main sociodemographic covariates (age, sex, education/income) and other important risk factors (e.g. smoking), only four out of nine studies considered dietary intake/total caloric intake in the model, and none considered the nutritional quality of the diet (e.g. ultra-processed food indexes). Therefore, the probability of residual confounding may explain at least part of the weak magnitude of associations between sitting time and cardiovascular diseases. For instance, a recent study including 104,851 participants have used negative control outcome to examine whether the association between physical activity and cardiovascular disease is explained by confounding. They found that association between physical activity and accidental deaths (a negative control outcome that had no plausible link with physical activity but displayed a similar confounding

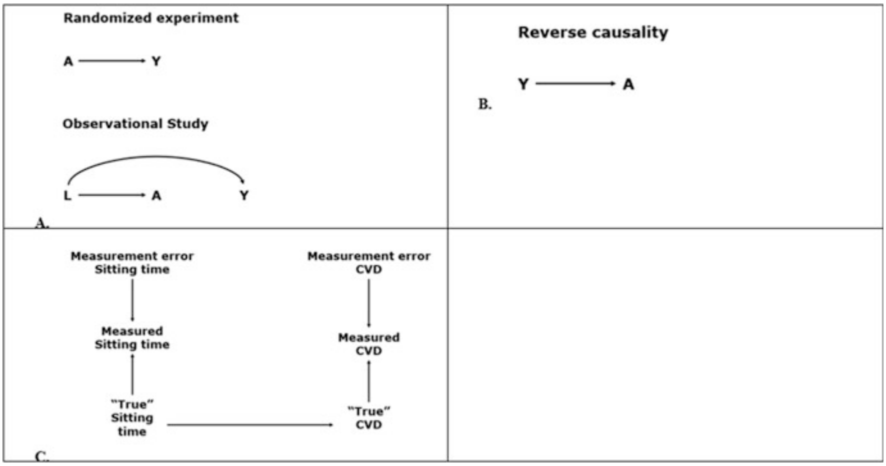

Fig. 8.5 Directed acyclic graphs relevant to observational sedentary behaviour research

structure) was in the same direction than physical activity and cardiovascular disease. These findings provide evidence that, at least part of the association between physical activity and cardiovascular disease, might be due to confounding [132].

Reverse Causality If the outcome Y causes the exposure A, we expect to find a statistical association between exposure A and outcome Y [133]. Reverse causality has also been referred in the literature as 'confounding due to pre-existing diseases' [128] (Fig. 8.5b).

Some cohorts still present short average lengths of follow-up, which increases the probability of reverse causality. For instance, studies examining the association between sitting time and cardiovascular disease mortality should consider that it is possible that cardiovascular diseases (and other non-communicable diseases) kill suddenly, but the vast majority of cases afflict people for several decades. During the course of disease, people change their daily life activities and may increase sitting time. Therefore, diagnosed, undiagnosed or prodromal pre-existing diseases may lead to overestimations of the association between sitting time and cardiovascular diseases. This is explained by the tendency for higher sitting times due to, for example, fatigue and other disease symptoms among people affected by pre-existing/undiagnosed diseases, and the higher likelihood to die early. In a recently published meta-epidemiological study on sitting and mortality, prospective studies with higher risk of confounding due to pre-existing diseases tended to show stronger, and a likely more biased, association between sedentary behaviour and mortality [128]. Studies with short follow-up length did not exclude participants with prevalence diseases (or did not adjust for them in the model), or did not exclude the first years of follow-up (i.e. assuming that deaths in the first years of follow-up are more likely due to pre-existing diseases than sitting time) showed stronger associations. Yet, studies with lower risk of confounding due to pre-existing diseases still found a positive association between sedentary behaviour and mortality, supporting the possibility that high sitting time may increase the risk of mortality (i.e. ignoring other sources of bias).

On the other hand, a recent compositional data analysis of the UK Biobank found an inverse association with incident cardiovascular disease for reallocating time from (wrist accelerometry assessed) sedentary behaviour light-intensity physical activity and moderate-to-vigorous physical activity [134]. However, sensitivity analysis investigating the potential influence of reverse causation showed a dramatic impact on main findings. For example, once participants with evidence for poor health of pre-existing cardiovascular disease were excluded, reallocating proportionally 1 hour/day from all other behaviours to sedentary behaviour (1.09, 95% CI: 0.89–1.45) or light-intensity physical activity (1.04, 95% CI: 0.88–1.21) was not associated with increased risk of incident cardiovascular disease [134]. These non-significant sedentary behaviour replacement estimates were almost identical to the negative control analyses of sedentary behaviour with accidents (1.08, 95% CI: 0.86–1.34), suggesting that unmeasured or residual confounding explains them. E-value (i.e. a metric that quantify the minimum strength of association, on the risk ratio scale, between unmeasured confounder and an exposure/outcome need to explain away the association) suggested that any unmeasured confounder with relatively modest associations of 1.09 (light-intensity physical activity) or 1.28 (sedentary behaviour) would nullify the observed associations [134].

Measurement Error Measurement error and misclassification bias are ubiquitous in epidemiological studies. This bias occurs when there is measurement error in the variables of the study, which produces a measure of associations different from the effect measure. There are at least four distinct forms of representing misclassification of exposure and outcome: (1) non-differential and independent, (2) non-differential and dependent, (3) differential and independent and (4) differential and dependent. Others have detailed described measurement error and misclassification bias using DAGs [135, 136].

In cohort studies, in which sitting time is measured by questionnaire years/decades before the occurrence of cardiovascular diseases, it is plausible to assume that the non-differential classification error of the exposure in respect to the outcome (Fig. 8.5c).

This bias is particularly relevant because, unlike the other types described above, the direction of bias in the statistical association tends to nullify. Furthermore, this type of bias does not produce a spurious statistical association when average causal effect under investigation is null [135, 136]. All nine studies included in Pandey et al. meta-analysis [89] measured sedentary time using questionnaires, which increases the probability of misclassification bias.

In conclusion, whether the association between sitting time and cardiovascular disease reflects a causal relationship or is due to alternative explanations can neither be confirmed nor refuted at this stage. Our very basic appraisal of causality against six of the Hill criteria suggests that a causal relationship between sedentary time and cardiovascular disease risk based on temporal relationship, (non-linear) dose-response relationship and consistency are insufficient to establish a probable causal

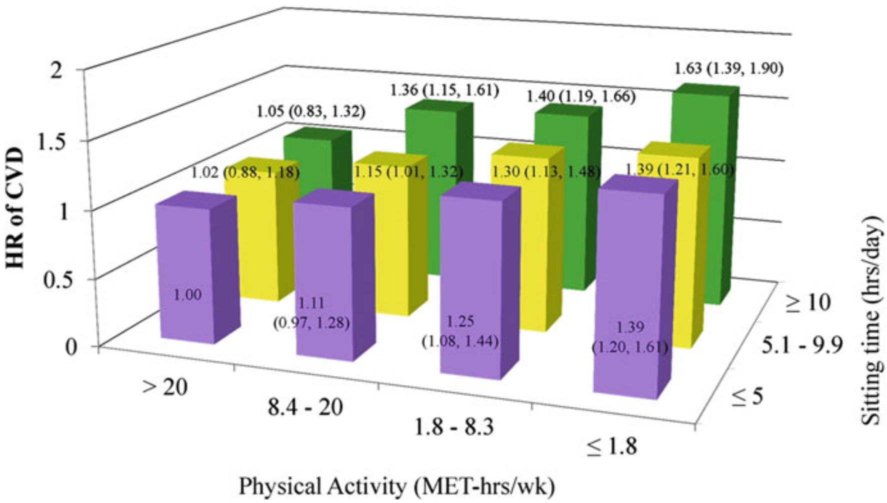

Fig. 8.6 Multivariable-adjusted hazard ratios (HR) for total cardiovascular disease (CVD) for a joint association between sedentary time and physical activity. For women with over 20 MET-h/week of physical activity there was no association between sitting and CVD events. 20 MET-hours per week is roughly equivalent to one hour of brisk walking per day. *Reproduced with permission from: Chomistek AK, Manson JE, Stefanick ML, Lu B, Sands-Lincoln M, Going SB,* et al. *Relationship of sedentary behavior and physical activity to incident cardiovascular disease: results from the Women's Health Initiative. Journal of the American College of Cardiology. 2013;61(23):2346–54*

effect. On the other hand, there is little evidence based on biological plausibility and strength of association, and current evidence does not preclude alternative explanations. We used DAGs to exemplify the influence of confounding, reverse causation and measurement error in prospective cohort studies on sitting time and cardiovascular diseases. Future studies using different study designs, analysis (i.e. life-course exposure to sedentary time), device-based measurement of sedentary time and careful adjustment for confounders, particularly pre-existing diseases/conditions, would enhance our knowledge and support better judgments of causal relationship between sedentary behaviour and cardiovascular disease.

Does Sufficient Physical Activity Offset or Eliminate the Cardiovascular Disease Risk of Sitting?

Although in Pandey et al.'s meta-analysis [89], all studies adjusted for physical activity to determine the independent effect of sedentary time, there were several studies showing that physical activity modified the effects of sitting time, and associations with hard cardiovascular outcomes were observed in physically inactive but not in the physically active participants, such as the Danish adults' study [137] and the American women's [101] studies above. For example, Fig. 8.6 shows that the association between sitting time and incident cardiovascular disease was evident only among women who reported less than 20 MET-hours of physical activity per week (corresponding to approximately 52 minutes of walking per day at 3.3 MET, 70% of the sample), in the remaining 30% of the sample who reported more physical activity no association was evident. A major study examining specifically the role of physical activity as a modifier of the association between sedentary behaviour and mortality was published as part of the 2016 Lancet Series on Physical Activity [138]. This was a pooled individual participant meta-analysis that involved 849,108 adults corresponding to 24,481 fatal cardiovascular events where sitting time was categorised as <4, 4 < 6, 6–8, >80 h/day, and the quartiles of physical activity had medians corresponding to roughly ≤5, 25–35, 50–65 and 60–75 minutes of moderate intensity per day. Compared to those in the lowest sitting and highest physical activity group (referent), a dose-response association between sitting time and cardiovascular death was noted in least physically active group with HR increasing from 1.34 (95% CI: 1.24–1.43) in the bottom to 1.74 (95% CI: 1.60–1.90) in the top sitting groups. Associations persisted in the second and third physical activity quartiles but were not dose-dependent for <8 h of sitting/day, less stable (e.g. the HR for 6–8 h of sitting/day in the third physical activity group was 1.04, 95% CI: 0.95–1.14) and lower in magnitude (highest HR was 1.37, 95% CI: 1.25–1.50 for those in the second lowest physical activity quartile that reported >8 h of sitting/day). There was no association between sitting time and cardiovascular mortality risk in the top physical activity quartile. Analogous findings were reported by a study based on the 45 and Up cohort from Australia [139]. Using a very similar analytic design to the 2016 Lancet Series study, Stamatakis and colleagues examined the joint associations of self-reported sitting and moderate-to-vigorous-intensity physical activity with cardiovascular disease mortality in 149,077 participants over an 8.9-year median follow-up. Sitting time was associated with cardiovascular disease in a nearly dose-response manner in the least active groups reporting <150, min/week. There were inconsistent associations with cardiovascular disease risks with more sitting among those meeting the upper (≥300 min/week) limits of the current, recommendation [41] Replacing sitting with walking showed no associations, while replacing sitting and showed stronger associations among high sitters, for example, the per-hour cardiovascular disease mortality HR for sitting replaced with moderate intensity activity was 0.80 (95% CI: 0.70–0.93) in those with >6 hour of sitting versus 0.95 (95% CI: 0.89–1.01) in those with <6 h of sitting per day.

Subject to the limitations of the literature noted above, these data provide compelling support to the idea that high levels of physical activity decrease the cardiovascular disease death risk, regardless of sitting too much. Translation of such evidence needs to also take into account the current population context of physical inactivity. The majority of the adult populations are very inactive [140, 141], and the average daily amount of physical activity needed to offset cardiovascular risk (approximately 45–60 minutes per day) is unattainable for large parts of the population, in particular for mid-aged and older adults who are very inactive and at imminent risk for developing cardiovascular disease. It is therefore important to acknowledge that although the above reports [16, 138] reminded us that physical activity should be the utmost public health priority, replacements of sedentary behaviour with physical activity of any intensity are also highly relevant for health promotion. Indeed, the 2020 WHO Guidelines on Physical Activity and Sedentary

Behaviour [41] included a 'hybrid' recommendation on aiming to exceed the recommended levels of moderate-to-vigorous physical activity (≥300 moderate-to-vigorous-intensity physical activity min/week) to counteract the adverse health effects of high levels of sedentary behaviour.

8.3.3 *Public Health Importance and Clinical Practice*

Despite the ongoing uncertainties on issues such as the biological plausibility, the independence of the associations from physical activity and the robustness of the relationship between sedentary behaviour and cardiovascular disease, reducing sedentary time has been incorporated in general public health guidance [142, 143]. The 2020 Canadian Movement Guidelines have already incorporated quantitative sedentary behaviour thresholds in their public health guidance.

Despite the relatively small magnitude of the observed associations, sedentary behaviour has likely increased since the industrial revolution. For instance, in the United States and Australia, people spend around 8 and 9 h in sedentary activities, respectively, which represents around 60% of the waking time [48, 51]. For additional information about the prevalence of sedentary behaviour, please refer to Chap. 2. As the 1985 Geoffrey Rose's paper on prevention strategies noted '*A large number of people at small risk may give rise to more cases of disease than a small number of people at high risk*' [144]. Statistical modelling studies that assessed the effects of replacing sedentary behaviour studies with light physical activities are suggestive for a measurable impact of such replacements at the population level. For instance, a cross-sectional study found that replacing sitting with equivalent amounts of light-intensity physical activity [145] is associated with lower cardiovascular surrogate markers (e.g. triglycerides). A recent compositional data analysis of the UK Biobank wrist accelerometry sub-study ($n = 87{,}498$) found beneficial associations with incident cardiovascular disease for reallocating 1 hour per day from sedentary behaviour to light physical activity (HR 0.96; 95% CI: 0.95–0.98) and 20 minutes per day to moderate-to-vigorous-intensity physical activity (0.92; 95% CI: 0.91–0.94). However, excluding events occurring in the first two years of follow-up and participants with poor health or cardiovascular disease medication subscription effectively eliminated these associations in the remaining 63,267 participants, a finding that highlights the likely role of reverse causation in sedentary behaviour research, as we discussed above.

As we alluded to at the start of this chapter, one of the main reasons of rapid growth of this research area is that increasing standing and light physical activities may be more successful than incidental moderate-intensity physical activity or vigorous exercise in westernised societies where opportunities to be sedentary are many and environments are not conducive for physical activities [142]. Theoretically, these low-intensity activities may help more people start engaging in other activities along the physical activity intensity continuum, including those with moderate-to-vigorous intensity [142]. Therefore, a central question relating to the potential of targeting sedentary behaviour to reduce cardiovascular disease burden is how feasible it is to achieve the likely large sedentary reductions needed for cardiovascular benefits. Current interventions aimed at reducing sedentary behaviour have found relatively modest effects (−42 minutes/day; 95% CI: −79 to −5 minutes for generic interventions and − 77 minutes; 95% CI: −120 to −35 min for interventions involving activity permissive workstations) [146, 147]. Whether such effects have clinical cardiovascular importance has yet to be determined. Finally, despite the popularity of some recent interventions to decrease sedentary time (sit-stand desks), a recent meta-analysis concluded that at present, there is very low to low-quality evidence that sit-stand desks may decrease workplace sitting between 30 min to 2 h/day [148].

In light of the best available evidence and considering how pervasive sedentary behaviour is in the modern world, it seems wise to aim at reducing long periods of sedentary time and incorporating *ambulatory* physical activity of any intensity to reduce cardiovascular disease risks in adults and elderly. When possible, the promotion of moderate-to-vigorous physical activity should still be the cornerstone of public health as higher physical intensity confers additional benefits [149] and high levels of physical activity seem to offset or eliminate the negative cardiovascular effects of sitting time [101, 137, 138].

8.4 Direction of Future Research

Cross-sectional studies that compared accelerometry-based and self-reported measures of sedentary time against cardiovascular risk factors [49, 150] often report differential associations between the two measurement types. Such studies further highlight the importance of improving and, when possible, standardising measurement of sedentary behaviour. While waist-worn accelerometers were undoubtedly a major step forward and are useful for understanding the health risks associated with the lack of ambulatory movement, they tell us little about the health risks of actual *sitting*. Questionnaires are useful and feasible for large-scale observational research and surveillance, but they may be prone to systematic reporting bias. Quantitative data from these instruments should be interpreted cautiously, and it seems premature to develop quantitative sitting guidelines based on self-reported data only, considering the major advances in the application of objective measures of sitting in ongoing epidemiological studies. Technology that uses thigh-worn sensors or combinations of placements (e.g. thigh and hip or back) is better capable for quantifying posture, including sitting time. As of October 2023, no published prospective sedentary behaviour study using such methods. Although the use of such tools in large population studies has been relatively limited in the past, it is feasible. Examples include the 1970 British Birth Cohort [151] that used thigh-worn sensors in a sample of 5412 middle aged adults and the Trøndelag Health Study (HUNT) cohort in Norway [152], which used two sensors (thigh-worn and lower back) in an sample of almost 35–40,000. The recently established Prospective Physical Activity, Sitting and Sleep consortium (ProPASS) [153] includes a number of thigh accelerometry studies that can be linked to mortality and incident morbidity records. It is likely that ProPASS and analogous initiatives, in the near future (perhaps within 4–5 years), will produce evidence on the prospective associations of actual *sitting* time, sedentary breaks and accumulation patterns with incident cardiovascular outcomes. Despite these uncertainties (that will hopefully be resolved as the field evolves), the collective capacity of all developments we highlighted in this chapter, including recent advances in activity type recognition [154], may change what we know about the health effects of sedentary behaviour within the next half decade. Developing credible prospective epidemiological evidence on the independent long-term health effects of *sitting* with long-term cardiovascular outcomes is one of the most important links in the public health evidence guidance chain.

Therefore, there is a need for well-designed prospective studies with device-based measurements of posture and physical activity. Very few existing prospective studies had narrowed cardiovascular disease outcomes such as myocardial infarction [137] that may provide better mechanistic clues. The concept of sedentary breaks needs to be more tightly defined to differentiate between interrupting sitting time with ambulatory activity versus standing, as such a differentiation will have important implications for interventions. Prospective studies to date were conducted almost exclusively in the United States/United Kingdom/Australia/Canada – we cannot know if these results are generalizable to non-Anglo-Saxon countries. In addition to being a threat to the biological ecological validity of the existing evidence, the different cultural, societal and economic contexts of sedentary behaviour make the existing literature less useful for public health and clinical cardiovascular disease guidance in other countries, in particular in the developing world.

8.5 Conclusions

Sedentary behaviour is ubiquitous across the life course in the developed as well as much of the developing world where cardiovascular disease is the main cause of premature death and chronic disease. Despite the reasonable research progress achieved in the past decade, our understanding of the influence of sedentary behaviour on cardiovascular health and cardiovascular risk occurrence is still incomplete. Multiple methodological issues have hindered a confident translation of available research into quantitative sedentary behaviour public health and clinical guidelines for primary prevention of cardiovascular disease. Such issues include unstandardised or measurement errors, unmeasured confounding, reverse causation, a paucity of prospective designs, limited understanding of what exactly the dominant health influences of screen time and TV time are, large heterogeneity in how epidemiologic studies are designed and analysed and the absence of a broadly replicated in humans convincing biological mechanism.

In young people, the overwhelming majority of the evidence examining the links between objectively assessed sedentary behaviour and surrogate markers of cardiovascular health is cross-sectional and the few prospective studies point towards no associations. The best available prospective epidemiologic evidence in adults and older adults suggests that there is a threshold effect with amounts of daily sitting over 10 h linked with increased risk for cardiovascular disease and death. However, the causal relation of sitting time to cardiovascular disease is far from established, for the reasons outlined above. In terms of sedentary behaviour as an intervention target for preventing cardiovascular disease and cardiovascular death, current evidence offers limited direction. It seems logical to promote ambulatory physical activity of any intensity that will naturally lead to sedentary time reductions in weak, sick populations. The risk for cardiovascular death in long duration sitters seems to be offset by approximately 45–60 moderate-intensity physical activity per day, which is well above the average physical activity levels in most high-income countries. The modest effect sizes of existing sedentary behaviour interventions suggest that reducing sedentary behaviour is not necessarily easier than promoting physical activity. Increasing 'sedentary breaks' has been researched less, but overall, there is very weak prospective epidemiologic or mechanistic evidence to support it as a stand-alone intervention.

The study of sedentary behaviour and cardiovascular health is a vibrant and exciting area of research that is set to grow rapidly in the years to come. The availability and recent popularity of wearable devices that quantify postural allocation as well as giving information on physical activity intensity offers great promise for future prospective studies examining the dose-response of sedentary behaviour and physical activity and cardiovascular health. As a research community, sedentary behaviour will benefit greatly from tighter communication and collaboration among research groups around the world to standardise the definition, measurement, research design and analytical protocols and from a more unified multidisciplinary approach involving scientists from diverse areas (such as media content experts, transportation experts and psychologists) that will help us better understand and contextualise the constituent components of sitting and its relevance for cardiovascular health and develop feasible and effective interventions for long term behaviour change.

References

1. Raichlen DA, Pontzer H, Zderic TW, Harris JA, Mabulla AZP, Hamilton MT, et al. Sitting, squatting, and the evolutionary biology of human inactivity. Proc Natl Acad Sci U S A. 2020;117(13):7115–21.
2. McCrady SK, Levine JA. Sedentariness at work: how much do we really sit? Obesity. 2009;17(11):2103–5.
3. Church TS, Thomas DM, Tudor-Locke C, Katzmarzyk PT, Earnest CP, Rodarte RQ, et al. Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. PLoS One. 2011;6(5):e19657.
4. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. Am J Prev Med. 2011;41(2):189–96.

5. GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet (London, England). 2020;396(10258):1204–22.
6. GBD 2013 Mortality and Causes of Death Collaborators. Global, regional, and national age-sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet (London, England). 2015;385(9963):117–71.
7. Fuster V, Kelly BB. Institute of Medicine (US) Committee on preventing the global epidemic of cardiovascular disease: meeting the challenges in developing countries. Washington, DC: National Academies Press; 2010.
8. Department of Health. Healthy lives, healthy people: a call to action on obesity in England London; 2011.
9. Heidenreich PA, Trogdon JG, Khavjou OA, Butler J, Dracup K, Ezekowitz MD, et al. Forecasting the future of cardiovascular disease in the United States: a policy statement from the American Heart Association. Circulation. 2011;123(8):933–44.
10. Thompson PD, Buchner D, Piña IL, Balady GJ, Williams MA, Marcus BH, et al. Exercise and physical activity in the prevention and treatment of atherosclerotic cardiovascular disease: a statement from the Council on Clinical Cardiology (Subcommittee on Exercise, Rehabilitation, and Prevention) and the Council on Nutrition, Physical Activity, and Metabolism (Subcommittee on Physical Activity). Circulation. 2003;107(24):3109–16.
11. Gordon NF, Gulanick M, Costa F, Fletcher G, Franklin BA, Roth EJ, et al. Physical activity and exercise recommendations for stroke survivors: an American Heart Association Scientific Statement from the Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical Activity, and Metabolism; and the Stroke Council. Circulation. 2004;109 (16):2031–41.
12. Prepared by: British Cardiac Society BHS, Diabetes UK, HEART UK, Primary Care Cardiovascular Society, The Stroke Association. JBS 2: Joint British Societies' guidelines on prevention of cardiovascular disease in clinical practice. Heart. 2005;91(suppl 5):v1–v52.
13. Ghorayeb N, Costa RVC, Daher DJ, Oliveira Filho JA, Oliveira MAB, Sociedade Brasileira de Cardiologia. Guideline in cardiology of sport and exercise of the Brazilian Society of Cardiology and the Brazilian Society of Sports Medicine. Arq Bras Cardiol. 2013;100(Suppl. 2): 1–41.
14. US Department of Health and Human Services. Physical activity and health: a report of the surgeon general. Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion; 1996.
15. Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary". Exerc Sport Sci Rev. 2008;36(4):173–8.
16. Stamatakis E, Ekelund U, Ding D, Hamer M, Bauman AE, Lee I-M. Is the time right for quantitative public health guidelines on sitting? A narrative review of sedentary behaviour research paradigms and findings. Br J Sports Med. 2019;53(6):377–82.
17. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary Behavior Research Network (SBRN) - Terminology consensus project process and outcome. Int J Behav Nutr Phys Act. 2017;14(1):75.
18. Network SBR. Standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab. 2012;37:540–2.
19. Ford ES, Caspersen CJ. Sedentary behaviour and cardiovascular disease: a review of prospective studies. Int J Epidemiol. 2012;41(5):1338–53.
20. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DRJ, Tudor-Locke C, et al. Compendium of physical activities: a second update of codes and MET values. Med Sci Sports Exerc. 2011;43(8):1575–81. https://doi.org/10.1249/MSS.0b013e31821ece12.

21. Morris JN, Heady JA, Raffle PA, Roberts CG, Parks JW. Coronary heart-disease and physical activity of work. Lancet (London, England). 1953;265:1111–20.
22. Umberson D, Montez JK. Social relationships and health: a flashpoint for health policy. J Health Soc Behav. 2010;51(1 suppl):S54–66.
23. Levine JA, Eberhardt NL, Jensen MD. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. Science. 1999;283(5399):212–4.
24. Levine JA, Lanningham-Foster LM, McCrady SK, Krizan AC, Olson LR, Kane PH, et al. Interindividual variation in posture allocation: possible role in human obesity. Science. 2005;307(5709):584–6.
25. Martinez-Gonzalez MA, Martinez JA, Hu FB, Gibney MJ, Kearney J. Physical inactivity, sedentary lifestyle and obesity in the European Union. Int J Obes Relat Metab Disord. 1999;23 (11):1192–201.
26. Salmon J, Bauman A, Crawford D, Timperio A, Owen N. The association between television viewing and overweight among Australian adults participating in varying levels of leisure-time physical activity. Int J Obes Relat Metab Disord. 2000;24(5):600–6.
27. Jakes RW, Day NE, Khaw KT, Luben R, Oakes S, Welch A, et al. Television viewing and low participation in vigorous recreation are independently associated with obesity and markers of cardiovascular disease risk: EPIC-Norfolk population-based study. Eur J Clin Nutr. 2003;57 (9):1089–96.
28. Hu FB, Leitzmann MF, Stampfer MJ, Colditz GA, Willett WC, Rimm EB. Physical activity and television watching in relation to risk for type 2 diabetes mellitus in men. Arch Intern Med. 2001;161(12):1542–8.
29. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes. 2007;56 (11):2655–67.
30. Hamilton MT, Healy GN, Dunstan DW, Zderic TW, Owen N. Too little exercise and too much sitting: inactivity physiology and the need for new recommendations on sedentary behavior. Curr Cardiovasc Risk Rep. 2008;2(4):292–8.
31. Department of Health. Start active, stay active: a report on physical activity for health from the four home countries. London: Chief Medical Officers; 2011.
32. Department of Health. Australia's physical activity and sedentary behaviour guidelines for adults (18–64 years). Canberra, Australia: Australian Government, Department of Health; 2014.
33. New Zealand Ministry of Health. Eating and activity guidelines for New Zealand adults. Wellington: New Zealand Ministry of Health; 2015.
34. Tremblay MS, Carson V, Chaput J-P, Connor Gorber S, Dinh T, Duggan M, et al. Canadian 24-hour movement guidelines for children and youth: an integration of physical activity, sedentary behaviour, and sleep. Appl Physiol Nutr Metab. 2016;41(6):S311–27.
35. Fuzeki E, Vogt L, Banzer W. German National Physical activity recommendations for adults and older adults: methods, database and rationale. Gesundheitswesen. 2017;79(S01):S20–8.
36. Health NDo. National recommendations: Physical activity and sedentary sitting; 2014. https://helsedirektoratet.no/folkehelse/fysisk-aktivitet
37. Young DR, Hivert MF, Alhassan S, Camhi SM, Ferguson JF, Katzmarzyk PT, et al. Sedentary behavior and cardiovascular morbidity and mortality: a science advisory from the American Heart Association. Circulation. 2016;134(13):e262–79.
38. Buckley JP, Hedge A, Yates T, Copeland RJ, Loosemore M, Hamer M, et al. The sedentary office: a growing case for change towards better health and productivity. Expert statement commissioned by Public Health England and the Active Working Community Interest Company. Br J Sports Med. 2015;49(21):1357–62.
39. Saunders TJ, McIsaac T, Douillette K, Gaulton N, Hunter S, Rhodes RE, et al. Sedentary behaviour and health in adults: an overview of systematic reviews. Appl Physiol Nutr Metab. 2020;45(10):S197–217.

40. Stamatakis E, Bauman AE. The bold sedentary behavior recommendations in the new Canadian guidelines: are they evidence-based? Response to "Sedentary Behavior Research Network members support new Canadian 24-Hour Movement Guideline recommendations". J Sport Health Sci. 2020;9(6):482–4.
41. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54(24):1451–62.
42. Piercy KL, Troiano RP, Ballard RM, Carlson SA, Fulton JE, Galuska DA, et al. The physical activity guidelines for Americans. JAMA. 2018;320(19):2020–8.
43. Chau JY, Grunseit AC, Chey T, Stamatakis E, Brown WJ, Matthews CE, et al. Daily sitting time and all-cause mortality: a meta-analysis. PLoS One. 2013;8(11):e80000.
44. Bauman A, Ainsworth BE, Sallis JF, Hagstromer M, Craig CL, Bull FC, et al. The descriptive epidemiology of sitting. A 20-country comparison using the International Physical Activity Questionnaire (IPAQ). Am J Prev Med. 2011;41(2):228–35.
45. Bennie JA, Chau JY, van der Ploeg HP, Stamatakis E, Do A, Bauman A. The prevalence and correlates of sitting in European adults - a comparison of 32 Eurobarometer-participating countries. Int J Behav Nutr Phys Act. 2013;10:107.
46. McLaughlin M, Atkin AJ, Starr L, Hall A, Wolfenden L, Sutherland R, et al. Worldwide surveillance of self-reported sitting time: a scoping review. Int J Behav Nutr Phys Act. 2020;17 (1):111.
47. Milton K, Gale J, Stamatakis E, Bauman A. Trends in prolonged sitting time among European adults: 27 country analysis. Prev Med. 2015;77:11–6.
48. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. Am J Epidemiol. 2008;167 (7):875–81.
49. Stamatakis E, Hamer M, Tilling K, Lawlor DA. Sedentary time in relation to cardio-metabolic risk factors: differential associations for self-report vs accelerometry in working age adults. Int J Epidemiol. 2012;41(5):1328–37.
50. Stamatakis E, Rogers K, Ding D, Berrigan D, Chau J, Hamer M, et al. All-cause mortality effects of replacing sedentary time with physical activity and sleeping using an isotemporal substitution model: a prospective study of 201,129 mid-aged and older adults. Int J Behav Nutr Phys Act. 2015;12:121.
51. Clark BK, Lynch BM, Winkler EA, Gardiner PA, Healy GN, Dunstan DW, et al. Validity of a multi-context sitting questionnaire across demographically diverse population groups: AusDiab3. Int J Behav Nutr Phys Act. 2015;12:148.
52. van der Berg JD, Stehouwer CD, Bosma H, van der Velde JH, Willems PJ, Savelberg HH, et al. Associations of total amount and patterns of sedentary behaviour with type 2 diabetes and the metabolic syndrome: the Maastricht Study. Diabetologia. 2016;59(4):709–18.
53. Hamer M, Stamatakis E. The descriptive epidemiology of standing activity during free-living in 5412 middle-aged adults: the 1970 British Cohort Study. J Epidemiol Community Health. 2020;74(9):757–60.
54. Hamer M, Stamatakis E, Chastin S, Pearson N, Brown M, Gilbert E, et al. Feasibility of measuring sedentary time using data from a thigh-worn accelerometer: the 1970 British Cohort Study. Am J Epidemiol. 2020;189(9):963–71.
55. Dunstan DW, Barr EL, Healy GN, Salmon J, Shaw JE, Balkau B, et al. Television viewing time and mortality: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Circulation. 2010;121(3):384–91.
56. Stamatakis E, Hamer M, Dunstan DW. Screen-based entertainment time, all-cause mortality, and cardiovascular eventspopulation-based study with ongoing mortality and hospital events follow-up. J Am Coll Cardiol. 2011;57(3):292–9.
57. Scholes S, Coombs N, Pedisic Z, Mindell JS, Bauman A, Rowlands AV, et al. Age- and sex-specific criterion validity of the health survey for England physical activity and sedentary

behavior assessment questionnaire as compared with accelerometry. Am J Epidemiol. 2014;179(12):1493–502.
58. Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. Am J Clin Nutr. 2012;95(2):437–45.
59. Stamatakis E, Coombs N, Rowlands A, Shelton N, Hillsdon M. Objectively-assessed and self-reported sedentary time in relation to multiple socioeconomic status indicators among adults in England: a cross-sectional study. BMJ Open. 2014;4(11):e006034.
60. Stamatakis E, Hillsdon M, Mishra G, Hamer M, Marmot M. Television viewing and other screen-based entertainment in relation to multiple socioeconomic status indicators and area deprivation: the Scottish Health Survey 2003. J Epidemiol Community Health. 2009;63(9): 734–40.
61. Pearson N, Biddle SJ. Sedentary behavior and dietary intake in children, adolescents, and adults. A systematic review. Am J Prev Med. 2011;41(2):178–88.
62. Hamer M, Stamatakis E, Mishra GD. Television- and screen-based activity and mental well-being in adults. Am J Prev Med. 2010;38(4):375–80.
63. Hamer M, Ding D, Chau J, Duncan MJ, Stamatakis E. Association between TV viewing and heart disease mortality: observational study using negative control outcome. J Epidemiol Community Health. 2020;74(4):391–4.
64. Szabo A, Hopkinson KL. Negative psychological effects of watching the news in the television: relaxation or another intervention may be needed to buffer them! Int J Behav Med. 2007;14(2):57–62.
65. Finegold JA, Asaria P, Francis DP. Mortality from ischaemic heart disease by country, region, and age: statistics from World Health Organisation and United Nations. Int J Cardiol. 2013;168(2):934–45.
66. Institute for Health Metrics and Evaluation (IHME). GBD compare. http://vizhub.healthdata.org/gbd-compare/. Seattle, WA, USA: IHME; 2019.
67. Aboderin I, Kalache A, Ben-Shlomo Y, Lynch JW, Yajnik CS, Kuh D, et al. Life course perspectives on coronary heart disease, stroke and diabetes: key issues and implications for policy and research. Geneva: World Health Organization; 2002.
68. Berry JD, Dyer A, Cai X, Garside DB, Ning H, Thomas A, et al. Lifetime risks of cardiovascular disease. New Engl J Med. 2012;366(4):321–9.
69. Wong ND. Epidemiological studies of CHD and the evolution of preventive cardiology. Nat Rev Cardiol. 2014;11(5):276–89.
70. Morrison JA, Glueck CJ, Wang P. Childhood risk factors predict cardiovascular disease, impaired fasting glucose plus type 2 diabetes mellitus, and high blood pressure 26 years later at a mean age of 38 years: the Princeton-lipid research clinics follow-up study. Metabolism. 2012;61(4):531–41.
71. Paffenbarger RS Jr, Hyde RT, Wing AL, Lee IM, Jung DL, Kampert JB. The association of changes in physical-activity level and other lifestyle characteristics with mortality among men. New Engl J Med. 1993;328(8):538–45.
72. Coombs N, Shelton N, Rowlands A, Stamatakis E. Children's and adolescents' sedentary behaviour in relation to socioeconomic position. J Epidemiol Community Health. 2013;67 (10):868–74.
73. Steele RM, van Sluijs EM, Cassidy A, Griffin SJ, Ekelund U. Targeting sedentary time or moderate- and vigorous-intensity activity: independent relations with adiposity in a population-based sample of 10-y-old British children. Am J Clin Nutr. 2009;90(5):1185–92.
74. Ekelund U, Anderssen SA, Froberg K, Sardinha LB, Andersen LB, Brage S, et al. Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European youth heart study. Diabetologia. 2007;50(9):1832–40.
75. Ekelund U, Brage S, Froberg K, Harro M, Anderssen SA, Sardinha LB, et al. TV viewing and physical activity are independently associated with metabolic risk in children: the European Youth Heart Study. PLoS Med. 2006;3(12):e488.

76. Hardy LL, Denney-Wilson E, Thrift AP, Okely AD, Baur LA. Screen time and metabolic risk factors among adolescents. Arch Pediart Adolesc Med. 2010;164(7):643–9.
77. Martinez-Gomez D, Eisenmann JC, Healy GN, Gomez-Martinez S, Diaz LE, Dunstan DW, et al. Sedentary behaviors and emerging cardiometabolic biomarkers in adolescents. J Pediatr. 2012;160(1):104–10.e2.
78. Ekelund U, Luan J, Sherar L, Esliger DW, Griew P, Cooper A. Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. JAMA. 2012;307(7):704–12.
79. Mitchell JA, Mattocks C, Ness AR, Leary SD, Pate RR, Dowda M, et al. Sedentary behavior and obesity in a large cohort of children. Obesity. 2009;17:1596–602.
80. Stamatakis E, Coombs N, Tiling K, Mattocks C, Cooper A, Hardy LL, et al. Sedentary time in late childhood and cardiometabolic risk in adolescence. Pediatrics. 2015;135(6):e1432–41.
81. Mielke GI, Brown WJ, Wehrmeister FC, Goncalves H, Oliveira I, Menezes AM, et al. Associations between self-reported physical activity and screen time with cardiometabolic risk factors in adolescents: findings from the 1993 Pelotas (Brazil) Birth Cohort Study. Prev Med. 2019;119:31–6.
82. Hjorth MF, Chaput JP, Damsgaard CT, Dalskov SM, Andersen R, Astrup A, et al. Low physical activity level and short sleep duration are associated with an increased cardio-metabolic risk profile: a longitudinal study in 8–11 year old Danish children. PLoS One. 2014;9(8):e104677.
83. Berentzen NE, Smit HA, van Rossem L, Gehring U, Kerkhof M, Postma DS, et al. Screen time, adiposity and cardiometabolic markers: mediation by physical activity, not snacking, among 11-year-old children. Int J Obes (Lond). 2014;38(10):1317–23.
84. Cliff DP, Hesketh KD, Vella SA, Hinkley T, Tsiros MD, Ridgers ND, et al. Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis. Obes Rev. 2016;17(4):330–44.
85. Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: a 21-year tracking study. Am J Prev Med. 2005;28(3):267–73.
86. Magnussen CG, Smith KJ, Juonala M. When to prevent cardiovascular disease? As early as possible: lessons from prospective cohorts beginning in childhood. Curr Opin Cardiol. 2013;28(5):561–8.
87. Grøntved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality. JAMA. 2011;305(23):2448–55.
88. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32.
89. Pandey ASU, Garg S, Ayers C, Kulinski J, Anand V, Mayo H, Kumbhani DJ, de Lemos J, Berry JD. Continuous dose-response association between sedentary time and risk for cardio-vascular disease: a meta-analysis. JAMA Cardiol. 2016;1(5):575–83.
90. Wilmot E, Edwardson C, Achana F, Davies M, Gorely T, Gray L, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012;55(11):2895–905.
91. Bailey DP, Hewson DJ, Champion RB, Sayegh SM. Sitting time and risk of cardiovascular disease and diabetes: a systematic review and meta-analysis. Am J Prev Med. 2019;57(3): 408–16.
92. Patterson R, McNamara E, Tainio M, de Sá TH, Smith AD, Sharp SJ, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. Eur J Epidemiol. 2018;33 (9):811–29.
93. Ahmad S, Shanmugasegaram S, Walker KL, Prince SA. Examining sedentary time as a risk factor for cardiometabolic diseases and their markers in South Asian adults: a systematic review. Int J Public Health. 2017;62(4):503–15.

94. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009;41(5):998–1005.
95. Borodulin K, Karki A, Laatikainen T, Peltonen M, Luoto R. Daily sedentary time and risk of cardiovascular disease: the national FINRISK 2002 study. J Phys Act Health. 2015;12(7): 904–8.
96. Kim Y, Wilkens LR, Park SY, Goodman MT, Monroe KR, Kolonel LN. Association between various sedentary behaviours and all-cause, cardiovascular disease and cancer mortality: the Multiethnic Cohort Study. Int J Epidemiol. 2013;42(4):1040–56.
97. Herber-Gast GC, Jackson CA, Mishra GD, Brown WJ. Self-reported sitting time is not associated with incidence of cardiovascular disease in a population-based cohort of mid-aged women. Int J Behav Nutr Phys Act. 2013;10:55.
98. Bjork Petersen C, Bauman A, Gronbaek M, Wulff Helge J, Thygesen LC, Tolstrup JS. Total sitting time and risk of myocardial infarction, coronary heart disease and all-cause mortality in a prospective cohort of Danish adults. Int J Behav Nutr Phys Act. 2014;11:13.
99. Matthews CE, Cohen SS, Fowke JH, Han X, Xiao Q, Buchowski MS, et al. Physical activity, sedentary behavior, and cause-specific mortality in black and white adults in the Southern Community Cohort Study. Am J Epidemiol. 2014;180(4):394–405.
100. Patel AV, Bernstein L, Deka A, Feigelson HS, Campbell PT, Gapstur SM, et al. Leisure time spent sitting in relation to total mortality in a prospective cohort of US adults. Am J Epidemiol. 2010;172(4):419–29.
101. Chomistek AK, Manson JE, Stefanick ML, Lu B, Sands-Lincoln M, Going SB, et al. Relationship of sedentary behavior and physical activity to incident cardiovascular disease: results from the women's health initiative. J Am Coll Cardiol. 2013;61(23):2346–54.
102. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ, et al. Breaks in sedentary time: beneficial associations with metabolic risk. Diabetes Care. 2008;31(4):661–6.
103. Cooper AR, Sebire S, Montgomery AA, Peters TJ, Sharp DJ, Jackson N, et al. Sedentary time, breaks in sedentary time and metabolic variables in people with newly diagnosed type 2 diabetes. Diabetologia. 2012;55(3):589–99.
104. Jefferis B, Parsons TJ, Sartini C, Ash S, Lennon L, Papacosta AO, Richard M, Wannamethee SG, Lee I-M, Whincup PH. Objectively measured physical activity, sedentary behaviour and all-cause mortality in older men: does volume of activity matter more than pattern of accumulation? Br J Sports Med. 2017;53(16) https://doi.org/10.1136/bjsports-2017-098733.
105. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003–06. Eur Heart J. 2011;32(5):590–7.
106. Chastin SF, Egerton T, Leask C, Stamatakis E. Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. Obesity. 2015;23(9):1800–10.
107. Hawari NS, Al-Shayji I, Wilson J, Gill JM. Frequency of breaks in sedentary time and postprandial metabolic responses. Med Sci Sports Exerc. 2016;48(12):2495–502.
108. Loh R, Stamatakis E, Folkerts D, Allgrove JE, Moir HJ. Effects of interrupting prolonged sitting with physical activity breaks on blood glucose, insulin and triacylglycerol measures: a systematic review and meta-analysis. Sports Med. 2020;50(2):295–330.
109. Henson J, Davies MJ, Bodicoat DH, Edwardson CL, Gill JM, Stensel DJ, et al. Breaking up prolonged sitting with standing or walking attenuates the postprandial metabolic response in postmenopausal women: a randomized acute study. Diabetes Care. 2016;39(1):130–8.
110. Mannucci E, Dicembrini I, Lauria A, Pozzilli P. Is glucose control important for prevention of cardiovascular disease in diabetes? Diabetes Care. 2013;36(Suppl 2):S259–S63.
111. Lipska KJ, Krumholz HM. Is hemoglobin a1c the right outcome for studies of diabetes? JAMA. 2017;317(10):1017–8.
112. Rodriguez-Gutierrez R, Montori VM. Glycemic control for patients with type 2 diabetes mellitus: our evolving faith in the face of evidence. Circ Cardiovasc Qual Outcomes. 2016;9 (5):504–12.

113. 2018 Physical Activity Guidelines Advisory Committee. 2018 Physical activity guidelines Advisory Committee Scientific Report. Washington, DC: U.S. Department of Health and Human Services; 2018.
114. van Uffelen JG, Wong J, Chau JY, van der Ploeg HP, Riphagen I, Gilson ND, et al. Occupational sitting and health risks: a systematic review. Am J Prev Med. 2010;39(4): 379–88.
115. Stamatakis E, Chau JY, Pedisic Z, Bauman A, Macniven R, Coombs N, et al. Are sitting occupations associated with increased all-cause, cancer, and cardiovascular disease mortality risk? a pooled analysis of seven British Population Cohorts. PLoS One. 2013;8(9): e73753.
116. Moe B, Eilertsen E, Nilsen TIL. The combined effect of leisure-time physical activity and diabetes on cardiovascular mortality: the Nord-Trøndelag Health (HUNT) cohort study, Norway. Diabetes Care. 2013;36(3):690–5.
117. Smith P, Ma H, Glazier RH, Gilbert-Ouimet M, Mustard C. The relationship between occupational standing and sitting and incident heart disease over a 12-year period in Ontario, Canada. Am J Epidemiol. 2018;187(1):27–33.
118. Dunstan DW, Dogra S, Carter SE, Owen N. Sit less and move more for cardiovascular health: emerging insights and opportunities. Nat Rev Cardiol. 2021;18(9):637–48.
119. Bey L, Hamilton MT. Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. J Physiol. 2003;551(Pt 2):673–82.
120. Thorp AA, Kingwell BA, Sethi P, Hammond L, Owen N, Dunstan DW. Alternating bouts of sitting and standing attenuate postprandial glucose responses. Med Sci Sports Exerc. 2014;46 (11):2053–61.
121. Bailey DP, Locke CD. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. J Sci Med Sport. 2015;18(3):294–8.
122. Miyashita M, Park JH, Takahashi M, Suzuki K, Stensel D, Nakamura Y. Postprandial lipaemia: effects of sitting, standing and walking in healthy normolipidaemic humans. Int J Sports Med. 2013;34(1):21–7.
123. Padilla J, Fadel PJ. Prolonged sitting leg vasculopathy: contributing factors and clinical implications. Am J Physiol Heart Circ Physiol. 2017;313(4):H722–h8.
124. Dunstan DW, Howard B, Healy GN, Owen N. Too much sitting - a health hazard. Diabetes Res Clin Pract. 2012;97(3):368–76.
125. Keyes K, Galea S. What is a cause? In: Keyes K, Galea S, editors. Epidemiology matters: a new introduction to methodological foundations. New York: Oxford University Press; 2014. p. 91–112.
126. Hill AB. The environment and disease: association or causation? Proc R Soc Med. 1965;58: 295–300.
127. Ioannidis JP. Exposure-wide epidemiology: revisiting Bradford Hill. Stat Med. 2016;35(11): 1749–62.
128. Rezende LFM, Lee DH, Ferrari G, Giovannucci E. Confounding due to pre-existing diseases in epidemiologic studies on sedentary behavior and all-cause mortality: a meta-epidemiologic study. Ann Epidemiol. 2020;52:7–14.
129. Hernán MA, Robins JM. Causal inference: what if. Boca Raton, FL: Chapman & Hall/ CRC; 2020.
130. Greenland S, Pearl J, Robins JM. Causal diagrams for epidemiologic research. Epidemiology. 1999;10(1):37–48.
131. Greenland S, Rothman KJLT. Measures of effect and measures of association. In: Modern epidemiology. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2008. p. 183–209.
132. Hamer M, Bauman A, Bell JA, Stamatakis E. Examining associations between physical activity and cardiovascular mortality using negative control outcomes. Int J Epidemiol. 2019;48(4):1161–6.

133. Rezende LFM, Lee DH, Giovannucci E. Possible reverse causation and confounding in study of the association of sedentary behavior with cancer mortality. JAMA Oncol. 2021;7(1): 138–9.
134. Walmsley R, Chan S, Smith-Byrne K, Ramakrishnan R, Woodward M, Rahimi K, et al. Reallocation of time between device-measured movement behaviours and risk of incident cardiovascular disease. Br J Sports Med. 2021;56(18):1008.
135. Hernán MA, Cole SR. Invited commentary: causal diagrams and measurement bias. Am J Epidemiol. 2009;170(8):959–62.
136. VanderWeele TJ, Hernán MA. Results on differential and dependent measurement error of the exposure and the outcome using signed directed acyclic graphs. Am J Epidemiol. 2012;175 (12):1303–10.
137. Petersen C, Bauman A, Gronbaek M, Helge J, Thygesen L, Tolstrup J. Total sitting time and risk of myocardial infarction, coronary heart disease and all-cause mortality in a prospective cohort of Danish adults. Int J Behav Nutr Phys Act. 2014;11(1):13.
138. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet (London, England). 2016;388(10051):1302–10.
139. Stamatakis E, Gale J, Bauman A, Ekelund U, Hamer M, Ding D. Sitting time, physical activity, and risk of mortality in adults. J Am Coll Cardiol. 2019;73(16):2062–72.
140. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc. 2008;40(1):181–8.
141. Bennie JA, Pedisic Z, van Uffelen JG, Gale J, Banting LK, Vergeer I, et al. The descriptive epidemiology of total physical activity, muscle-strengthening exercises and sedentary behaviour among Australian adults--results from the National Nutrition and Physical Activity Survey. BMC Public Health. 2016;16(1):73.
142. Smith L, Ekelund U, Hamer M. The potential yield of non-exercise physical activity energy expenditure in public health. Sports Med. 2015;45(4):449–52.
143. Sparling PB, Howard BJ, Dunstan DW, Owen N. Recommendations for physical activity in older adults. BMJ. 2015;350:h100.
144. Rose G. Sick individuals and sick populations. Int J Epidemiol. 1985;14(1):32–8.
145. Buman MP, Winkler EA, Kurka JM, Hekler EB, Baldwin CM, Owen N, et al. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. Am J Epidemiol. 2014;179(3):323–34.
146. Martin A, Fitzsimons C, Jepson R, Saunders DH, van der Ploeg HP, Teixeira PJ, et al. Interventions with potential to reduce sedentary time in adults: systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1056–63.
147. Neuhaus M, Eakin EG, Straker L, Owen N, Dunstan DW, Reid N, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. Obesity Rev. 2014;15(10):822–38.
148. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Bhaumik S. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2016;3:CD010912.
149. Gebel K, Ding D, Chey T, Stamatakis E, Brown WJ, Bauman AE. Effect of moderate to vigorous physical activity on all-cause mortality in middle-aged and older Australians. JAMA Intern Med. 2015;175(6):970–7.
150. Stamatakis E, Davis M, Stathi A, Hamer M. Associations between multiple indicators of objectively-measured and self-reported sedentary behaviour and cardiometabolic risk in older adults. Prev Med. 2012;54(1):82–7.
151. Elliott J, Shepherd P. Cohort profile: 1970 British Birth Cohort (BCS70). Int J Epidemiol. 2006;35(4):836–43.
152. Krokstad S, Langhammer A, Hveem K, Holmen TL, Midthjell K, Stene TR, et al. Cohort profile: the HUNT study, Norway. Int J Epidemiol. 2013;42(4):968–77.

153. Stamatakis E, Koster A, Hamer M, Rangul V, Lee I-M, Bauman AE, et al. Emerging collaborative research platforms for the next generation of physical activity, sleep and exercise medicine guidelines: the Prospective Physical Activity, Sitting, and Sleep consortium (ProPASS). Br J Sports Med. 2020;54(8):435–7.
154. Crowley P, Skotte J, Stamatakis E, Hamer M, Aadahl M, Stevens ML, et al. Comparison of physical behavior estimates from three different thigh-worn accelerometers brands: a proof-of-concept for the Prospective Physical Activity, Sitting, and Sleep consortium (ProPASS). Int J Behav Nutr Phys Act. 2019;16(1):65.

Chapter 9
Sedentary Behaviour and Cancer

Christopher T. V. Swain, Terry Boyle, Shahid Mahmood, and Brigid M. Lynch

Abstract This chapter summarises the growing body of evidence relating to sedentary behaviour and cancer. We conducted meta-analyses for sites with at least three studies comparing the highest to lowest category of sedentary behaviour. Based on the findings of 121 different studies that have examined 21 different cancer sites, we conclude that there is limited evidence that sedentary behaviour is associated with an increased risk of cancer. Meta-analyses demonstrated a small risk increase for colon (RR = 1.12, 95% CI: 0.98, 1.27), endometrial (RR = 1.16, 95% CI: 0.84, 1.48), ovarian (RR = 1.16, 95% CI: 0.96, 1.36) and pancreatic cancers (RR = 1.10, 95% CI: 0.79, 1.41). We showed a very small risk increase for breast cancer (RR = 1.06, 95% CI: 1.01, 1.11). Studies examining all cancer incidence showed no strong relationship for self-reported sedentary behaviour, whereas accelerometer-measured sedentary time showed a greater risk increase. Sedentary behaviour appears to increase the risk for all-cancer mortality (RR = 1.11, 95% CI: 1.04, 1.18) and colorectal cancer-specific mortality (RR = 1.38, 95% CI: 1.08, 1.75 for pre-diagnosis sitting time; RR = 1.61, 95% CI: 1.23, 2.11 for post-diagnosis sitting time). The effect of sedentary behaviour on cancer risk and mortality is biologically plausible. Postulated mechanisms include body composition (most evidence relates to adiposity), sex hormones, metabolic function, inflammation and immune function. Better mechanistic understanding will help strengthen causal inference from epidemiological data. The adoption of contemporary epidemiological methods and analytic techniques will also facilitate improved causal inference.

C. T. V. Swain · B. M. Lynch (✉)
Cancer Epidemiology Division, Cancer Council Victoria, Melbourne, VIC, Australia
e-mail: chris.swain@cancervic.org.au; brigid.lynch@cancervic.org.au

T. Boyle
Australian Centre for Precision Health, UniSA Allied Health & Human Performance, University of South Australia, Adelaide, Australia
e-mail: terry.boyle@unisa.edu.au

S. Mahmood
Department of Community Medicine, Allama Iqbal Medical College, Lahore, Punjab, Pakistan

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_9

What Is New?

- The field has grown considerably since the first edition of this chapter. There have now been 121 studies (versus 25) to examine sedentary behaviour and cancer.
- Previously, we concluded that sedentary behaviour increased the risk of endometrial and ovarian cancers and that there was suggestive evidence for breast, colorectal and lung cancers. Based on the current literature, we now conclude there is limited evidence that sedentary behaviour increases cancer risk. The risk increases for endometrial and ovarian cancer are about half of what was previously estimated.
- As previously reported, sedentary behaviour does appear to increase all-cause mortality risk and mortality following a colorectal cancer diagnosis.
- All research is still based on a single exposure assessment. The research to date is also subject to a number of biases, including selection bias, measurement error and unmeasured (or residual confounding).

9.1 Introduction

Over the past decade, a number of reviews, meta-analyses and expert panel assessments have suggested that sedentary behaviour contributes to an increased risk of cancer across a number of sites [1–5]. Sedentary behaviour is highly prevalent, modifiable and amenable to intervention; therefore, there are promising cancer control implications. The aim of this chapter is to provide an up-to-date overview of the evidence pertaining to sedentary behaviour and cancer, both in terms of risk and mortality. We will also summarise the emerging literature examining the biological mechanisms whereby sedentary behaviour influences cancer risk and provide an overview of the main findings. Finally, we will reflect upon the strength of the evidence accrued to date, particularly in respect to causal inference.

9.1.1 Prevalence and Trends of Cancer

Cancer is a generic term representing a group of diseases that are characterised by the rapid creation of abnormal cells that are self-sufficient, are able to divide without stopping, can invade nearby tissues and can spread (or metastasize) to distant places in the body. Cancer is caused by complex interactions between genetic, environmental and lifestyle factors. This interplay introduces gradual changes to genes, which, accrued over time, can result in uncontrolled cell division, altered growth and resistance to cell death. Over 100 different types of cancer exist. Among males, cancers of the lung (14% of all worldwide incident cancers in males in 2020), prostate (14%), colorectum (11%), stomach (7%) and liver (6%) are the five most common malignancies [6]. Among females, the five most common cancers are breast (24% of all worldwide incident cancers in females in 2020), colorectal (9%), lung (8%), cervical (6%) and thyroid (5%) [6].

Globally, it has been estimated that in 2020 there were 19.3 million new cases of cancer diagnosed, 10 million deaths due to cancer and 50.5 million people living with cancer (within five years of diagnosis) [7]. Cancer (all types combined) was the second leading cause of death worldwide in 2019, behind only cardiovascular disease [8]. With a combination of an ageing population, continued population growth and an increased adoption of 'Western' behavioural and lifestyle habits in developing countries, it is estimated that by 2040 the number of worldwide incident cancer cases and cancer deaths will rise to approximately 30.2 million and 16.3 million, respectively [9]. The increasing number of incident cancer cases, along with continued improvements in early diagnosis and cancer treatments, means the number of prevalent cancer cases is also expected to rise steadily.

More than half (59%) of all incident cancer cases, approximately two-thirds (71%) of all cancer deaths, and nearly half (49%) of all prevalent cases in 2020 occurred in low- to middle-income countries [7]. Cancer incidence rates vary greatly across different regions and countries, with fivefold variations in rates seen among males and fourfold variations seen in females [6]. For most cancer types, trends over time also differ across regions [10], providing clues about the aetiology of the disease.

9.1.2 Cancer Risk Factors

Age is by far the major determinant of cancer risk. Worldwide, cancer incidence rates increase sharply with age, increasing from 54 per 100,000 people in those aged 15–44 years, to 435 per 100,000 people in those aged 45–64 years and to 1310 per 100,000 years on those aged 65 years and older, in 2020 [7]. Other known cancer risk factors can be broadly grouped into five categories: lifestyle, occupational and environmental, reproductive and hormonal, infections and genetic.

Lifestyle-related cancer risk factors include tobacco smoking, alcohol consumption, obesity, diet and physical inactivity. Tobacco smoking is by far the strongest modifiable risk factor for cancer. It increases the risk of at least 20 different types of cancer, with the greatest risk increase observed for lung and laryngeal cancers [11]. Approximately 31% of all cancer deaths in males, and 6% in females, can be attributed to tobacco smoking [12]. Epidemiological research indicates that alcohol consumption increases the risk of at least seven cancers, notably colorectal, female breast and liver [13], and around 4% of all cancer deaths worldwide in 2016 can be attributed to alcohol consumption [14]. There is strong evidence that being overweight or obese during adulthood is a risk factor for at least 12 types of cancer, including advanced prostate, colorectal, postmenopausal breast, stomach and liver cancers [13]. Dietary factors such as high intake of processed meat and low intake of dietary fibre intake have been shown to increase the risk of specific cancers [13]. There is strong evidence that being physically active is associated with decreased risks of seven cancers (breast, bladder, colon, endometrial, oesophageal adenocarcinoma, renal and gastric cancers) [15].

More than 50 occupational agents have been classified by the International Agency for Research on Cancer as carcinogenic or probably carcinogenic to humans [16], and it is estimated that between 2% and 8% of cancers in developed countries are attributable to occupational carcinogens [17]. Many of these carcinogens, such as asbestos, diesel engine exhaust, ionising radiation and solar radiation, are also found in non-occupational settings. Other environmental causes of cancer that have been identified include arsenic, outdoor air pollution, radon and second-hand tobacco smoke [18].

Reproductive and hormonal factors, such as number of pregnancies, breastfeeding duration, age at menarche, oral contraceptive use and menopausal hormone therapy, have been associated with cancer risk, primarily cancers of the breast and ovary. A number of viruses (e.g. hepatitis B and C viruses, human papilloma viruses) and bacteria (e.g. *Helicobacter pylori*) are risk factors for specific cancers (liver, cervical and gastric cancers in particular), with around 13% of all incident cancers in 2018 attributable to infections [19]. Finally, around 5–10% of all cancers are thought to be caused by highly penetrant genetic mutations [20].

9.2 Methods

This chapter updates the summary of the evidence published in the first edition of this book [21]. Here, we have incorporated relevant studies published to August 2021. Studies that examined the relationship between sedentary behaviour and cancer incidence or cancer-specific mortality were eligible for inclusion. Where multiple publications from the same study were found, the most recent publication was included. We prioritised total sitting time as the exposure for inclusion in this meta-analysis. If total sitting time was not available, we included risk estimates for leisure-time sitting (including television viewing time) or occupational sitting. The risk ratios extracted from studies represent the highest versus lowest category of sedentary behaviour. Where possible, we included multivariable-adjusted risk estimates that were not adjusted for body mass index or another measure of adiposity, as adiposity may be an important mediating variable in the sedentary behaviour – cancer association [3]. For studies that asked participants to report their occupational activity on an ordinal scale, we used ‘standing’ or ‘mostly standing’ as the referent category against which to compare the ‘sitting’ category, as has been previously recommended [1]. We excluded studies where the occupational activity scale progressed straight from ‘sitting’ to ‘walking’ or another type of physical activity, as the risk estimates generated would not solely reflect the effect of sedentary behaviour on cancer risk (i.e. part of the risk could be attributed to the (inverse) of the risk reduction associated with walking) [1].

Random-effect meta-analysis was used to estimate the summary relative risks (RRs) for the highest compared to the lowest (reference) category of sedentary behaviour for cancer incidence (by site) and mortality, if at least three studies had been published. Forest plots were generated to depict study-specific and pooled estimates. Statistical heterogeneity among studies was examined using the I^2 statistic [22]. Publication bias was assessed by examining funnel plot asymmetry for the cancer sites included in the meta-analyses.

We conducted sensitivity analyses, firstly excluding studies assessing occupational sedentary behaviour, as these are likely to be heavily confounded by socio-economic position, which is difficult to adequately adjust for. We also performed the meta-analyses after excluding case-control studies, as this design may be subject to recall bias and reverse causality [4]. All statistical analyses were performed using Stata version 16 (Stata Corporation, College Station, Texas, USA).

9.3 Sedentary Behaviour and Cancer Risk

Table 9.1 summarises studies investigating the associations of sedentary behaviour and risk of all incident cancer (two studies based on self-reported sitting time; two based on accelerometer-measured sedentary time), bladder cancer (three), brain cancer (one), breast cancer [20], colorectal/colon/rectal cancer [16], endometrial cancer (seven), oesophageal cancer (three), gallbladder cancer (one), head and neck cancer (two), haematological cancer (one), kidney cancer (four), liver cancer (three), lung cancer (eight), melanoma (two), multiple myeloma (one), myeloid malignancies (one), non-Hodgkin lymphoma (two), ovarian cancer (seven), pancreatic cancer (three), prostate cancer (seven) and stomach cancer (four).

9.3.1 Sedentary Behaviour and All Cancer Incidence

Four prospective cohort studies examined the relationship between sedentary behaviour and the risk of developing any time of cancer: one study looked at self-reported occupational sitting time [24]; another study had assessed self-reported total sitting time [25], and two studies used ActiGraph accelerometers to measure sedentary time [26, 27]. Because self-report questionnaires and accelerometers actually measure different aspects of sedentary behaviour [28], we did not meta-analyse these four studies. We observed minimal to no increase in risk of incident cancer in the self-report studies [24, 25] but an increase in risk of 67% (95% CI: 1.24–2.24) [26] and 37% (95% CI: 0.91–2.08) [27] for the accelerometer studies.

Table 9.1 Studies investigating the associations of sedentary behaviour and cancer risk

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
All cancer incidence						
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	965 women and 2842 men diagnosed with cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 1.08 (0.98, 1.18) Men RR = 1.12 (0.99, 1.26)	Age, area, history of diabetes, smoking status, alcohol intake, body mass index, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Rangul et al., 2018. Norway	Prospective cohort study	19,039 women and 18,7771 men in the Nord-Trøndelag Health Study, aged ≥20 years at enrolment. Median follow-up 16 years	1761 women and 2435 men diagnosed with cancer, identified via linkage to the Cancer Registry of Norway	Total sitting time (single question, participants prompted to include sitting at work, mealtimes, watching TV, sitting in a car, etc), categorised as <8 (ref.) or ≥8 h/day	Women RR = 1.02 (0.91, 1.14) Men RR = 1.08 (0.98, 1.18)	Age, education, smoking, alcohol, BMI
All cancer incidence (accelerometer)						
Dempsey et al., 2020. United Kingdom	Prospective cohort study	7820 participants of the EPIC-Norfolk study, aged 40–79 at baseline	516 incident cancers were identified via hospital records	Actigraph GT1M and GT3X+ (harmonised; right hip) worn during waking hours. Sedentary time (<100 counts	HR for 90th vs. 10th percentile (equivalent to 11 h/ day vs. 8 h/ day) = 1.67 (1.24, 2.24)	Sex, accelerometer wear time, moderate-to-vigorous physical activity, education, social class, smoking status, alcohol intake,

				per minute) as continuous variable (h/day)		baseline history of diabetes or taking diabetes medication, medication use for hypertension, dyslipidaemia or depression, family history of CVD, diabetes or cancer (age underlying time metric)
Dohrn et al., 2019. Sweden	Prospective cohort study	1220 adults from the Sweden Attitude Behaviour and Change study, aged 18–75 years at enrolment	161 cancers identified through linkage with the Swedish Cause of Death Register	Actigraph 7164 worn on lower back during waking hours. Sedentary time (<100 counts per minute) categorised as tertiles	HR = 1.37 (0.91, 2.08)	Age, sex, smoking, education, hypertension, diabetes, arthritis, wear time
Bladder cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40–69 years from the UK Biobank study	677 bladder cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 1.29 (0.97, 1.73)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	15 women and 93 men diagnosed with bladder cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 0.79 (0.14, 4.27) Men RR = 0.56 (0.27, 1.17)	Age, area, history of diabetes, smoking status, alcohol intake, body mass index, coffee, walking time at work, strenuous time at work), moderate-to-

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						vigorous physical activity in leisure time, type of job and total working hours
Patel et al., 2015. United States	Prospective cohort study	146, 722 participants of the ACS CPS II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	271 women and 1187 men diagnosed with bladder cancer; identified via self-report with subsequent verification by medical record or linkage with state cancer registries	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 1.17 (0.80, 1.70) Men RR = 1.01 (0.86, 1.19)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI

Brain cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40–69 years from the UK Biobank study	463 brain tumours identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 0.96 (0.63, 2.06)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Breast cancer						
Sanchez-Bayona et al., 2021. Spain	Prospective cohort study	10,812 female graduates from the University of Navarra. Mean age at recruitment 35.7 years	101 confirmed via medical records or linkage to National Death Index	TV time categorised as <1 (ref.), 1–2, >2 h/day	All women HR = 1.67 (1.03, 2.72), p trend = 0.02. Premenopausal women HR = 2.22 (1.15, 4.28), p trend = 0.01 Postmenopausal women HR = 1.07 (0.45, 2.60), p trend = 0.87	Height, family history of breast cancer, smoking status, lifetime tobacco exposure, age at menarche, obstetric history, lifetime breast feeding, years of university study, Mediterranean diet adherence score, physical activity, alcohol consumption, daily energy intake, BMI, sugar-sweetened beverage consumption, time spent sitting in car or using computer. For postmenopausal women only: HRT, duration of HRT, age at menopause (age underlying time metric)

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
Hunter et al., 2020. United Kingdom	Prospective cohort study	253,188 women aged between 40–69 years from the UK Biobank study	5072 breast cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 0.99 (0.87, 1.12)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	174 women diagnosed with breast cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1 h/day; 1 to <3 h/day (ref.); 3 to <5 h/day; 5 to <7 h/day; or longer, ≥7 h/day	RR = 1.11 (0.69, 1.81).	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Cao et al., 2019. Japan	Prospective cohort study	32,276 women in the Japan Collaborative Cohort Study for Evaluation of Cancer Risk, aged 40 to 79 years at enrolment. Median follow-up 16.8 years	247 women diagnosed with breast cancer, identified via population-based cancer registries or local major hospital records	Time spent watching TV, categorised as <1.5 (ref.), 1.5–2.9, 3–4.4 or ≥4.5 h/day	All Women RR = 1.45 (0.91, 2.32) Premenopausal women OR = 1.34 (0.76, 2.36) Postmenopausal women OR = 2.37 (0.92, 6.10)	Age, age of menarche, BMI, parity, family history of breast cancer, education level, married status, daytime napping, sleep duration, mental stress, alcohol intake, hormone use, smoking status, sport time, walking time, and

						history of diabetes (for postmenopausal women adjusted further for age of menopause, type of menopause)
Rangul et al., 2018. Norway	Prospective cohort study	19,039 women in the Nord-Trøndelag Health Study, aged ≥20 years at enrolment. Median follow-up 16 years	513 women diagnosed with breast cancer, identified via linkage to the Cancer Registry of Norway	Total sitting time (single question, participants prompted to include sitting at work, mealtimes, watching TV, sitting in a car, etc), categorised as <8 (ref.) or ≥8 h/day	RR = 1.04 (0.85, 1.27)	Age, education, smoking, alcohol, BMI
Huerta et al., 2019. Spain	Case-control study	1389 cases from hospitals in 10 regions of Spain. 1712 controls (frequency-matched by sex, age and region) randomly recruited from general practitioner lists	Incident breast cancer cases	Leisure-time sitting in the last year, categorised as <3 (ref.), 3–5.9, 6–8.9, or ≥9 h/day	All women OR = 1.08 (0.82, 1.42) Premenopausal women OR = 1.14 (0.81, 1.61) Postmenopausal women OR = 1.10 (0.70, 1.71)	Age, sex, socioeconomic status, study area, family history of breast cancer, age at menarche, age at first pregnancy, menopausal status, use of oral contraceptives, use of hormone replacement therapy, smoking, BMI, intake of total energy, red meat, vegetables and alcohol, physical activity domains

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
Nomura et al., 2017. United States	Prospective cohort study	70,233 postmenopausal women from the Women's Health Initiative Observation Study, aged between 50 and 79 at baseline	4115 incident cases of breast determined via medical records and physician review	Sitting time categorised as <5 (ref.), 6–10, >10 h/day	HR = 1.00 (0.92, 1.09)	Age, region, race/ethnicity, education, NSAID usage, BMI, parity, recreational physical activity, mammogram frequency over past 5 years, pack years smoking, alcohol intake, unopposed oestrogen, oestrogen, progestin, HEI 2005 score
Boyle et al., 2016. Australia and Canada	Case-control study (pooled data from two studies)	1762 cases recruited via cancer registries and 2532 controls	Incident invasive breast cancer cases	Occupational diary reported each job held for more than six months. Participants self-reported if job sedentary (cumulative time calculated as self-reported years, categorised as 0 [ref.], 0.1–6.99, 7–18.49, ≥18.5 years). A job-exposure matrix used to assess sedentary behaviour in each job (cumulative time	Premenopausal women $OR_{self\text{-}reported\ years}$ = 1.51 (0.91, 2.51) $OR_{job\text{-}exposure\ matrix\ years}$ = 1.12 (0.61, 2.06) Postmenopausal women $OR_{self\text{-}reported\ years}$ = 0.86 (0.59, 1.26) $OR_{job\text{-}exposure\ matrix\ years}$ = 0.94 (0.60, 1.47)	Age, study location, education, ethnicity, recreational physical activity in early adulthood, BMI in early adulthood, number of births, breastfeeding status, shift work status, years worked in an active occupation

				calculated as job-exposure matrix years, categorised as 0 [ref.], 0.1–6.99, 7–18.49, ≥18.5 years)		
Nomura et al., 2016. United States	Prospective cohort study	46,734 participants from the Black Women's Health Study, aged 21–69 at enrolment	2041 incident breast cancers notified via self-report and follow-up through cancer registries and hospitals	Baseline total sitting derived by adding time spent sitting at work with TV viewing time. Categorised as <5 (ref.), 5–<7, 7–<10, ≥10 h/day	All women HR = 1.27 (1.06, 1.53) Premenopausal women HR = 1.03 (0.80, 1.46) Postmenopausal women HR = 1.36 (1.06, 1.76)	Age, geographic region, BMI, education, recreational physical activity, caloric intake, parity, age at menarche, menopausal hormone use, oral contraceptive use, family history of breast cancer, mammogram, smoking
Patel et al., 2015. USA. After Hildebrand et al., 2013	Prospective cohort study	77,462 women in the ACS CPS-II nutrition cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	4165 invasive breast cancers self-reported, with subsequent verification via medical record, state cancer registry or National Death Index	Leisure-time sitting (TV, reading, etc) categorised as <3 (ref.), 3–5, or ≥6 h/day	RR = 1.10 (1.00, 1.21)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						status (women), post-menopausal hormone use (women), mammogram screening, BMI
Ekenga et al., 2015. United States and Puerto Rico	Prospective cohort study	47,649 women, aged 30–74 at enrolment into the Sister Study. Mean follow-up 4.7 years	1789 breast cancer cases identified by self-report. Excellent agreement with medical records/pathology reports (99.5%)	Predefined categories of occupational activity collapsed into four categories: mostly sitting, sitting and standing equally, mostly standing, active. HRs presented here as mostly standing (ref.) vs mostly sitting	Longest held job: HR = 1.04 (0.87, 1.25) Current job (at baseline): HR = 1.08 (0.90, 1.28)	Race/ethnicity, education, income, parity, menopausal status, age at menopause, BMI, recreational physical activity, total number of work years, work at night. (age underlying time metric)
Rosenberg et al., 2014. United States	Prospective cohort study	44,708 African American women, aged 30 or older at enrolment in the black Women's Health Study. Mean follow-up 16 years	1364 invasive breast cancers identified by self-report followed by confirmation via hospital or cancer registry	Predefined categories for time spent sitting watching TV (<1 [ref.], 1–2, 3–4, ≥ 5 h/day) or sitting at work (<1 [ref.], 1–2, 3–4, ≥ 5 h/day)	All women TV: RR = 1.13 (0.91, 1.40). Occupational sitting: RR = 1.05 (0.90, 1.22) ER+ TV: RR = 0.94 (0.69, 1.28). Occupation: RR = 0.92 (0.74, 1.13) ER−	Age, questionnaire cycle, BMI, education, parity, fruit/vegetable intake, meat/fried foods intake, vigorous PA, mutual adjustment for TV/occupational sitting

					TV: RR == 1.39 = (0.94, 2.07). Occupation: RR = 1.19 (0.90, 1.57)	
Catsburg et al., 2014. Canada	Case-cohort	1097 cases, 3320 controls from Canadian Cohort Study of Diet, Lifestyle, and Health	Incident cases of breast cancer ascertained via record linkage to the Canadian Cancer Registry and the Ontario Cancer Registry	Total sitting time (time spent driving/sitting away from home, sitting watching TV, other sitting at home) categorised as <12.5 (ref.), 12.5–24, 24–39, 39–54, >54 h/week. TV time categorised as ≤1 (ref.), 2–5, 6–10, 11–20, ≥21 h/week	All women Total sitting: HR = 0.98 (0.76, 1.25) TV: HR = 1.17 (0.86, 1.59) Premenopausal women Total sitting: HR = 0.99 (0.68, 1.43) TV: HR = 1.08 (0.65, 1.79) Postmenopausal women Total sitting: HR = 0.98 (0.69, 1.39) TV: HR = 1.20 (0.81, 1.80)	Age at menarche, use of oral contraceptives, use of hormone therapy, number of live births, age at first live birth, family history of breast cancer, menopausal status at baseline, alcohol intake, BMI
Cohen et al., 2013. United States	Nested case-control study	546 cases and 2184 matched controls from the Southern Community Cohort Study, aged 40–79 at enrolment	All cases of invasive breast cancer diagnosed after date of study enrolment via linkage to state cancer registries	Total sitting time (sitting in a car or bus, at work, watching TV/movies, using a computer, other reasons). Quartiles according to control	All women Top vs bottom quartile of sitting OR = 1.41 (1.01, 1.95) Black women OR = 1.23 (0.82,	Age, race, menopausal status, enrolment source, education, household income, BMI at age 21, smoking, ever use HRT, parity, age at

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
				distribution (<5.5 [ref.], 5.5–8.1, 8.2–11.9, ≥12 h/day)	1.83) White women OR = 1.94 (1.01, 3.70)	menopause, family history, health insurance
Lynch et al., 2013. Canada	Case-control study	1222 cases identified through the Alberta Cancer Registry, and 1230 matched controls from random digit dialling. Age range 25–85 years	Histologically confirmed incident primary breast cancer	Lifetime occupational sitting derived from the Life Time Physical Activity Questionnaire. Quartiles according to control distribution (0 [ref.], 0.1–2.1, 2.1–7.2, ≥7.3 h/week/year)	Premenopausal women OR = 0.85 (0.58, 1.24) Postmenopausal women OR = 0.71 (0.52, 0.97)	Age, educational attainment, lifetime PA, caloric intake, every alcohol consumption, smoking status, WHR, total number of mammograms, family history, ever use of HRT, number of children breastfeed
George et al., 2010. United States	Prospective cohort study	97,039 women from the NIH-AARP Diet and Health Study, aged 51–72 at risk factor assessment	2866 invasive breast cancers identified through linkage to 11 state cancer registries	Time spent watching TV or videos during a typical 24 h period in the past 12 months (<3 [ref.], 3–4, 5–6, 7–8, ≥9 h/day); time spent sitting during a typical 24 h period in the past 12 months (<3 [ref.], 3–4, 5–6, 7–8, ≥9 h/day)	TV: RR = 1.17 (0.93, 1.47), p trend = 0.493 Total sitting: RR = 1.12 (0.95, 1.31), p trend = 0.101	Age, energy intake, recreational MVPA, parity/age at first live birth, menopausal hormone therapy use, number of breast biopsies, alcohol intake, race, education

Mathew et al., 2009. India	Case-control study	1866 cases treated at one of four hospitals in South India. 1873 controls matched by 5-year age group and place of residence (urban/rural)	Histologically confirmed incident primary breast cancer	Time spent watching TV during weekdays (<60 [ref.], 60–119, 120–179, ≥180 m/day) and weekends (<60 [ref.], 60–179, ≥180 m/day). Cases asked to report TV from the year preceding diagnosis	Premenopausal women Weekday TV: OR = 0.94 (0.62, 1.45), p trend = 0.035 Weekend TV: OR = 0.91 (0.61, 1.34), p trend = 0.10 Postmenopausal women Weekday TV: OR = 0.82 (0.51, 1.35), p trend = 0.33 Weekend TV: OR = 1.01 (0.64, 1.59), p trend = 0.313	Age, locality, religion, marital status, education, socioeconomic status, residence status, BMI, waist and hip sizes, parity, age at first childbirth, duration of breast feeding, physical activity
Peplonska et al., 2008. Poland	Case-control study	2176 cases identified through cancer registries. 2326 controls recruited via Polish Electronic System of Population Evidence and matched by city of residence and 5-year age group	Cytologically or histologically confirmed in situ or invasive breast cancer	Self-reported time spent sitting at work, quartiles created according to control distribution (<11.3 [ref,], 11.3–29.7, >29.7–47.8, >47.8 MET h/week across lifetime)	OR = 1.09 (0.90–1.31)	Age, study site, education, BMI, age at menarche, menopausal status, age at menopause (in postmenopausal women), number of full-term births, age at first full-term birth, breastfeeding, family history of breast cancer, and previous screening mammography, lifetime

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						recreational, household activity physical activity
Lahmann et al., 2007. Nine European countries	Prospective cohort study	218,169 women from EPIC, aged 20–80 years at baseline. Mean follow-up 6.4 years	3423 incident invasive breast cancers identified through cancer registries or by active follow-up	Predefined categories for current occupational activity (sedentary, standing, manual/heavy manual). HRs presented here as standing (ref.) vs sitting	Premenopausal women HR = 0.98 (0.82, 1.16) Postmenopausal women HR = 1.08 (0.95, 1.23)	Age, study Centre, education, smoking, alcohol consumption, BMI, age at menarche, age at first pregnancy, current OC pill use (premenopausal), current HRT use (postmenopausal)
Levi et al., 1999. Switzerland	Case-control study	246 cases treated at a Swiss hospital, and 374 controls admitted to the same hospital for acute conditions	Histologically confirmed, incident breast cancer	Predefined categories for occupational activity (mainly sitting, standing, very tiring/tiring) for jobs held at various life-stages. HRs presented here as standing (ref.) vs sitting	15–19 years: OR = 1.67 (1.10, 2.50) 30–39 years: OR = 2.22 (1.14, 4.26) 50–59 years: OR = 1.85 (0.98, 3.45)	Age, education, age at menarche, age at first birth, parity, menopausal status, age at menopause, calorie intake, previous benign breast disease, family history of breast cancer
Colorectal/colon/rectal cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40–69 years from the UK Biobank study	3358 colorectal cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	Colorectal cancer HR = 1.05 (0.90, 1.22) Colon cancer HR = 1.19 (1.00,	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI,

					1.42) Rectal cancer HR = 0.84 (0.63, 1.11)	height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	212 women and 555 men diagnosed with colorectal cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1 to <3 (ref.), 3 to <5, 5 to <7, ≥7 h/day	Women RR = 0.94 (0.58, 1.53) Men RR = 1.17 (0.91, 1.52)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Park et al., 2019. United States	Prospective cohort study	93,469 women and 79,033 men in the Multiethnic Cohort Study, aged 45–75 years at enrolment. Median follow-up 16.8 years	2089 women and 2341 men diagnosed with colorectal cancer, identified via linkage to the tumour registries	Total sitting time (sum of sitting: In car/bus, at work, watching TV, at meals, and other sitting), categorised as <5 (ref.), 5–6.9, 7–8.9, 9–10.9 or ≥11 h/day	Women RR = 0.92 (0.80, 1.07) Men RR = 0.96 (0.84, 1.10).	Age, ethnicity, family history of colorectal cancer, history of colorectal polyp, BMI, pack-years of cigarette smoking, multivitamin use, NSAID use, MHT use for women only, and intake of alcohol, total energy, red meat, dietary fibre, calcium, folate and vitamin D
Quang et al., 2019. Vietnam	Case control study	136 cases and 154 controls from Hanoi, Vietnam. Cases were patients at the Bach Mai Hospital	Histologically confirmed, incident colorectal cancer	Sitting time categorised as <1.5 (ref.), 1.5–3, >3 h/day	OR = 1.57 (0.84, 2.92)	Age, sex, marital status, occupation, education, family history of colon diseases, income, smoking,

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						alcohol consumption, coffee consumption
Gorczyca et al., 2018. United States	Prospective cohort study	74,870 postmenopausal women from the Women's Health Initiative Observation Study, aged between 50 and 79 at baseline	1145 incident cases of colorectal cancer determined via hospital records	Sitting time categorised as <5 (ref.), 6–10, >10 h/day	Colorectal cancer HR = 1.15 (0.95, 1.40) Colon cancer HR = 1.17 (0.95, 1.45) Rectal cancer HR = 0.97 (0.61, 1.53)	Age, race, education, income, marital status, cigarette smoking, family history of CRC, history of CRC screening, alcohol consumption, hormone replacement therapy, total energy intake, fibre intake, vitamin D intake, red meat intake, aspirin use, multivitamin use and physical activity
Nunez et al., 2018. Australia	Prospective cohort study	226,584 participants in the 45 and up study, aged 45 years and over at enrolment	846 incident cases of colon cancer and 369 incident cases of rectal cancer; identified via linkage with the New South Wales Cancer Registry	Total sitting time, categorised as <3 (ref.), 3–<5, 5–<8 or ≥8 h/day	Colon cancer HR = 0.92 (0.67, 1.28) rectal cancer HR = 0.90 (0.61, 1.32)	Birth cohort, sex, education, BMI, sitting time, time spent on moderate and vigorous activity, smoking, alcohol, country of birth, guidelines of fruit and vegetables, weekly intake of processed food, red meat and fibre, aspirin, parental history of

						colorectal cancer and history of colorectal testing
Rangul et al., 2018. Norway	Prospective cohort study	19,039 women and 18,7771 men in the Nord-Trøndelag Health Study, aged ≥20 years at enrolment. Median follow-up 16 years	255 women and 388 men diagnosed with colorectal cancer, identified via linkage to the Cancer Registry of Norway	Total sitting time (single question, participants prompted to include sitting at work, mealtimes, watching TV, sitting in a car, etc), categorised as <8 (ref.) or ≥8 h/day	Women RR = 1.02 (0.75, 1.39) Men RR = 1.14 (0.91, 1.43)	Age, education, smoking, alcohol, BMI
Eaglehouse et al., 2017. Singapore	Prospective cohort study	63,257 participants in the Singapore Chinese health study, aged 45–74 years at enrolment. Median follow-up 16.8 years.	1994 participants diagnosed with colorectal cancer, identified via linkage to the Singapore Cancer Registry	Time spent sitting watching TV, categorised as ≤2 (ref.) or ≥3 h/day.	RR = 1.04 (0.95, 1.14).	Age, dialect group, interview year, education level, BMI, sex, cigarette smoking, alcohol use, sleep, dietary fiber, family history of colorectal cancer, and diabetes
Keum et al., 2016. United States	Prospective cohort study	69,715 women in the Nurses Health Study and 36,806 men in the Health Professionals Follow-Up Study	1119 women and 913 men diagnosed with colorectal cancer, identified via self-report with subsequent verification by medical record	Time spent sitting watching TV, categorised as <7 (ref.), 7–13.9, 14–20.9, or ≥21 h/week	Women RR = 1.21 (1.02, 1.43) Men RR = 1.06 (0.84, 1.34)	Age, questionnaire cycle, race, physical activity, family history of colon cancer, personal history of endoscopy and polyps, smoking habits, baseline aspirin use, current multivitamin use, intakes of total calorie, alcohol, red and processed meat, fibre, total folate at baseline,

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						total calcium at baseline, total vitamin D, and menopausal status and hormone use (women only)
Patel et al., 2015. United States	Prospective cohort study	146, 722 participants of the ACS CPS II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	1199 women and 1447 men diagnosed with CRC; identified via self-report with subsequent verification by medical record or linkage with state cancer registries	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 0.95 (0.79, 1.14) Men RR = 1.01 (0.87, 1.18)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI

Howard et al., 2008. United States	Prospective cohort study	300,673 participants from the NIH-AARP Diet and Health Study, aged 51–72 years at questionnaire administration	4722 incident colorectal cancers identified through linkage to 11 state cancer registries	Predefined categories for sitting during a typical 24 h period in past 12 months (<3 [ref.], 3–4, 5–6, 7–8, ≥9 h/day)	Women RR = 1.24 (0.90, 1.70), p trend = 0.361 Men RR = 1.24 (0.98, 1.57), p trend = 0.050.	Age, smoking, alcohol consumption, education, race, family history of colon cancer, total energy intake, energy-adjusted intakes of red meat, calcium, whole grains, fruits and vegetables, menopausal hormone therapy (women), physical activity
Johnsen et al., 2006. Denmark	Prospective cohort study	54,478 participants from the Danish Diet, Cancer and Health cohort, aged 50–64 at baseline	297 colon cancer cases identified through the Danish Cancer Registry	Predefined categories of occupational activity (sitting, standing, manual, not working). HRs presented here as standing (ref.) vs sitting	Women IRR = 0.87 (0.52, 1.47) Men IRR = 0.90 (0.56, 1.45)	Leisure time physical activity, BMI, education, NSAID, present use of HRT, smoking and intake of total energy, fat, dietary fibre, red meat, alcohol
Friedenreich et al., 2006. Nine European countries	Prospective cohort study	413,044 EPIC participants, mainly aged 35–70 years at baseline. Mean follow-up 6.4 years	1094 incident colon cancers and 599 rectal cancers identified through cancer registries or by active follow-up	Predefined categories for current occupational activity (from sedentary, standing, manual/heavy manual, not working). HRs presented here as standing (ref.) vs sitting	All participants, colon HR = 1.02 (0.84, 1.23) All participants, rectal HR = 0.90 (0.70, 1.18)	Age, study Centre, energy intake, education, smoking, height, weight, fibre intake. Age as underlying time scale
Steindorf et al., 2000. Poland	Case-control study	180 cases treated at a Polish hospital, and 180 age- and sex-matched controls selected from patients	Histologically confirmed incident cases of colon and rectal cancer	Time spent watching TV in leisure-time, categorised as tertiles (<1.14 [ref], 1.14–2, ≥2 h/day)	OR = 2.22 (1.19, 4.17)	Education, total energy intake

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
		without cancer or digestive tract disorders				
Levi et al., 1999. Switzerland	Case-control study	223 cases treated at a Swiss hospital, and 491 controls admitted to the same hospital for acute conditions	Histologically confirmed, incident colorectal cancer	Predefined categories for occupational activity (mainly sitting, standing, very tiring/ tiring) for jobs held at various life-stages. HRs presented here as standing (ref.) vs sitting	15–19 years: OR = 1.25 (0.83, 1.92) 30–39 years: OR = 1.85 (1.09, 3.13) 50–59 years: OR = 1.61 (0.94, 2.70)	Sex, age, total alcohol intake, total energy intake, education
Tavani et al., 1999. Italy	Case-control study	1225 colon cases recruited from local hospitals, and 4154 controls admitted to the same hospitals for acute conditions	Histologically confirmed, incident colon cancer	Predefined categories of occupational activity (mainly sitting, standing, average, heavy, very heavy). HRs presented here as standing (ref.) vs sitting	Women 15–19 years: OR = 137 (1.04, 1.82) 30–39 years: OR = 1.54 (1.08, 2.17) 50–59 years: OR = 1.45 (1.00, 2.13) Men 15–19 years: OR = 1.12 (0.81, 1.56) 30–39 years:	Study centre, age, total alcohol intake, total energy intake, education

					OR = 0.99 (0.94, 1.69) 50–59 years: OR = 0.94 (0.70, 1.28)	
Endometrial/uterine cancer						
Hunter et al., 2020. UK.	Prospective cohort study.	253,188 females aged between 40–69 years from the UK Biobank study.	Uterine cancer cases identified via cancer registry linkage.	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day.	HR = 0.63 (0.44, 0.88).	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake.
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	50 women diagnosed with endometrial cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	RR = 0.49 (0.15, 1.52)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours.
Patel et al., 2015. USA. After Patel et al., 2008	Prospective cohort study	77,462 women from the CPS-II nutrition cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	776 endometrial cancer cases identified by self-report (verified by state cancer registries or medical records) or through National Death Index	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	RR = 1.21 (0.97, 1.50)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI
Arem et al., 2011. United States	Case-control study	667 cases from Connecticut hospitals. 662 age-matched controls recruited through random digit dialling	Incident, primary endometrial cancers	Time seated watching multimedia or sitting at work (<4 [ref.], 4–<6, 6–<8, ≥8 h/day)	OR = 1.52 (1.07, 2.16), *p* trend = 0.024	Age, race, parity, menopausal status, OC pill use, smoking, hypertension, BMI
Friedenreich et al., 2010. Canada	Case-control study	542 cases identified through the Alberta Cancer Registry. 1032 age-matched controls recruited from the community	Incident, histologically confirmed invasive cases of endometrial cancer	Lifetime occupational sitting time (h/week/year) assessed by total lifetime physical activity questionnaire. Quartiles according to control distribution (≤3.59 [ref.], 3.60–9.26, 9.27–16.94, ≥16.95 h/week/year)	OR = 1.28 (0.89, 1.83), *p* trend = 0.12 For each h/week/year increase in occupational sitting time OR = 1.02 (1.00, 1.04). For 5 h/week/year increase in sitting time OR = 1.11 (1.01, 1.22)	Age, BMI, waist circumference, age at menarche, hypertension, number of pregnancies ≥20 weeks gestation

Moore et al., 2010. USA. After Gierach et al, 2009	Prospective cohort study	69,648 women from the NIH-AARP diet and health study, aged 51–72 years at questionnaire administration	888 incident endometrial cancers identified through linkage to 11 state cancer registries	Sitting during a typical 24 h period in past 12 months (<3 [ref.], 3–4, 5–6, 7–8, ≥9 h/day)	RR = 1.45 (1.10, 1.92), p trend <0.01	Age, race, smoking, parity, oral contraceptive use, age at menopause, hormone therapy use, vigorous physical activity
Friberg et al., 2006. Sweden	Prospective cohort study	33,723 women from the Swedish mammography cohort, aged 50–83 years at baseline. Mean follow-up of 7.25 years	199 incident endometrial cancers identified through national and regional cancer registries	Predefined categories for time spent per day watching TV/other leisure sitting (<5 [ref.], ≥5 h/day)	RR = 1.80 (1.14, 2.83)	Age, parity, history of diabetes, education, total fruit and vegetable intake, oral contraceptive use, postmenopausal hormone use, age at menarche, age at menopause, smoking, total energy intake, leisure-time physical activity
Oesophageal cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40–69 years from the UK Biobank study	541 oesophagus and stomach cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 1.02 (0.73, 1.42)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	8 women and 100 men diagnosed with oesophageal cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 2.38 (0.35, 16.45) Men RR = 1.05 (0.58, 1.87)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						physical activity time in leisure time, type of job and total working hours
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	315 oesophageal cancer cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 1.13 (0.47, 2.72) Men RR = 1.04 (0.74, 1.46)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI

Gallbladder cancer						
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	90 gallbladder cancer cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 1.43 (0.65, 3.14) Men RR = 2.11 (0.87, 5.09)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI
Head and neck cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40 and 69 years from the UK Biobank study	557 oropharyngeal cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 1.48 (1.09, 2.01)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	371 head and neck cancer cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 1.49 (0.86, 2.61) Men RR = 1.22 (0.88, 1.69)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI
Haematological cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40 and 69 years from the UK Biobank study	2468 haematological malignancies identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 0.97 (0.82, 1.16)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake

Hepatobiliary tract						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40 and 69 years from the UK Biobank study	456 hepatobiliary tract cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 1.26 (0.90, 1.77)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Kidney cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40–69 years from the UK Biobank study	779 kidney cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 1.08 (0.82, 1.42)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	12 women and 57 men diagnosed with kidney cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 4.15 (0.66, 26.11) Men RR = 1.04 (0.44, 2.47)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	565 kidney cancer cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 0.97 (0.62, 1.51) Men RR = 1.09 (0.80, 1.48)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI
George et al., 2011. United States	Prospective cohort study	289,512 participants from the NIH-AARP Diet and Health Study, aged 51–72 years at risk factor assessment	1206 incident renal cell carcinomas identified through linkage to 11 state cancer registries	Predefined categories for (i) time spent watching TV or videos (<3 [ref.], 3–4, 5–6, 7–8, ≥ 9 h/day), and (ii) sitting during a typical 24 h period in past 12 months (<3 [ref.], 3–4, 5–6, 7–8, ≥ 9 h/day)	TV: RR = 1.56 (0.89, 1.41), p trend = 0.707 Total sitting: RR = 1.08 (0.92, 1.27), p trend = 0.765	Age, sex, race, history of diabetes, smoking, alcohol intake, diet quality, energy intake, recreational physical activity

Liver cancer						
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	21 women and 134 men diagnosed with liver cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 0.30 (0.04, 2.20) Men RR = 1.54 (0.92, 2.58)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	250 liver cancer cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 0.73 (0.35, 1.53) Men RR = 0.83 (0.54, 1.28)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women),

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						endoscopy screening, BMI
Lung cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40 and 69 years from the UK Biobank study	2076 lung cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 1.09 (0.93, 1.26)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	81 women and 369 men diagnosed with lung cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 2.80 (1.33, 5.90) Men RR = 1.07 (0.75, 1.51)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Wang et al., 2018. United States	Prospective cohort study	129,401 postmenopausal women from the Women's Health Initiative Observation Study and Clinical Trial cohort, aged between 50 and 79 at	1329 incident lung cancer cases determined via hospital records, death certificates, autopsy, and coroner reports	Self-report questionnaire with predefined categories of sitting. Categories collapsed to ≤5 (ref.), 6–9, 10–13, >13 min/day	HR = 1.10 (0.95, 1.28)	Age, race/ethnicity, BMI, family history of cancer, personal history of cancer, history of asthma, history of emphysema or chronic bronchitis, smoking,

		baseline. Mean follow up 11.8 years				education, alcohol intake, vitamin D use, hormone therapy, oral contraceptive use, hysterectomy status, NSAID use, servings of fruit, vegetables, red meat
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II nutrition cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	3021 lung cancer cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 0.98 (0.82, 1.17) Men RR = 1.01 (0.89, 1.15)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), BMI
Lam et al., 2013. United States	Prospective cohort study	158,415 never-smokers from the NIH-AARP Diet and Health Study, aged 50–71 years at	532 incident lung cancers identified through linkage to 11 state cancer registries	Predefined categories for (i) time spent watching TV or videos (<3 [ref.], 3–4, ≥5 h/	TV: HR = 1.06 (0.77, 1.46), p trend = 0.53 Total sitting:	Age, BMI, education, ethnicity, vigorous physical activity,

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
		baseline. Mean follow-up 11 years		day), and (ii) sitting during a typical 24 h period in past 12 months (<3 [ref.], 3–4, ≥ 5 h/day)	HR = 1.28 (0.96, 1.72), p trend = 0.23	alcohol intake, total caloric intake
Ukawa et al., 2013. Japan	Prospective cohort study	54,258 participants from Japan Collaborative Cohort Study for Evaluation of Cancer Risk, aged40–79 years at baseline. Median follow-up 15.6 years	798 participants diagnosed with lung cancer; data collected from cancer registries or local major hospitals	Predefined categories for time spent watching TV	Women HR = 1.03 (0.67, 1.62), *p* trend = 0.40 Men HR = 1.36 (1.04, 1.80), *p* trend = 0.06	Age, BMI, education, marital status, alcohol intake, smoking, intake of green leafy vegetables, oranges and other fruits. Walking time not included as it did not make meaningful contribution to model
Steindorf et al., 2006. Nine European countries	Prospective cohort study	416,227 participants from EPIC, mostly aged 35–70 years at baseline. Mean follow-up 6.3 years	1083 incident lung cancers identified through cancer registries or by active follow-up	Predefined categories for current occupational activity (sitting, standing, manual/heavy manual). HRs presented here as standing (ref.) vs sitting	Women RR = 0.88 (0.64, 1.20) Men RR = 0.74 (0.56, 0.98)	Age, study Centre, smoking, weight, height, education, total energy intake without energy from alcohol, alcohol intake, fruit intake, vegetable intake, red/processed meat intake, occupational exposure to lung carcinogens, non-occupational physical activity

Bak et al., 2005. Denmark	Prospective cohort study	54,422 participants from the Danish Diet, Cancer and Health cohort, aged 50–64 years at baseline	367 incident lung cancers identified through the Danish Cancer Registry	Predefined categories of occupational activity (sitting, standing, light activity, heavy activity, not working). HRs presented here as standing (ref.) vs sitting	Women IRR = 0.58 (0.37, 0.93) Men IRR = 0.60 (0.38, 0.94)	Leisure-time physical activity, smoking, school education, fruit and vegetable intake, occupational exposure to lung carcinogens. Age as underlying time scale
Melanoma						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40–69 years from the UK Biobank study	1635 cases of melanoma/skin cancer identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 1.01 (0.90, 1.29)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	1154 melanoma cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 0.99 (0.79, 1.25) Men RR = 1.05 (0.88, 1.24)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women),

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						postmenopausal hormone use (women), endoscopy screening, BMI
Multiple myeloma						
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	414 multiple myeloma cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 1.65 (1.07, 2.54) Men RR = 1.00 (0.68, 1.45)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI

Myeloid malignancies						
Rees-Punia et al., 2019. United States	Prospective cohort study	109,030 participants of the CPS-II Nutrition Cohort, aged 50–74 years at enrolment. Mean follow-up 10.0 years	255 myeloid leukaemia cases diagnosed (acute = 155 acute myeloid leukaemia) identified through linked with National Death Index and subsequently via state tumour registries	Leisure-time sitting (TV, reading, etc) categorised as <3 (ref.), 3–5, or ≥ 6 h/day	Myeloid leukaemia HR = 1.28 (0.89, 1.85) Acute myeloid leukaemia HR = 1.00 (0.89, 1.85)	Age, sex, race/ethnicity, education, alcohol use, pesticide exposure, formaldehyde exposure, smoking status/duration/frequency, BMI
Non-Hodgkin lymphoma						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40 and 69 years from the UK Biobank study	1193 cases identified via cancer registry linkage	TV time categorised as ≤ 1, 1–≤ 3 (ref.), 3–≤ 5, >5 h/day	HR = 0.85 (0.65, 1.26)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Patel et al., 2015. USA. After Teras et al., 2012	Prospective cohort study	146,722 participants from the CPS-II nutrition cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	1728 non-Hodgkin lymphoma cases identified by self-report (verified by state cancer registries or medical records) or through National Death Index	Leisure-time sitting (TV, reading, etc) categorised as <3 (ref.), 3–5, or ≥ 6 h/day	Women RR = 1.07 (0.86, 1.35) Men RR = 1.04 (0.86, 1.25)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease,

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						diabetes, menopausal status (women), post-menopausal hormone use (women), BMI
Ovarian cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	253,188 females aged between 40 and 69 years from the UK Biobank study	578 cases of ovarian cancer identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 0.93 (0.63, 1.38)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	24 women diagnosed with ovarian cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 1.51 (0.48, 4.72)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Ukawa et al., 2018. Japan	Prospective cohort study	34,758 women in the Japan Collaborative Cohort Study for Evaluation of Cancer Risk (JACC Study), aged	59 women diagnosed with ovarian cancer, identified via population-based	Time spent watching TV, categorised as <2 (ref.),2–2.9, 3–3.9, 4–4.9 or 5 h/day	RR = 1.81(0.75, 4.39)	Age, age of menarche, BMI, parity, family history of breast/ovarian/prostate cancer, education level, sleep

		40–79 years at enrolment. Median follow-up 19.4 years	cancer registries or local major hospital records			duration, alcohol intake, hormone use, smoking status, walking time, age of menopause
Hildebrand et al., 2015. USA. After Patel et al., 2015. Patel et al., 2006	Prospective cohort study	63, 972 women from the CPS-II Nutrition Cohort, aged 50–74 years baseline. Mean follow-up 19 years	638 ovarian cancer cases identified by self-report (verified by state cancer registries or medical records) or through National Death Index	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Total ovarian cancer RR = 1.44 (1.12, 1.85), p trend = 0.006 Serous ovarian cancer RR = 1.52 (1.06, 2.16), p trend = 0.01 Non-serous ovarian cancer RR = 1.08 (0.57, 2.04), p trend 0.83	Age, education, BMI, smoking status, number of live births, use of OC pill, postmenopausal hormone use (time dependent)
Lee et al., 2013. China	Case control study	500 cases and 500 controls aged <75 years residing in Guangzho	Histologically confirmed incident epithelial ovarian cancer	Sitting time categorised as ≤4 (ref.), 4.5–8, ≥8.5 h/day	OR = 1.07 (0.77, 1.48)	Age, parity, oral contraceptive use, BMI, menopausal status, education level, smoking status, family history of ovarian or breast cancer
Xiao et al., 2013. United States	Prospective cohort study	95,768 women from the NIH-AARP Diet and Health Study, aged 50–71 years at baseline	753 incident cases of ovarian cancer identified through linkage to 11 state cancer registries	Predefined categories for (i) time spent watching TV or videos (<3 [ref.], 3–4, 5–6, ≥7 h/day), and (ii) sitting during a typical 24 h period in past 12 months (<3	TV: RR = 1.02 (0.67, 1.55) Total sitting: RR = 1.06 (0.81, 1.39)	Age, parity, age at menarche, age at menopause, race, education, marital status, oral contraceptive use, MHT use, smoking. Additional adjustment

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
				[ref.], 3–4, 5–6, ≥7 h/day)		for MVPA and BMI (data not shown)
Zhang et al., 2004. China	Case-control study	254 women under 75 recently treated for ovarian cancer in hospitals in Hangzhou, China, and 652 age-matched controls	Epithelial ovarian cancer histologically diagnosed in past three years	Number of hours spent in variety of sitting tasks five years ago recalled. Calendars were used to assist recall. Total sitting time summed and categorised (<4 [ref.], 4–10, >10 h/day)	TV: OR = 3.39 (1.0, 11.5), p trend = 0.88 Total sitting: OR = 1.77 (1.0, 3.1), p trend = 0.08	Age, locality, education, family income, BMI, smoking, alcohol consumption, tea consumption, physical activity, marital status, menopausal status, parity, oral contraceptive use, tubal ligation, hormone replacement therapy, ovarian cancer in first degree relatives, total energy intake
Pancreatic cancer						
Hunter et al., 2020. United Kingdom	Prospective cohort study	470,578 adults aged between 40 and 69 years from the UK Biobank study	615 pancreatic cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 1.07 (0.77, 1.49)	Age, sex, ethnicity, deprivation index, education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective	39 women and 76 men diagnosed with pancreatic cancer; identified via population-based	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 0.90 (0.26, 3.07) Men	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking

		Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	cancer registries or local major hospital records		RR = 2.25 (1.17, 4.34)	time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	425 melanoma cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 1.02 (0.73, 1.41) Men RR = 1.14 (0.87, 1.49)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI
Prostate cancer						
Hunter et al., 2020.	Prospective cohort study	217,390 adults aged between 40 and	5979 prostate cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day	HR = 0.94 (0.83, 1.38)	Age, sex, ethnicity, deprivation index, education, fruit and

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
United Kingdom		69 years from the UK Biobank study				vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	521 men diagnosed with prostate cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, $1–<3$ (ref.), $3–<5$, $5–<7$, ≥ 7 h/day	RR = 1.10 (0.84, 1.45)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total working hours
Rangul et al., 2018. Norway	Prospective cohort study	18,7771 men in the Nord-Trøndelag Health Study (HUNT), aged ≥ 20 years at enrolment. Median follow-up 16 years	889 men diagnosed with colorectal cancer, identified via linkage to the Cancer Registry of Norway	Total sitting time (single question, participants prompted to include sitting at work, mealtimes, watching TV, sitting in a car, etc), categorised as <8 (ref.) or ≥ 8 h/day	RR = 1.22 (1.05, 1.42)	Age, education, smoking, alcohol, BMI
Van Hoang et al., 2018. Vietnam	Case control study	231 male cases and 409 male controls aged between 64 and 75 years from Ho Chi Min City.	Histologically confirmed incident prostate cancer	Sitting time categorised as <45.5 (ref.), 45.5–62, >62 h/week	OR = 1.40 (0.85, 2.31)	Age, age at marriage, BMI, alcohol consumption, total energy intake, education level, marital status,

						smoking habit, prostate cancer in the first-degree relatives
Patel et al., 2015. United States	Prospective cohort study	69,260 men from the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	8276 incident prostate cancers (1705 advanced) identified by self-report (verified by medical records, cancer registries or NDI)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Total prostate cancer RR = 0.97 (0.91, 1.03) Advanced prostate cancer RR = 0.96 (0.85, 1.09)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, PSA testing, BMI
Lynch et al., 2014. United States	Prospective cohort study	170,481 men from the NIH-AARP Diet and Health Study, aged 51–72 years at risk factor questionnaire. Mean follow-up 8.5 years	13,751 incident prostate cancers (including 1365 advanced cases; 669 deaths from prostate cancer) identified through 11 state cancer registries or National Death Index	Predefined categories for (i) time spent watching TV or videos (<1 [ref.], 1–2, 3–4, 5–6, ≥7 h/day) and (ii) sitting (<3 [ref.], 3–4, 5–6, 7–8, ≥9 h/day) during a typical 24-hour period in past 12 months	Total prostate cancer TV: HR = 1.03 (0.92, 1.15), *p* trend = 0.53 Total sitting: HR = 0.98 (0.91, 1.05) *p* trend = 0.09 Advanced prostate cancer TV: HR = 0.93 (0.79, 1.09) *p* trend = 0.49	Age, age squared, race, marital status, education, family history of prostate cancer, DRE in past 3 years, PSA in past 3 years, history of diabetes, smoking, caloric intake, alcohol intake, recreational physical activity, BMI

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
					Total sitting: HR = 0.91 (0.77, 1.08) p trend = 0.16 Fatal prostate cancer TV: HR = 1.07 (0.85, 1.33) p trend = 0.15 Total sitting: HR = 1.07 (0.84, 1.35) p trend = 0.98	
Orsini et al., 2009. Sweden	Prospective cohort study	Population-based sample of 45,887 Swedish men, aged 45–79 years at baseline	2735 incident prostate cancers identified through national and regional cancer registries, and 190 deaths identified through the Swedish Register of Death Causes	Predefined categories for occupational activity levels (mostly sitting, sitting half the time, mostly standing, heavy manual labour). HRs presented here as mostly standing (ref.) vs mostly sitting	Total prostate cancer OR = 1.27 (1.10, 1.45) Localised prostate cancer OR = 1.39 (1.11, 1.72) Advanced prostate cancer OR = 1.14 (0.89, 1.45) Fatal prostate cancer OR = 1.14 (0.63, 2.04)	Lifetime walking and bicycling levels, waist-hip ratio, height, diabetes, alcohol consumption, smoking status, education, total energy intake, consumption of dairy products, red meat consumption, parental history of prostate cancer. Age as underlying time scale
Stomach cancer						
Hunter et al., 2020.	Prospective cohort study	470,578 adults aged between 40 and			HR = 1.03 (0.69, 1.53)	Age, sex, ethnicity, deprivation index,

United Kingdom		69 years from the UK Biobank study	346 stomach cancer cases identified via cancer registry linkage	TV time categorised as ≤1, 1–≤3 (ref.), 3–≤5, >5 h/day		education, fruit and vegetable, BMI, height, smoking status, alcohol intake
Ihira et al., 2020. Japan	Prospective cohort study	13,277 women and 20,030 men in Japan Public Health Center-based Prospective Study, aged 50–79 at enrolment. Mean follow-up 10.2 years	127 women and 552 men diagnosed with stomach cancer; identified via population-based cancer registries or local major hospital records	Occupational sitting time, categorised as <1, 1–<3 (ref.), 3–<5, 5–<7, ≥7 h/day	Women RR = 1.03 (0.59, 1.81) Men RR = 1.08 (0.82, 1.41)	Age, area, history of diabetes, smoking status, alcohol intake, BMI, coffee, walking time at work, strenuous time at work), moderate-to-vigorous physical activity time in leisure time, type of job and total [23] working hours
Huerta et al., 2017. Spain	Case-control study	428 cases from hospitals in ten regions of Spain. 3264 controls (frequency-matched by sex, age and region) randomly recruited from general practitioner lists	Incident stomach cancer cases	Leisure-time sitting in the last year, categorised as <3 (ref.), 3–5.9, 6–8.9, or ≥9 h/day	OR = 0.78 (0.51, 1.19)	Age, sex, socioeconomic status, study area, smoking, presence of gastric symptomatology, use of anti-inflammatory drugs, family history of gastric cancer, *Helicobacter pylori* seropositivity, BMI, intake of total energy, red and processed meats, vegetable and fruits, past alcohol consumption, physical activity domains

(continued)

Table 9.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
Patel et al., 2015. United States	Prospective cohort study	146,722 participants of the ACS CPS-II Nutrition Cohort, aged 50–74 at enrolment. Mean follow-up 15.8 years	306 melanoma cases identified by self-report (verified through medical records, cancer registries or National Death Index)	Leisure-time sitting (TV, reading, etc) categorised as 0–<3 (ref.), 3–5, or ≥6 h/day	Women RR = 1.06 (0.55, 2.03) Men RR = 1.05 (0.71, 1.55)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of smoking among current smokers, years since quitting among former smokers, education, alcohol intake, total energy intake, red/processed meat intake, family history of cancer, prevalent chronic disease, diabetes, menopausal status (women), postmenopausal hormone use (women), endoscopy screening, BMI

Abbreviations: Hazard ratio (HR), Odds ratio (OR), Risk ratio (RR), Body mass index (BMI), Oestrogen receptor positive (ER+), Oestrogen receptor negative (ER-), Hormone replacement therapy (HRT), American Cancer Society (ACS), Cancer Prevention Study (CPS), National Institutes of Health (NIH), American Association of Retired Persons (AARP), European Prospective Investigation into Diet and Nutrition (EPIC), non-steroidal anti-inflammation drug (NSAID), healthy eating index (HEI)

9.3.2 Sedentary Behaviour and Bladder Cancer

Three prospective cohort studies have examined sedentary behaviour and bladder cancer risk: one study looked at television viewing time [23], another at occupational sitting [24] and the third study assessed leisure time sitting [29]. Our meta-analysis showed no relation (RR = 1.02, 95% CI: 0.77–1.27), but there was considerable heterogeneity present ($I^2 = 47\%$). See Fig. 9.1.

After excluding the study examining occupational sedentary behaviour [24], there was minimal change to the risk estimate (RR = 1.09, 95% CI: 0.91–1.27) and lower heterogeneity ($I^2 = 18\%$).

9.3.3 Sedentary Behaviour and Brain Cancer

The analysis conducted by Hunter et al. using the UK Biobank data was the only study to examine sedentary behaviour (television viewing time) and brain cancer risk. They found no relation (HR = 0.96, 95% CI: 0.63–2.06) [23].

9.3.4 Sedentary Behaviour and Breast Cancer

Twenty studies have examined the association of sedentary behaviour with breast cancer risk (see Table 9.1) [23–25, 29–45]. Twelve of these studies involved prospective cohorts [23–25, 29–31, 33, 34, 38, 39, 42, 43], six were case-control studies [32, 35, 36, 40, 41, 44], one was a nested case-control study [37] and one used a case-cohort design [45]. Six studies generated an estimate of total sitting time [25, 33, 34, 37, 38, 45], two assessed leisure-time sitting [29, 32], five studies examined television viewing time [23, 30, 31, 41, 42], four studies examined occupational sitting [24, 35, 40, 44] and the remaining studies used an ordinal scale of occupational exposure (we compared the 'sitting' to the 'standing' category) [36, 39, 43].

Our meta-analysis found that sedentary behaviour was associated with a very small increase in breast cancer risk (RR = 1.06; 95% CI: 1.01–1.11) (Fig. 9.1). We observed low heterogeneity across the studies ($I^2 = 7\%$). The exclusion of studies assessing occupational sedentary behaviour did not change the risk estimate (RR = 1.08, 95% CI: 1.02–1.14), and no heterogeneity was observed ($I^2 = 0\%$). When we restricted our inclusion to prospective cohort studies only, the risk increase was similar to our main meta-analysis (RR = 1.08, 95% CI: 1.03–1.14), and there was no heterogeneity evident ($I^2 = 0\%$). We did not see any evidence of publication bias when reviewing funnel plot asymmetry.

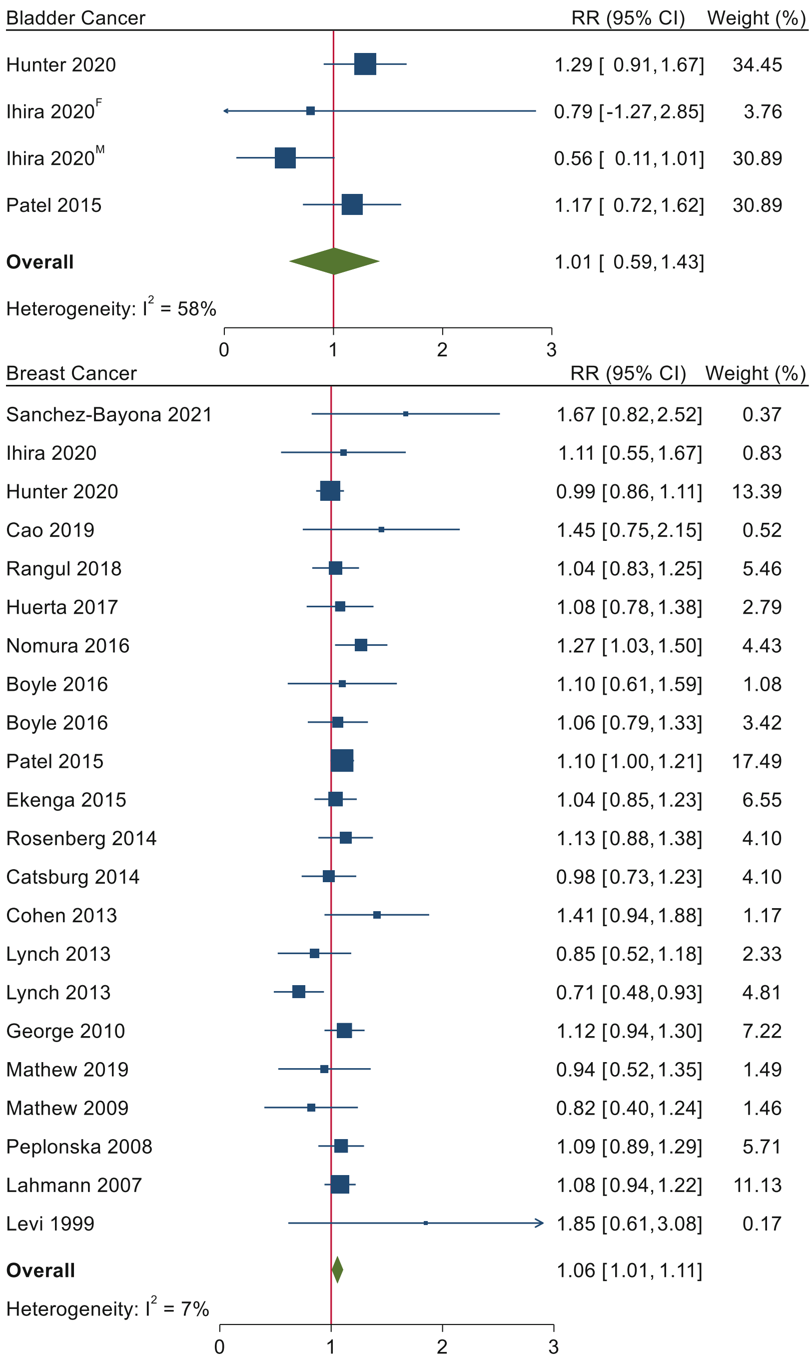

Fig. 9.1 Forest plot for main random effects meta-analysis synthesising the associations of sedentary behaviour with bladder and breast cancer. RR = relative risk; CI = confidence intervals

9.3.5 Sedentary Behaviour and Colorectal Cancer

Sixteen studies have examined the association of sedentary behaviour with colorectal, colon and/or rectal cancer risk [23–25, 29, 46–57]. The main design features and results of these studies are summarised in Table 9.1. Five of these studies examined colorectal cancer [23–25, 29, 46, 47, 49–51, 53, 57], and six examined both colon and rectal cancers [29, 48, 52–54, 57], whereas two studies only included colon cancers [55, 56]. Twelve studies were prospective cohort studies [23–25, 29, 46–49, 51–53, 55], and four were case-control studies [50, 54, 56, 57]. Six studies assessed total sitting time [25, 48–51, 53], four examined television viewing time [23, 46, 47, 54], one reported on risks associated with leisure-time sitting [29], one assessed occupational sitting time [24] and the remaining studies used an ordinal scale of occupational exposure (we compared the 'sitting' to the 'standing' category) [52, 55–57].

Comparing the highest category of sedentary behaviour to lowest category (reference), we observed no association between sedentary behaviour and colorectal cancer (RR = 1.03; 95% CI: 0.98–1.08) and no heterogeneity across the colorectal cancer studies ($I^2 = 0\%$). See Fig. 9.2. The exclusion of studies examining occupational sedentary behaviour resulted in no change to the risk estimate. When we restricted our inclusion to prospective cohort studies only, the risk estimate was also the same. Finally, we restricted meta-analysis to colon cancer only; here, we saw a suggestive risk increase for highest versus lowest categories of sedentary behaviour (RR = 1.12, 95% CI: 0.98–1.27; $I^2 = 0\%$). There was no evidence of publication bias suggested by funnel plot asymmetry.

9.3.6 Sedentary Behaviour and Endometrial Cancer

Seven studies have examined the association of sedentary behaviour with endometrial cancer risk (see Table 9.1) [23, 24, 29, 58–61]. Five were prospective cohort studies [23, 24, 29, 59, 61], whereas two used a case-control design [58, 60]. Two studies assessed total sitting time [58, 61], two examined television viewing time [23, 59], one reported on risks associated with sitting in leisure-time [29], and two reported occupational sitting [24, 60].

Across the seven studies, sedentary behaviour was associated with a 16% risk increase (95% CI: 0.84–1.48). We observed high heterogeneity across the studies ($I^2 = 76\%$). See Fig. 9.2. The exclusion of studies examining occupational sedentary behaviour resulted in a small increase in the risk estimate (RR = 1.24, 0.85–1.64), but heterogeneity remained high ($I^2 = 82\%$). When we restricted our inclusion to prospective cohort studies only, the risk estimate was attenuated (RR = 1.08, 95% CI: 0.65–1.51), and heterogeneity remained high ($I^2 = 83\%$). There was no evidence of publication bias suggested by funnel plot asymmetry.

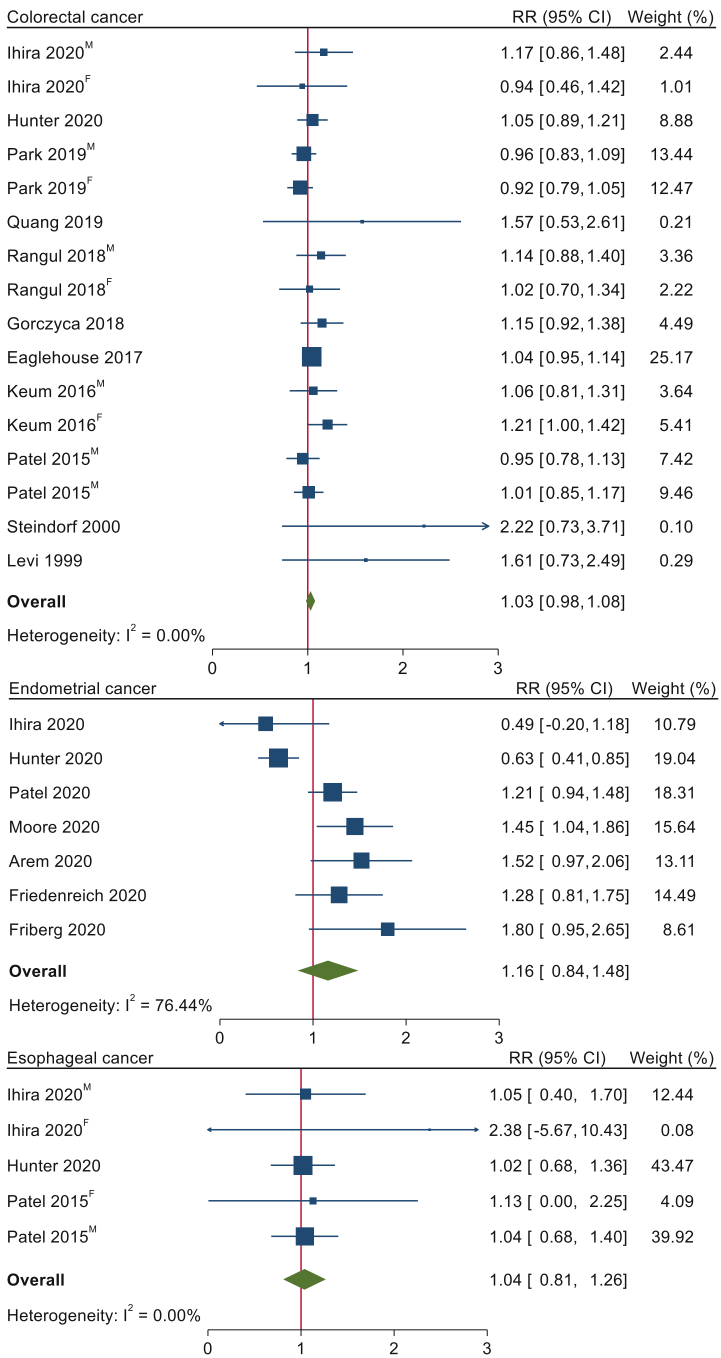

Fig. 9.2 Forest plot for main random effects meta-analysis synthesising the associations of sedentary behaviour with colorectal, endometrial and oesophageal cancer. RR = relative risk; CI = confidence intervals

9.3.7 Sedentary Behaviour and Oesophageal Cancer

Three prospective cohort studies have examined the relationship between sedentary behaviour and oesophageal cancer to date (see Table 9.1) [23, 24, 29]. Patel et al. examined risk associated with leisure-time sitting, [29] Hunter et al. assessed television viewing time [23], and Ihira et al. assessed occupational sitting [24].

Figure 9.2 shows that sedentary behaviour was not related to any risk increase for oesophageal cancer (RR = 1.04, 95% CI: 0.81–1.26). There was no heterogeneity noted ($I^2 = 0\%$). The sensitivity analysis removing the study of occupational sitting made no change to the effect estimate (RR = 1.03, 95% CI: 0.79–1.28) nor heterogeneity ($I^2 = 0\%$). There was no evidence of publication bias suggested by funnel plot asymmetry.

9.3.8 Sedentary Behaviour and Gall Bladder Cancer

Only one published study has examined the relationship between sedentary behaviour and gall bladder cancer (see Table 9.1). Patel et al. assessed leisure-time sitting in the Cancer Prevention Study II Nutrition Cohort [29]. They reported a risk increase for both women (RR = 1.43, 95% CI: 0.65–3.14) and men (RR = 2.11, 95% CI: 0.87–5.09); however, there were only 57 women and 33 men included in their analysis.

9.3.9 Sedentary Behaviour and Head and Neck Cancer

Two prospective cohort studies have examined the association of sedentary behaviour with head and neck cancer (see Table 9.1) [23, 29]. Patel et al. examined risk associated with leisure-time sitting [29], while Hunter et al. assessed television viewing time [23].

Both studies reported elevated risks for higher levels of sedentary behaviour compared to lower. Patel et al. demonstrated a risk increase for both women (RR = 1.49, 95% CI: 0.86–2.61) and men (RR = 1.22, 95% CI: 0.88–1.69). Hunter et al. reported a risk increase of 48% (95% CI: 1.09–2.01).

9.3.10 Sedentary Behaviour and Haematological Cancers

One prospective cohort study examined the relationship between television viewing time and risk of haematological cancers, pooling lymphomas, multiple myeloma and leukaemias together (see Table 9.1). Hunter et al. observed no relation (HR = 0.97, 95% CI: 0.82–1.16) of sedentary behaviour to these cancers [23].

9.3.11 Sedentary Behaviour and Hepatobiliary Cancers

Hunter et al. also examined the relationship between television viewing time and risk of hepatobiliary cancers, pooling liver, bile duct and gall bladder cancers (see Table 9.1). A risk increase was observed for highest versus lowest category of television viewing time (HR = 1.26, 95% CI: 0.90–1.77) [23].

9.3.12 Sedentary Behaviour and Kidney Cancer

Four prospective cohort studies have examined the relationship of sedentary behaviour with kidney cancer to date (see Table 9.1) [23, 24, 29, 62]. One study examined risk associated with total sitting [62], one study examined leisure-time sitting [29], one study examined television viewing time [23] and one study assessed occupational sitting [24].

Overall, sedentary behaviour was associated with no substantial relation to kidney cancer risk (RR = 1.07; 95% CI: 0.94–1.20), and there was no heterogeneity across studies ($I^2 = 0\%$). See Fig. 9.3. The sensitivity analysis where studies of occupational sitting were removed did not change the result (RR = 1.07; 95% CI: 0.94–1.20; $I^2 = 0\%$). There was no evidence of publication bias suggested by funnel plot asymmetry.

9.3.13 Sedentary Behaviour and Liver Cancer

Two prospective cohort studies have estimated the effect of sedentary behaviour on lung cancer to date (see Table 9.1) [24, 29]. One study examined risk associated with leisure-time sitting [29], and the other assessed occupational sitting [24].

Findings from the Cancer Prevention Study II Nutrition Cohort suggested a potential protective relation for both women (RR = 0.73, 95% CI: 0.35–1.53) and men (RR = 0.83, 95% CI: 0.54–1.28). Findings from Japan Public Health Centre-based Prospective Study also showed an inverse relation for the highest versus lowest category of occupational sitting in women (RR = 0.30, 95% CI: 0.04–2.20); however, this analysis was based on only 21 incident liver cancers. In contrast, this study suggested elevated risk for men (RR = 1.54, 95% CI: 0.92–2.58).

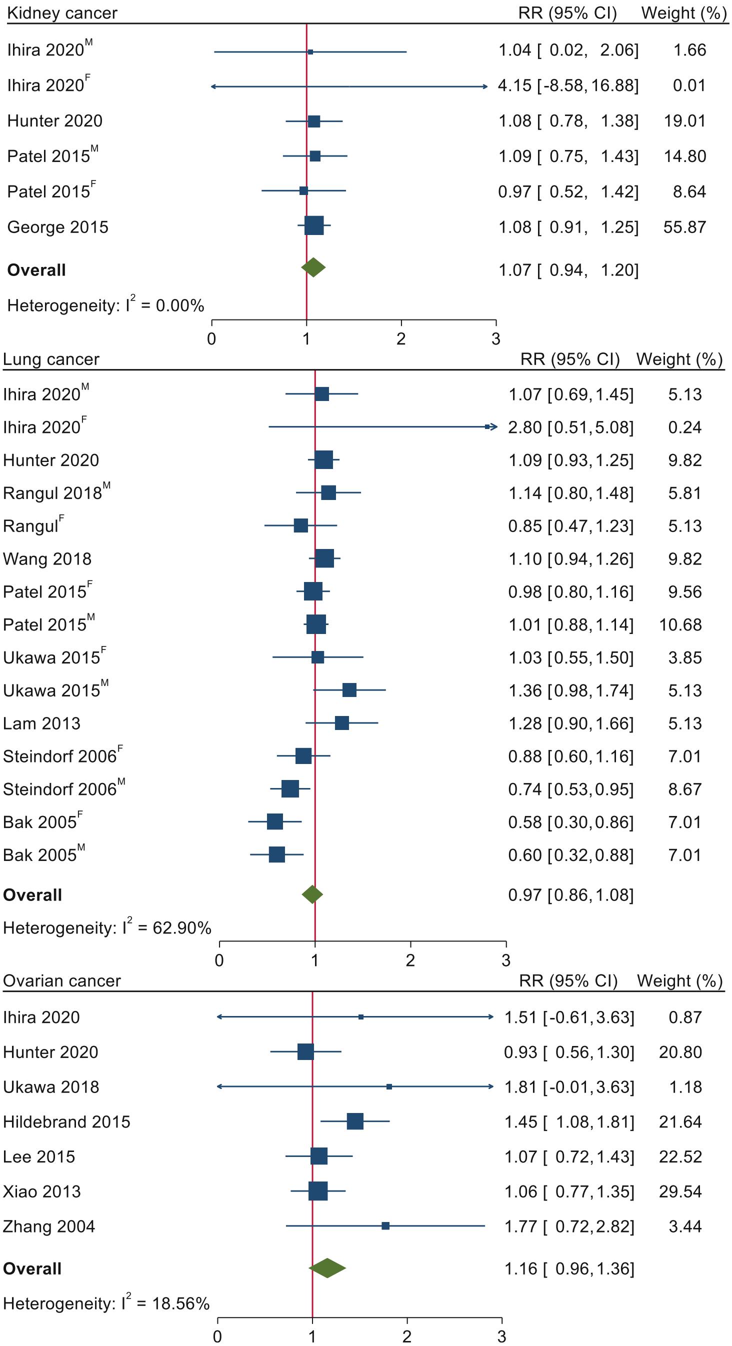

Fig. 9.3 Forest plot for main random effects meta-analysis synthesising the associations of sedentary behaviour with kidney, lung and ovarian cancer. RR = relative risk; CI = confidence intervals

9.3.14 Sedentary Behaviour and Lung Cancer

Eight prospective cohort studies have examined the association of sedentary behaviour with lung cancer to date (see Table 9.1) [23, 24, 29, 63–67]. Two studies assessed total sitting time [65, 67], one study examined risk associated with leisure-time sitting [29], two studies examined television viewing time [23, 66] and three examined occupational sitting [24, 63, 64].

Overall, sedentary behaviour was not associated with lung cancer risk (RR = 0.97; 95% CI: 0.86–1.08). Heterogeneity across the studies was high ($I^2 = 63\%$) (Fig. 9.3). The exclusion of studies examining occupational sedentary behaviour changed the risk estimate somewhat (RR = 1.06, 95% CI: 0.99–1.13), with no heterogeneity ($I^2 = 0\%$). Visual inspection of the funnel plot did not suggest any publication bias was present.

9.3.15 Sedentary Behaviour and Melanoma

Two prospective cohort studies have estimated the effect of sedentary behaviour on melanoma (see Table 9.1) [23, 29]. One study examined risk associated with leisure-time sitting [29], and the other assessed television viewing time [23].

Both studies concluded that there was no relationship between sedentary behaviour and melanoma. In the Cancer Prevention Study II Nutrition Cohort, Patel et al. reported results separately for women (RR = 0.99, 95% CI: 0.79–1.25) and men (RR = 1.05, 95% CI: 0.88–1.24) [29]. Hunter et al. undertook their analysis using data from the UK Biobank (HR = 1.01, 95% CI: 0.90–1.29) [23].

9.3.16 Sedentary Behaviour and Multiple Myeloma

Only one study presented results for multiple myeloma (Table 9.1). Patel et al. examined risk associated with leisure-time sitting, which suggested an increase in risk for women (RR = 1.65, 1.07–2.54) but not men (RR = 1.00, 95% CI: 0.68–1.45) [29].

9.3.17 Sedentary Behaviour and Myeloid Malignancies

Rees-Punia et al. examined the relationship between leisure-time sitting and risk of myeloid malignancies (Table 9.1). They reported a risk increase for myeloid leukaemia (HR = 1.28, 95% CI: 0.89–1.85) but null results for acute myeloid leukaemia (HR = 1.00, 95% CI: 0.89–1.85) [68].

9.3.18 Sedentary Behaviour and Non-Hodgkin Lymphoma

Two prospective cohort studies have estimated the relation of sedentary behaviour to non-Hodgkin lymphoma (see Table 9.1) [23, 29]. One study examined risk associated with leisure-time sitting [29], and the other assessed television viewing time [23].

Findings from the Cancer Prevention Study II Nutrition Cohort did not show evidence of a relationship for either women (RR = 1.07, 95% CI: 0.86–1.35) or men (RR = 1.04, 95% CI: 0.86–1.25) [29]. The UK Biobank analysis suggests a protective relation for highest versus lowest television viewing time (HR = 0.85, 95% CI: 0.65–1.26) [23].

9.3.19 Sedentary Behaviour and Ovarian Cancer

Sedentary behaviour and ovarian cancer risk have been investigated by seven studies (see Table 9.1) [23, 24, 69–73]. All but two of these studies were prospective cohort studies; Lee et al. and Zhang et al. used a case-control design [70, 73]. Three studies examined total sitting time [69, 70, 73], one study assessed sitting during leisure-time [72], television viewing time was assessed by two studies [23, 71] and one study examined occupational sitting [24].

Figure 9.3 shows the results of our primary meta-analysis. Highest versus lowest categories of sedentary behaviour were associated with a 16% risk increase (95% CI: 0.96–1.36). We observed low heterogeneity across the studies ($I^2 = 19\%$). Excluding the study of occupational sitting made no substantial difference to the result (RR = 1.15, 95% CI: 0.95–1.36; $I^2 = 22\%$). After excluding the case-control study from the meta-analysis, the result was also very similar (RR = 1.16, 95% CI: 0.89–1.44; $I^2 = 35\%$). There was no evidence of publication bias suggested by funnel plot asymmetry for the primary analysis nor for the sensitivity analyses.

9.3.20 Sedentary Behaviour and Pancreatic Cancer

Three prospective cohort studies have examined sedentary behaviour and pancreatic cancer risk (see Table 9.1) [23, 24, 29]. One study examined leisure-time sitting [29], one study examined television viewing time [23] and one study assessed occupational sitting [24].

Figure 9.4 shows the primary meta-analysis result (RR = 1.10, 95% CI: 0.79–1.41; $I^2 = 0\%$). The sensitivity analysis removing the occupational sitting study returned a similar result (RR = 1.06, 95% CI: 0.74–1.38, $I^2 = 0\%$). There was no evidence of publication bias suggested by funnel plot asymmetry.

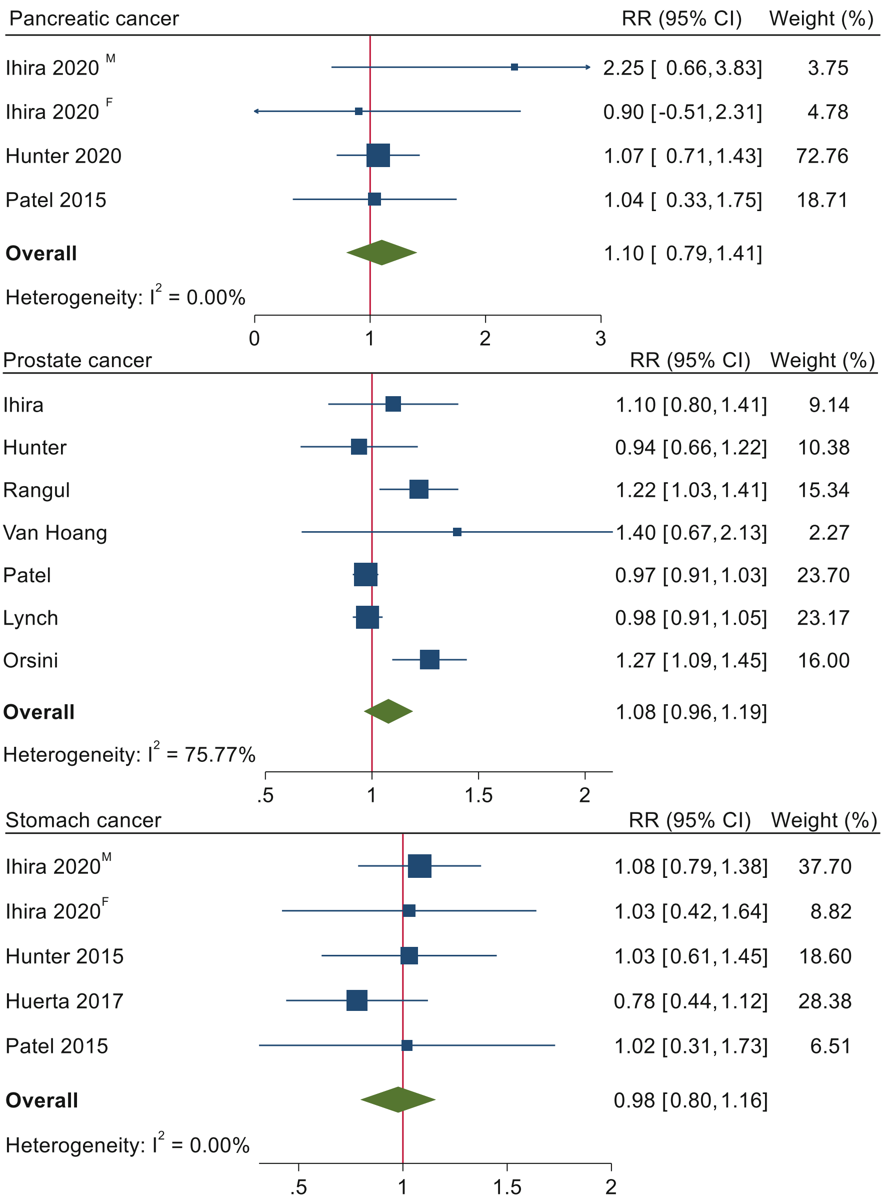

Fig. 9.4 Forest plot for main random effects meta-analysis synthesising the associations of sedentary behaviour with pancreatic, prostate and stomach cancer. RR = relative risk; CI = confidence intervals

9.3.21 Sedentary Behaviour and Prostate Cancer

Six prospective cohort studies [23–25, 29, 74, 75] and one case-control study [76] have estimated the effect of sedentary behaviour on prostate cancer risk (see Table 9.1). Three studies assessed total sitting time [25, 74, 76], one reported on risks associated with sitting in leisure-time [29], one study examined television viewing time [23] and two studies assessed occupational sitting [24, 75].

Across these seven studies, sedentary behaviour was possibly associated with a slight risk increase (RR = 1.08; 95% CI: 0.96–1.19), but there was high heterogeneity present (I^2 = 76%). See Fig. 9.4. Excluding the occupational sedentary behaviour studies resulted in a null relation (RR = 1.02, 95% CI: 0.92–1.12, I^2 = 64%). When only prospective cohort studies were included in the meta-analysis, the result was similar to the primary analysis (RR = 1.07, 95% CI: 0.95–1.19; I^2 = 79%). We did not see any evidence of publication bias when reviewing funnel plot asymmetry.

9.3.22 Sedentary Behaviour and Stomach Cancer

Three prospective cohort studies [23, 24, 29] and one case-control study [77] have examined sedentary behaviour and stomach cancer risk (see Table 9.1). Two studies examined leisure-time sitting [29, 77], one study examined television viewing time [23] and one study assessed occupational sitting [24].

Meta-analysis demonstrated no relation (RR = 0.98, 95% CI: 0.80–1.16; I^2 = 0%). After excluding the study of occupational sitting time, the results indicated a potentially inverse relation (RR = 0.90, 95% CI: 0.65–1.14; I^2 = 0%). When only prospective cohort studies were included in the meta-analysis, the results were slightly different (RR = 1.06, 95% CI: 0.84–1.27; I^2 = 0%). We did not see any evidence of publication bias in the funnel plots.

9.4 Sedentary Behaviour and Cancer Mortality

9.4.1 All-Cancer Mortality

Table 9.2 summarises the 12 studies examining all-cancer mortality (ten studies based on self-reported sitting time; two based on accelerometer-measured sedentary time). Eight prospective cohort studies have examined the association of sedentary behaviour with all-cancer mortality [78–87]. The main design features and results of these studies are summarised in Table 9.2. Five studies examined risk associated with total sitting time [80, 82, 84–86], one assessed sitting in leisure-time [79] and four examined television viewing time [78, 81, 83, 87].

Table 9.2 Studies investigating the associations of sedentary behaviour and cancer-related mortality, participants without cancer at exposure assessment

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
All cancer mortality						
Troeschel et al., 2021. United States	Prospective cohort study	17,465 participants in the REasons for Geographic and Racial Differences in Stroke study, aged 45 and older at baseline. Mean follow-up 10.3 years	1002 cancer deaths determined via death certificates, medical records or linkage with Social Security Administration and the National Death Index	Predefined categories for time spent watching TV or videos during a typical 24-hour period in past 12 months. Categories collapsed to <1 [ref.], 1, 2, 3, ≥4 h/day	HR = 1.05 (0.84, 1.31) p trend = 0.73	Age, race, income, marital status, health insurance/hormone therapy use, region, presence of comorbidities at baseline, aspirin use, non-aspirin NSAID use, total energy intake, diet, physical activity, waist circumference, smoking history, alcohol use
Patel et al., 2018. USA. After Patel et al., 2010. United States	Prospective cohort study	127,554 adults aged 50–74 and free from major chronic disease at study entry. Median follow-up 20.3 years	14,550 cancer deaths determined by linkage with the National Death Index	Leisure time sitting categories <3 (ref.), 3–5, ≥6 h/day	RR = 1.11 (1.05, 1.17)	Sex, race, education, employment status, alcohol intake, marital status, smoking status, comorbidities, diet score, aspirin use, BMI, recreational physical activity
Lee et al., 2016. United States	Prospective cohort study	77,801 postmenopausal women from the Women's Health Initiative Observation Study, aged between 50 and	2629 cancer deaths determined via hospital records, death certificates, autopsy, and coroner reports	Self-report questionnaire with predefined categories of sitting. Categories collapsed to	HR = 1.35 (1.08, 1.70)	Age, current weight, education, current employment status, ethnicity, leisure-time physical activity,

		79 at baseline. Mean follow up 10.8 years		≤5 (ref.), 6–9, 10–13, >13 min/day		current smoking status, alcohol consumption, general perception of own health, physical functioning score, ever treated for diabetes, history of CVD, cancer, stroke
Keadle et al., 2015. USA. After Matthews et al., 2012	Prospective cohort study	221,426 chronic disease-free participants from the NIH-AARP Diet and Health Study, aged 50–71 at baseline. Mean follow-up 14.1 years	15,161 cancer deaths determined through linkage with the Social Security Administration Master File and National Death Index	Predefined categories for time spent watching TV or videos (<1 [ref.], 1–2, 3–4, 5–6, ≥7 h/day)	HR = 1.17 (1.06, 1.29) *p* trend <0.001 Per 2 h/day increase in TV time: HR = 1.07 (1.03, 1.11)	Age, sex, race, education, smoking status, MVPA, diet quality
Matthews et al., 2014. United States	Prospective cohort study	63,308 participants from the Southern Community Cohort Study, aged 40–79 years at baseline. Mean follow-up 6.4 years	1227 cancer deaths determined via linkage with Social Security Administration and the National Death Index	Overall sedentary behaviour (<5.76 [ref.], 5.76–8.50, 8.51–12.00, >12 h/day) derived from series of questions about typical sitting behaviours	Blacks HR = 1.12 (0.92, 1.36) *p* trend = 0.17 Whites HR = 1.04 (0.74, 1.46) *p* trend = 0.29	(age underlying metric) sex, source of enrolment, education, household income, smoking, BMI, diabetes, employment, physical activity
Seguin et al., 2014. United States	Prospective cohort study	92,234 women from the WHI Observational Study, aged 50–79 at baseline. Mean follow-up 12 years	4759 cancer deaths documented through postal surveys and National Death Index follow-up	Overall sedentary behaviour (≤4 [ref.], >4–8, >8–11, ≥11 h/day) derived from question about total time spent sitting plus total time spent lying down (when not asleep)	HR = 1.21 (1.07, 1.37) *p* trend = 0.0002	Age, race, education, marital status, BMI, self-rated health status, smoking, alcohol consumption, number of chronic diseases, hormone use, depressed mood, living alone,

(continued)

Table 9.2 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
						number of falls in past year, activity of daily living disability, history of CHD or CHF, physical functioning score, physical activity level, history of stroke, treated diabetes, hypertensive, arthritis, cancer, COPD, history of hip fracture over 55 years
Kim et al., 2013. United States	Prospective cohort study	134,596 participants from the Multiethnic Cohort Study, aged 45–75 years at baseline. Median follow-up 13.7 years	6698 cancer deaths identified through linkage to death certificate files in Hawaii and California; also linkage with National Death Index	Overall sedentary behaviour (<5 [ref.], 5–<10, ≥10 h/day) derived from series of questions about typical sitting behaviours	Men HR = 0.97 (0.87, 1.07) p trend = 0.62 Women HR = 0.97 (0.87, 1.09) p trend = 0.75	Age, education, ethnicity, smoking, hypertension, diabetes, alcohol intake, energy intake, MVPA
Wijndaele et al., 2011.	Prospective cohort study	13,197 English adults from the EPIC-Norfolk cohort, aged 45–79.	570 cancer deaths identified through the Office	Hours per week spent watching TV and videos over past year	For each 1 h/day increase in TV:	Age, sex, education level, smoking status, alcohol consumption,

United Kingdom		Mean follow-up 9.5 years	of National Statistics (UK).		HR = 1.04 (0.98, 1.10).	hypertension medication, dyslipidaemia medication, baseline history of diabetes, family history of cardiovascular disease, family history of cancer, physical activity energy expenditure
Dunstan et al., 2010. Australia	Prospective cohort study	8800 Australian adults (≥25 years at baseline) from the AusDiab study. Median follow-up 7 years	125 cancer deaths identified through the Australian National Death Index	Total time spent watching TV or videos in past 7 days (<2 [ref.], 2–<4, ≥4 h/day)	HR = 1.48 (0.88, 2.49) For each 1 h/day increase in TV: HR = 1.09 (0.96, 1.23)	Age, sex, waist circumference, exercise. Models assessing association with categorical TV time additionally adjusted for smoking, education, total energy intake, alcohol intake, diet quality index, hypertension, total plasma cholesterol, HDL-C, serum triglycerides, lipid-lowering medication use, glucose tolerance
Katzmarzyk et al., 2009. Canada	Prospective cohort study	17,013 Canadians aged 18–90 years at baseline	547 cancer deaths identified through the Canadian Mortality Database	Predefined categories for time spent sitting during the course of most days of the week ('none of the time' [ref.], '1/4 of the time', '1/2 of the time', '3/4 of the time', 'all of the time'	HR = 1.07 (0.72, 1.61)	Age, smoking, alcohol consumption, leisure-time physical activity, Physical Activity Readiness Questionnaire

(continued)

Table 9.2 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
All cancer mortality (accelerometer)						
Gilchrist et al., 2020. United States	Prospective cohort study	18,002 participants in the REasons for Geographic and Racial Differences in Stroke study, aged 45 and older at baseline. Mean follow-up 5.3 years	268 cancer deaths determined via death certificates, medical records or linkage with Social Security Administration and the National Death Index	Hip-worn accelerometer-derived sedentary time during waking hours. Categorised as <709.7 (ref.),709.7–782.5, ≥782.6 mins/16-hour day	HR = 1.52 (1.01, 2.27) p trend = 0.07	Age, race, sex, region of residence, educational level, season the accelerometer was worn, current smoking, alcohol use, body mass index, diabetes, hypertension, dyslipidaemia, history of coronary heart disease, history of stroke, and MVPA
Ensrud et al., 2014. United States	Prospective cohort study	2918 men in the Osteoporotic Fractures in Men Study, aged 71 and older at baseline. Mean follow up 4.5 years	109 cancer deaths determined via death certificates, physician review, and medical records	Activity monitor (SenseWear Pro arm band). Participants divided into four categories based on minutes/24-hour day: <772.2 (ref.), 772–844.6, 844.7–914.9, ≥915	HR = 1.25 (0.74, 2.10), p trend = 0.52	Age, race, site, season, education, marital status, health status, smoking, comorbidity burden, depressive symptoms, cognitive function, number of instrumental activities of daily living impairments, percentage body fat

Abbreviations: Hazard ratio (HR), Odds ratio (OR), Risk ratio (RR), Body mass index (BMI), Cancer Prevention Study (CPS), National Institutes of Health (NIH), American Association of Retired Persons (AARP), non-steroidal anti-inflammatory drug (NSAID), moderate-vigorous physical activity (MVPA), high-density lipoprotein-cholesterol (HDL-C), coronary heart disease (CHD), congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD)

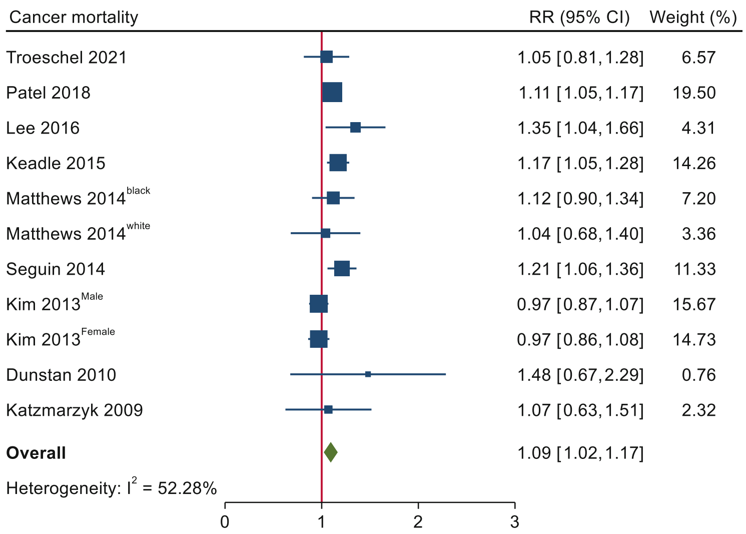

Fig. 9.5 Forest plot for main random effects meta-analysis synthesising the associations between sedentary behaviour and all cancer mortality. RR = relative risk; CI = confidence intervals

Comparing the highest category of sedentary behaviour to lowest category (reference), we observed a 12% risk increase for all-cancer mortality (RR = 1.09; 95% CI: 1.02–1.17). We observed considerable heterogeneity across these studies (I^2 = 52%). See Fig. 9.5. There was no evidence of publication bias suggested by funnel plot asymmetry.

9.4.2 *Site-Specific Cancer Mortality*

Table 9.3 outlines the studies of cancer-related mortality in which participants had already been diagnosed with cancer at the time sedentary behaviour was assessed. One study examined the relationship between sitting time and all-cancer mortality in a population of cancer survivors [88], three studies focused on colorectal cancer-specific mortality [89–91], and one focused on hematologic cancer-specific survival, one on kidney cancer-specific survival, one on liver cancer-specific mortality, one on lung cancer-specific mortality and one on prostate cancer-specific mortality.

9.4.3 *Colorectal Cancer-Specific Mortality*

Three prospective cohort studies have examined the associations of sedentary behaviour (exposure assessed pre- and post-diagnosis) with colorectal cancer-

Table 9.3 Studies investigating the associations of sedentary behaviour and cancer-related mortality, participants with cancer at exposure assessment

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
All cancer mortality						
Ricci et al., 2020. United States	Prospective cohort study	2371 participants in the National Health and Nutrition Examination Survey, diagnosed with any cancer, aged 18 and older at baseline. Mean follow-up 5.7 years	180 cancer deaths determined linkage with the US mortality registry	Total sitting time, continuous measure of minutes/day	For each 187 min/day increase HR = 1.10 (0.91, 1.33)	Age, sex, year of survey, ethnicity, education, smoking status, alcohol use, type of cancer, any cardiovascular disease, systolic and diastolic blood pressure, BMI
Colorectal cancer-specific mortality						
Cao et al., 2015. United States	Prospective cohort study	Participants from the Health Professionals Follow-up Study, diagnosed with Stage I–III CRC. 926 participants in pre-diagnosis analyses; 714 included in post-diagnosis analyses	169 CRC-specific deaths reported by family or postal authorities, or via National Death Index	Average time spent watching TV (0–6 [ref.], 7–13, 14–20, ≥21 h/week)	Pre-diagnosis HR = 1.99 (1.25, 3.17) p trend = 0.01 Post-diagnosis HR = 1.42 (0.80, 2.51) p trend = 0.26	Age at diagnosis, years of diagnosis, stage of disease, grade of differentiation, tumour site, prediagnostic smoking status, regular aspirin use, alcohol intake, folate, calcium, read meat intake, and energy intake, leisure time physical activity
Arem et al., 2015. United States	Prospective cohort study	Participants from the NIH-AARP Diet and Health Study, diagnosed with invasive, nonmetastatic CRC. For	745 CRC-specific deaths ascertained from linkage to Social Security Administration Death Master File and the	Predefined categories for time spent watching TV or videos during a typical 24-hour period in past 12 months.	Pre-diagnosis ≥5 vs 0–2 h/day HR = 1.21 (0.99, 1.49) p trend = 0.068	Age (as underlying metric), sex, tumour site, tumour grade, tumour stage, surgery, radiation,

		pre-diagnosis analyses: $n = 3784$, mean follow-up 12.8 years. Post-diagnosis analyses: $n = 1630$, mean follow-up 7.1 years	National Death Index Plus	Categories collapsed to 0–2 (ref.), 3–4, ≥5 h/day for pre-diagnosis TV and 0–2 (reference), >2–4, >4 h/day for post-diagnosis TV	Post-diagnosis HR = 1.73 (1.11, 2.72) p trend = 0.079	chemotherapy, leisure time physical activity, smoking status
Campbell et al., 2014. United States	Prospective cohort study	Participants of the CPS-II Nutrition Cohort diagnosed with invasive, nonmetastatic CRC. For pre-diagnosis analyses: n = 2293, mean follow-up 13.8 years. Post-diagnosis analyses: n = 1656, mean follow-up 4.5 years	379 CRC-specific deaths ascertained from linkage to National Death Index	Leisure-time sitting (TV, reading, etc) categorised as <3 (ref.), 3–5, or ≥6 h/day. Assessment in 1992–93 used as pre-diagnosis exposure for all participants; first survey following CRC diagnosis taken as post-diagnosis exposure measure	Pre-diagnosis RR = 1.33 (0.96, 1.84) Post-diagnosis RR = 1.62 (1.07, 2.44)	Age at diagnosis, sex, smoking, BMI, red meat intake, SEER stage at diagnosis, education, recreational physical activity
Haematologic cancer-specific mortality						
Schmid et al., 2019. United States	Prospective cohort study	Participants from the NIH-AARP Diet and Health Study, diagnosed with a haematologic cancer. For pre-diagnosis analyses: $n = 8182$. For post-diagnosis analyses: $n = 1636$	1775 (pre-diagnosis analyses) and 306 haematologic cancer-specific deaths ascertained from linkage to Social Security Administration Death Master File and the National Death Index Plus	Predefined categories for time spent watching TV or videos during a typical 24-hour period in past 12 months. Categories collapsed to 0–2 (ref.), 3–4, ≥5 h/day for pre-diagnosis TV and 0–2 (ref.), >2–4, >4 h/day for post-diagnosis TV	Pre-diagnosis HR = 1.10 (0.96, 1.25) p trend = 0.14 Post-diagnosis HR = 1.13 (0.84, 1.52) p trend = 0.47	Age at exposure assessment, age at cancer diagnosis, sex, education, ethnicity, smoking, alcohol consumption, chemotherapy, hematologic cancer subtype, physical activity
Kidney cancer-specific mortality						

(continued)

Table 9.3 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs lowest exposure categories)	Multivariable adjustment
Schmid et al., 2018. United States	Prospective cohort study	633 participants from the NIH-AARP Diet and Health Study, diagnosed with incident, renal cell cancer. Median follow-up 7.1 years	54 renal cell cancer specific deaths ascertained from linkage to Social Security Administration Death Master File and the National Death Index Plus	Postdiagnosis total sitting time, categorised into three groups (<5 [ref.], 5–8, >8 h/day)	HR = 1.19 (0.54, 2.62), p trend = 0.64)	Age at exposure assessment, age at cancer diagnosis, sex, education, ethnicity, history of diabetes, history of hypertension, smoking, alcohol consumption, surgery, chemotherapy, radiation, stage, MVPA
Liver cancer-specific mortality						
Ukawa et al., 2014. Japan	Prospective cohort study	69,752 adults enrolled in the Japanese Collaborative Cohort Study. Mean follow-up 19.4 years	267 deaths from liver cancer confirmed by death certificates	TV time categorised into three groups (<2 [ref.], 2–<4, ≥4 h/day)	All participants HR = 1.20 (0.82, 1.77) p trend = 0.27 Men HR = 1.23 (0.76, 2.02) p trend = 0.64 Women HR = 1.13 (0.62, 2.13) p trend = 0.34	Age, study area, smoking status, alcohol intake, coffee consumption, BMI, education, marital status, history of diabetes, history of gall bladder disease, previous blood transfusion
Lung cancer-specific mortality						
Wang et al., 2018. United States	Prospective cohort study	129,401 postmenopausal women from the Women's Health	814 lung cancer deaths for the sitting time analysis, determined via	Self-report questionnaire with predefined categories of sitting. Categories	HR = 1.16 (0.96, 1.40), p trend = 0.23	Age, race/ethnicity, BMI, family history of cancer, personal history

		Initiative Observation Study and Clinical Trial cohort, aged between 50 and 79 at baseline. Mean follow up 11.8 years	hospital records, death certificates, autopsy, and coroner reports	collapsed to ≤5 (ref.), 6–9, 10–13, >13 min/day		of cancer, history of asthma, history of emphysema or chronic bronchitis, smoking, education, alcohol intake, vitamin D use, hormone therapy, oral contraceptive use, hysterectomy status, NSAID use, servings of fruit, vegetables, red meat
Prostate cancer-specific mortality						
Friedenreich et al., 2016. Canada	Prospective cohort study	830 men who completed first follow-up of cases from a case-control study of prostate cancer. Median follow-up from diagnosis to censoring 15.5 years	170 deaths from prostate cancer confirmed by population-based registry	Postdiagnosis occupational sitting time categorised as 0 (ref.), >0–2.4, 2.4–7.9 or >7.9 h/week	HR = 0.66 (0.37, 1.18) *p* trend = 0.19	Age at diagnosis, overall stage, treatment, Gleason score, region, number of times PSA test done, prediagnosis physical activity, postdiagnosis comorbidity, postdiagnosis non-sedentary behaviour. Deaths from other causes constituted competing events

Abbreviations: Hazard ratio (HR), Odds ratio (OR), Risk ratio (RR), Body mass index (BMI), Cancer Prevention Study (CPS), National Institutes of Health (NIH), American Association of Retired Persons (AARP), non-steroidal anti-inflammatory drug (NSAID), moderate-vigorous physical activity (MVPA), prostate specific antigen (PSA)

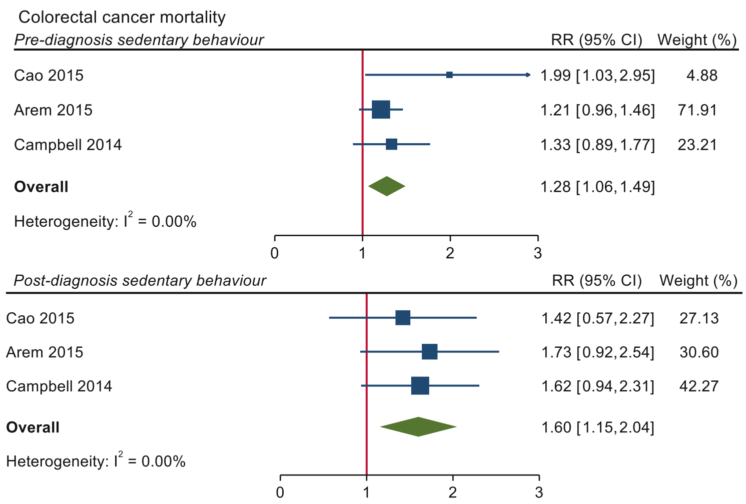

Fig. 9.6 Forest plot for main random effects meta-analysis synthesising the associations between sedentary behaviour and colorectal cancer mortality. RR = relative risk; CI = confidence intervals

specific mortality [89–91]. The studies by Cao et al. [91] and Arem et al. [89] examined risk associated with television viewing time, whereas Campbell et al. assessed sitting during leisure-time [90]. Within these cohort studies, multiple exposure assessments were taken, so that baseline questionnaires (risk-factor questionnaire for the NIH-AARP Diet and Health Study) provided the pre-diagnosis estimate of sedentary behaviour, and a follow-up questionnaire was used for the estimate of post-diagnosis sedentary behaviour. Cohort participants diagnosed with colorectal cancer after the baseline questionnaire made up the sample for the pre-diagnosis sedentary behaviour analyses; participants diagnosed with colorectal cancer between the two questionnaire administrations, and who had completed both questionnaires, comprised the sample for the post-diagnosis analyses.

Sedentary behaviour performed prior to a colorectal cancer diagnosis was associated with a 28% risk increase for colorectal cancer-specific mortality (95% CI: 1.06–1.49). We did not observe any heterogeneity across these studies ($I^2 = 0\%$). Post-diagnosis sedentary behaviour had a stronger relationship with colorectal cancer-specific mortality (RR = 1.60, 95% CI: 1.15–2.04; $I^2 = 0\%$). See Fig. 9.6. Minimal funnel plot asymmetry was observed on visual inspection.

9.4.4 *Hematologic Cancer-Specific Mortality*

One study has considered the association of television viewing time with hematologic cancer-specific mortality [92]. Schmid et al. identified 1775 (for pre-diagnosis television viewing time, from 8182 diagnosed cases) and 306 (for post-diagnosis television viewing, from 1636 diagnosed cases) hematologic cancer deaths in the NIH-AARP Diet and Health Study. Participants watching more than 5 h of television a day (versus up to 2 h) prior to diagnosis had a slight risk increase for hematologic cancer-specific death (HR = 1.10, 95% CI: 0.96–1.25). A similar relation was seen for post-diagnosis television viewing time (HR = 1.13, 95% CI: 0.84.1.52) [92].

9.4.5 Kidney Cancer-Specific Mortality

One analysis, from the NIH-AARP Diet and Health Study, has considered the association of postdiagnosis total sitting time with kidney cancer-specific mortality [93]. Schmid et al. identified 633 kidney cancer cases from which there were 54 deaths from kidney cancer. Participants in the highest category of sitting time (>8 h/day) compared to the lowest (≤2 h/day) had a 19% highest risk of kidney cancer-specific death (95% CI: 0.54–2.62) [93].

9.4.6 Liver Cancer-Specific Mortality

One study has considered the association of television viewing time with liver cancer-specific mortality [94]. Ukawa et al. identified 267 deaths from liver cancer within the Japanese Collaborative Cohort Study. Participants watching four or more hours of television a day had a modest, non-significant risk increase for liver cancer death than participants who watched less than 2 h/day (HR = 1.20, 95% CI: 0.82–1.77) [94].

9.4.7 Prostate Cancer-Specific Mortality

Friedenreich et al. followed up the cases from a case-control study of prostate cancer risk, and there were 170 prostate cancer-specific deaths included in their analysis. The authors reported a reduced risk for all-cause and prostate cancer-specific death for the highest versus lowest category of occupational sedentary behaviour (HR = 0.72, 05% CI: 0.50–1.05 and HR = 0.66, 95% CI: 0.37–1.18, respectively) [95].

9.5 Underlying Biologic Mechanisms

A number of biologic pathways linking sedentary behaviour to the development and progression of cancer have been proposed, but these have not been extensively studied [1]. In this section, for each proposed biologic pathway, we first outline how it is related to carcinogenesis and then summarise what is known about its association with sedentary behaviour. Many of these proposed mechanisms are interrelated, and it is hypothesised that their relative contribution varies according to cancer site. Molecular pathways involving endogenous sex hormones, metabolic hormones and inflammatory peptides dominate the literature. The genetic and cellular processes involved in carcinogenesis, immune response and the tumour microenvironment have not yet become a focus of research in the sedentary behaviour field.

9.5.1 Body Composition

It is well accepted that adiposity may facilitate carcinogenesis directly, or through a number of pathways including increased levels of sex and metabolic hormones, chronic inflammation and altered secretion of adipokines [13]. Contemporary evidence suggests that adiposity increases the risk of cancers of the colon and rectum, breast (postmenopausal women only), ovaries, endometrium, kidneys, oesophagus, gastric cardia, liver, pancreas, meningioma, thyroid, multiple myeloma and gall bladder [96].

Sedentary behaviour displaces time spent in physical activities that expend higher amounts of energy. There are significant differences in the metabolic/energy cost of sitting and standing: Júdice et al. demonstrated both $\dot{V}O_2$ and energy expenditure were significantly higher when standing than when sitting, independent of sex and body mass [97]. Postural transitions and unstructured movement throughout the day differ sufficiently between obese and lean individuals to explain differences in body mass [98, 99]. However, there is limited epidemiologic evidence that sedentary behaviour causes weight gain. Nonetheless, it is understood that the relationship between sedentary behaviour and adiposity is bi-directional [1, 100], and it is difficult to disentangle the effects without repeated measures of both variables.

A number of studies included in this chapter presented risk estimates for the association between sedentary behaviour and cancer without, and with, adjustment for body mass index (BMI). As noted by Schmid and Leitzmann, the associations across these studies were not consistently attenuated by additional adjustment for BMI [101]. However, we cannot confidently conclude that adiposity has a limited mechanistic role by simply comparing models without and with adjustment for BMI, as this hierarchical method of mediation analysis may introduce confounding where none existed before [102]. Further complicating the interpretation of the evidence to date is the almost exclusive reliance on BMI as a measure of adiposity, which does not differentiate between fat and lean mass [101]. Both adipose tissue and skeletal muscle are active endocrine organs that secrete biologically active proteins and polypeptide hormones, which have pro- and anti-carcinogenic properties [103, 104].

9.5.2 Molecular Pathways

Sex Hormones

Exposure to circulating endogenous sex hormones may increase the risk of some cancers, particularly breast, endometrial, ovarian and prostate cancers [104, 105]. Animal and in vivo studies have demonstrated that oestrogens have mitogenic and mutagenic effects [104]. Higher circulating levels of oestrogen-related hormones are linked most strongly to breast and endometrial cancer risk [104, 106]. Sex hormone binding globulin (SHBG) may also affect cancer risk by binding to oestrogens and androgens, rendering them biologically inactive [107].

Sedentary behaviour could plausibly affect endogenous sex hormones through a number of other biological mechanisms. If sedentary behaviour increases adiposity, it would likely also increase bioavailable oestrogens in postmenopausal women via aromatisation (the conversion of adrenal androgens to estrone, which occurs within peripheral adipose tissue) [108, 109] and through the production of adipokines (which influence oestrogen biosynthesis) [110]. If sedentary behaviour increases blood insulin (see next section), this would decrease hepatic synthesis of SHBG, in turn increasing bioavailability of endogenous sex hormones [111].

Dallal et al. examined the associations between accelerometer-assessed sedentary behaviour and urinary oestrogens and oestrogen metabolites in 542 postmenopausal women. While sedentary behaviour was not associated with total oestrogen metabolites, longer duration of sedentary time was significantly associated with higher levels of estrone and estradiol. Sedentary time was also positively associated with methylated catecholamines in the 2- and 4-hydroxylation pathways and inversely associated with a lower 16-pathway/parent oestrogen (estrone, estradiol) ratio. From these findings, the authors concluded that sedentary behaviour may be associated with reduced oestrogen metabolism, after adjusting for time spent in physical activity [112]. An earlier, cross-sectional study of 565 postmenopausal women found no associations between self-reported sedentary behaviour and various oestrogens, androgens or SHBG [113].

Metabolic Dysfunction

Elevated blood insulin levels increase growth promoting signalling [104] and enhance activation of the IGF-1 system, which is involved in cell differentiation, proliferation and apoptosis. High levels of insulin also suppress hepatic synthesis of SHBG [111]. Hyperglycaemia may promote carcinogenesis by providing an amiable environment for tumour growth [114]. Associations between insulin and glucose levels with colorectal, postmenopausal breast, pancreatic and endometrial cancers have been demonstrated in epidemiological studies [1].

Sedentary behaviour could increase cancer risk by decreasing insulin sensitivity and increasing insulin and glucose levels. Stephens et al. exposed young, healthy participants to 24 h of sedentary behaviour, which resulted in dramatic increases in the amount of insulin required to clear a standardised glucose infusion [115]. A number of other experimental studies have also demonstrated the beneficial effects – on insulin, glucose and other cardiometabolic biomarkers – of standing or light ambulation over sitting [116]. The muscular inactivity that characterises sedentary behaviour may reduce glucose uptake through blunted translocation of GLUT-4 glucose transporters to the skeletal muscle surface [117]. The acute metabolic response to sedentary behaviour suggested by these experimental studies supports the epidemiological findings that link sitting time with type 2 diabetes [117], which is itself a risk factor for developing several solid and hematologic malignancies, including non-Hodgkin lymphoma and bladder, breast, colorectal, endometrial, kidney, liver and pancreatic cancers [118].

Inflammation, Including Adipokines and Myokines

Inflammation is a risk factor for most types of cancer [105, 107]. Inflammation can stimulate cell proliferation, micro-environmental changes and oxidative stress, which can deregulate normal cell growth and promote progression and malignant conversion [119]. Adipose tissue secretes multiple biologically active polypeptides (adipokines) [120, 121]. Adiponectin is the only known anti-inflammatory adipokine; others, including leptin, adipsin, tumour necrosis factor-α (TNF-α) and interleukin-6 (IL-6) are proinflammatory.

Adipokines may play a role in the development of insulin resistance, as leptin and adiponectin enhance insulin sensitivity through activation of AMP protein kinase [120]. Adipokines might also increase cancer risk by affecting oestrogen biosynthesis and activity [110].

Skeletal muscle is an active endocrine organ that produces, expresses and releases cytokines or other peptides known collectively as myokines [103]. Through myokine signalling, skeletal muscle communicates with other organs, including adipose tissue, the liver, pancreas and brain. Myokines may also counteract the harmful effects of proinflammatory adipokines [103]. When seated, the large, postural muscles used to keep the body upright are not fully activated [121, 122]. Thus, an altered myokine response may underlie the association between sedentary behaviour and cancer.

Henson et al. examined the associations of accelerometer-assessed sedentary time with a range of adipokines in a cross-sectional study of adults at high risk of type 2 diabetes. They found that sedentary time was associated with IL-6, leptin and leptin/adiponectin ratio in multivariate models, but after additionally adjusting for moderate-vigorous physical activity, only the association with IL-6 remained statistically significant [123]. C-reactive protein (CRP) is an acute phase protein produced in the liver in response to TNF- α and IL-6 levels, and there have been a number of studies examining the association of sedentary behaviour with this biomarker of inflammation. Cross-sectional data from the National Health and Nutrition Examination Survey have shown significant associations between accelerometer-assessed sedentary time and CRP in postmenopausal women [124] and in the broader adult population [125]. However, prospective studies examining television viewing time and CRP have found no association [126, 127].

9.6 Interpretation of the Evidence and Causality

Sedentary behaviour and cancer are still an emerging field of research, and the evidence accrued to date has, for the most part, not been consistent across sites. The findings of our meta-analysis (which included literature published through to August 2021) differ somewhat from the findings presented by earlier meta-analyses, including our chapter in the first edition of this book [3, 4, 21]. Our findings do not support the conclusions of the 2018 Physical Activity Guidelines for Americans Committee, which reported moderate evidence for a 20% or higher increase in risk for colon, endometrial and lung cancer [5]. Our meta-analysis suggests that sedentary behaviour increases the risk of endometrial and ovarian cancer by 16%. There also seems to be a small risk increase for colon cancer (12%), pancreatic cancer (10%) and a very small but robust increase for breast cancer (6%). There was also evidence of an elevated risk for hepatobiliary (collectively) cancers, gall bladder cancer and head and neck cancer but based on only one or two studies. The first edition of this chapter concluded that there was a much stronger relation for endometrial (36%) and ovarian cancer (31%). Based on sensitivity analyses, we could not rule out an increased risk for breast, colorectal and lung cancers [21]. Schmid and Leitzmann drew somewhat different conclusions, acknowledging a significant risk increase for colorectal, endometrial and lung cancer [3], while Shen et al. reported that sedentary behaviour increased the risk of breast, colorectal, endometrial and lung cancer [4]. The primary reason for the different conclusions drawn by our meta-analysis is the inclusion of new publications: there were only 25 different studies on sedentary behaviour and cancer risk of cancer-specific mortality in the first edition of this chapter, whereas we have included 112 publications in this edition.

Across the cancer sites, we identified as being associated with (or possibly associated with) sedentary behaviour, risk increase was typically small (around 10% higher for the highest versus lowest categories of sitting time). We recognise, however, that self-reported estimates of sedentary behaviour are subject to substantial misclassification bias, which may have attenuated the outcomes of studies to date. It is possible that sedentary behaviour may increase cancer risk more substantially than the research to date suggests. Indeed, the two studies with accelerometer data that had examined all-cancer risk [26, 27] reported substantially higher risk estimates than the two studies with self-report data looking at all-cancer risk [24, 25].

There is a need to improve the accuracy of sedentary behaviour assessment in epidemiologic studies, in order to ascertain clearer estimates of the true association between sedentary behaviour and cancer risk. Large-scale cohort studies are increasingly incorporating objective monitoring into their data collection. It is also feasible to conduct validation studies within cohorts and use regression calibration methods to adjust risk estimates derived from self-reported sedentary behaviour data collected on all participants [128, 129]. Cohort studies that incorporate such validation sub-studies may provide improved estimates of the association between sedentary behaviour and cancer risk.

We have presented a comprehensive meta-analysis of studies examining the association between sedentary behaviour and cancer-related mortality. Our results suggest that there is a modest, 9% increased risk of dying from cancer for individuals in the highest versus lowest category of sedentary behaviour. It is likely that etiological pathways differ between cancer sites and that sedentary behaviour is a risk factor for some, but not all, cancers. Thus, the true cancer mortality risk attributable to sedentary behaviour may be much higher for specific sites and null for others. There appears to be a strong association between sedentary behaviour and colorectal cancer-specific mortality, for both pre- (28%) and post-diagnosis sitting time (60%). However, findings should be considered in the context of important methodological limitations.

Selection bias may affect the effect estimates for measures of pre-diagnosis sedentary behaviour and survival after cancer. This arises due to how follow-up time is handled. To avoid biases, it is critical for time zero of follow-up time, eligibility criteria and treatment assignment to align [130]. Studies examining the relationship of pre-diagnosis sedentary behaviour and survival after cancer tend to initiate follow-up time at cancer diagnosis. This creates a scenario where the exposure (pre-diagnosis sedentary behaviour) is measured before study eligibility criteria (cancer diagnosis) is met. If participants who survive long enough after to develop cancer after sedentary behaviour has been measured are systematically different from those who do not, selection bias is introduced [130].

Another issue that may affect estimates of pre-diagnosis sedentary behaviour on survival after a cancer diagnosis is inappropriate adjustment for mediators. All three of the studies of pre-diagnosis sedentary behaviour and colorectal cancer risk adjusted for stage or disease and treatment-related factors [89–91]. However, pre-diagnosis sedentary behaviour may influence colorectal cancer stage at diagnosis and therefore the treatment received; adjusting for these variables removes their role in the causal effect that sedentary behaviour has on survival after colorectal cancer diagnosis.

The stronger relation noted for post-diagnosis sedentary behaviour to colorectal cancer-specific mortality may be a function of reverse causation. Studies of post-diagnosis physical activity are also subject to immortal time bias [130], which can bias the results away from the null. Thus, the causal nature of the relationships observed in the studies of cancer survival are not certain.

9.6.1 Improving Causal Inference

In an ideal world, epidemiologists would be able to precisely quantify the causal effects of sedentary behaviour, at a population level, by conducting a randomised, controlled trial (RCT). In practice, RCTs are limited by a number of methodological challenges, including selection bias, loss to follow-up and compromised intervention compliance. It is unlikely that a RCT to test the efficacy of reducing sitting time for cancer prevention would be feasible, due to required sample size, trial duration and cost of ensuring adherence to the intervention, all of which would be prohibitive [131]. Therefore, observational studies are likely to remain the dominant method through which we investigate the association between sedentary behaviour and cancer risk.

In observational studies, estimates of association cannot be generally interpreted as measures of effect, as the exposed and unexposed are not exchangeable [130]. However, there are multiple statistical techniques that can be applied to observational data in order to reduce bias and improve causal inference from these studies, such as use of propensity scores, inverse probability weighting and instrumental variable analysis [132]. Of particular relevance to sedentary behaviour and cancer research are analytic methods that allow for time-dependent exposure and confounding, such as marginal structural models and the g-formula. These methods may address the bias inherent when assessing a time-varying exposure in the presence of time-varying confounders that are affected by previous exposure [132]. For example, consider the relation of sedentary behaviour to colon cancer risk. Sedentary behaviour might be high because an individual is obese (BMI $>$ kg/m^2); BMI is also associated with colon cancer risk, and hence, BMI is a confounder. If, however, sedentary behaviour decreases, weight loss may result (making BMI a potential mediator). In turn, having lower BMI may result in less sedentary behaviour. In this example, BMI is a time-dependent confounder, which may also be in the causal pathway from sedentary behaviour to breast cancer. Simple adjustment for baseline sedentary behaviour and BMI in Cox proportional hazards regression models, as has been done in cohort studies examining sedentary behaviour and cancer risk to date, does not address the time-dependent nature of the exposure, but this can be addressed with methods that deal with time-dependent confounding [133]. Thus, there is scope for researchers to return to existing cohort studies and more fully exploit the repeated measures data available, to account for time-dependent exposure and confounding and to ascertain stronger causal inference.

Another analytic approach that may help improve causal inference around sedentary behaviour and cancer is Mendelian randomisation. This method uses germline genetic variants as instrumental variables to test the causal effect of an exposure [134]. Doherty et al. had trained a machine-learning model using body cameras and diaries and applied this to identify sedentary activities (sitting/reclining; MET-value typically $\leq$1.5) in UK Biobank accelerometry data [135, 136]. Six single nucleotide polymorphisms (SNPs) were identified as associated with percentage time spent sedentary, calculated as the ratio of sedentary-to-total 30-second periods

[135]. These SNPs explained 0.08% of variance in sedentariness [135]. Dixon-Suen et al. recently used this genetic instrument to examine risk of breast cancer. They found an elevated risk for breast cancer overall (odds ratio (OR) = 1.20, 95% CI: 0.93–1.55) and a strong risk increase for triple negative breast cancer (OR = 2.04, 95% CI: 1.06–3.93) in the Breast Cancer Association Consortium [137].

There is also a need within sedentary behaviour and cancer research for clearer conceptual approaches to analysis. An important element of this is to formalise assumptions made in modelling. Directed acyclic graphs (DAGs) are useful tools for helping researchers clarify their research questions and examine potential confounding pathways [138]. Encoding the direction of association between variables makes these assumptions clear to the reader. The use of DAGs in sedentary behaviour and cancer research may help to overcome inappropriate and unnecessary adjustment in multivariate models. Researchers may be able to construct different, but equally plausible, iterations of a DAG, which would inform different hypotheses to be tested, or sensitivity analyses to be undertaken. In particular, DAGs may be useful to help conceptualise and undertake appropriate mediation analyses, which are needed to better understand the relative contributions of different biological pathways through with sedentary behaviour acts on cancer risk.

9.7 Summary

Based on the evidence available, we suggest that sedentary behaviour is associated with in increased risk of endometrial (16%) and ovarian cancers (12%). There also seems to be a small risk increase for colon cancer (12%), pancreatic cancer (10%) and a very small but robust increase for breast cancer (6%). There is evidence of a small risk increase for all-cancer mortality (9%) and a significant risk increase for colorectal cancer-specific mortality (28% for pre-diagnosis sitting time; 60% for post-diagnosis sitting time). There is biologic plausibility for the observed and postulated associations between sedentary behaviour and cancer risk. Better mechanistic understanding will strengthen causal inference from epidemiological data, provide insights into gene-environment interactions and potentially inform precision public health initiatives.

References

1. Lynch BM. Sedentary behavior and cancer: a systematic review of the literature and proposed biological mechanisms. Cancer Epidemiol Biomark Prev. 2010;19(11):2691–709.
2. Patel AV, Friedenreich CM, Moore SC, Hayes SC, Silver JK, Campbell KL, et al. American College of Sports Medicine roundtable report on physical activity, sedentary behavior, and cancer prevention and control. Med Sci Sports Exerc. 2019;51(11):2391–402.
3. Schmid D, Leitzmann MF. Television viewing and time spent sedentary in relation to cancer risk: a meta-analysis. J Natl Cancer Inst. 2014;106(7):dju098.

4. Shen D, Mao W, Liu T, Lin Q, Lu X, Wang Q, et al. Sedentary behavior and incident cancer: a meta-analysis of prospective studies. PLoS One. 2014;9(8):e105709.
5. Katzmarzyk PT, Powell KE, Jakicic JM, Troiano RP, Piercy K, Tennant B. Sedentary behavior and health: update from the 2018 physical activity guidelines advisory committee. Med Sci Sports Exerc. 2019;51(6):1227–41.
6. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2021;71(3):209–49.
7. Ferlay JEM, Lam F, Colombet M, Mery L, Piñeros M, Znaor A, Soerjomataram I, Bray F. Global cancer observatory: cancer today. International Agency for Research on. Cancer. 2020; Available from https://gco.iarc.fr/today
8. World Health Organization. Global Health estimates 2020: deaths by cause, age, sex, by country and by region, 2000–2019. World Health Organization; 2020. https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-leading-causes-of-death
9. Ferlay JLM, Ervik M, Lam F, Colombet M, Mery L, Piñeros M, Znaor A, Soerjomataram I, Bray F. Global cancer observatory: cancer tomorrow. International Agency for Research on Cancer; 2020. https://gco.iarc.fr/today
10. Forman D, Ferlay J. The global and regional burden of cancer. In: Stewart BW, Wild CP, editors. World cancer report. Lyon, France: IARC; 2014. p. 16–53.
11. Freedman ND, Thun MJ. Tobacco products: massive and still growing causes of cancer worldwide. In: Wild CPWE, Stewart BW, editors. World cancer report: cancer research for cancer prevention. Lyon, France: International Agency for Research on Cancer; 2020. p. 50–60.
12. Jha P. Avoidable global cancer deaths and total deaths from smoking. Nat Rev Cancer. 2009;9(9):655–64.
13. World Cancer Research Fund/American Institute for Cancer Research. Diet, nutrition, physical activity and cancer: a global perspective; 2018. http://www.dietandcancerreport.org/
14. World Health Organization. Global status report on alcohol and health 2018. World Health Organization; 2018. Available from https://www.who.int/substance_abuse/publications/global_alcohol_report/en/
15. McTiernan A, Friedenreich CM, Katzmarzyk PT, Powell KE, Macko R, Buchner D, et al. Physical activity in cancer prevention and survival: a systematic review. Med Sci Sports Exerc. 2019;51(6):1252–61.
16. Siemiatycki J, Rushton L. Occupation: the need for continuing vigilance. In: Wild CPWE, Stewart BW, editors. World cancer report: cancer research for cancer prevention. Lyon, France: International Agency for Research on Cancer; 2020. p. 127–36.
17. Purdue MP, Hutchings SJ, Rushton L, Silverman DT. The proportion of cancer attributable to occupational exposures. Ann Epidemiol. 2015;25(3):188–92.
18. Comba P, Iavarone I, Kogevinas M. Contamination of air, water, soil, and food: the challenge is to characterize specific risks. In: Wild CPWE, Stewart BW, editors. World cancer report: cancer research for cancer prevention. Lyon, France: International Agency for Research on Cancer; 2020. p. 115–26.
19. de Martel C, Georges D, Bray F, Ferlay J, Clifford GM. Global burden of cancer attributable to infections in 2018: a worldwide incidence analysis. Lancet Glob Health. 2020;8(2):e180–e90.
20. Schrader KA, Sharaf R, Alanee S, Offit K. Genetic factors: hereditary cancer predisposition syndromes. In: Niederhuber JE, Armitage JO, Doroshow JH, Kastan MB, Je T, editors. Abeloff's clinical oncology. 5th ed. Philadeliphia, PA: Elsevier; 2014.
21. Lynch BM, Mahmood S, Boyle T. Sedentary behavior and cancer. In: Leitzmann M, Jochem C, Schmid D, editors. Sedentary behavior epidemiology. Berlin: Springer; 2018.
22. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med. 2002;21(11):1539–58.

23. Hunter RF, Murray JM, Coleman HG. The association between recreational screen time and cancer risk: findings from the UK biobank, a large prospective cohort study. Int J Behav Nutr Phys Act. 2020;17(1):97.
24. Ihira H, Sawada N, Yamaji T, Goto A, Shimazu T, Kikuchi H, et al. Occupational sitting time and subsequent risk of cancer: the Japan public health center-based prospective study. Cancer Sci. 2020;111(3):974–84.
25. Rangul V, Sund ER, Mork PJ, Røe OD, Bauman A. The associations of sitting time and physical activity on total and site-specific cancer incidence: results from the HUNT study, Norway. PLoS One. 2018;13(10):e0206015.
26. Dempsey PC, Strain T, Khaw KT, Wareham NJ, Brage S, Wijndaele K. Prospective associations of accelerometer-measured physical activity and sedentary time with incident cardiovascular disease, cancer, and all-cause mortality. Circulation. 2020;141(13):1113–5.
27. Dohrn IM, Welmer AK, Hagströmer M. Accelerometry-assessed physical activity and sedentary time and associations with chronic disease and hospital visits - a prospective cohort study with 15 years follow-up. Int J Behav Nutr Phys Act. 2019;16(1):125.
28. Guo W, Key TJ, Reeves GK. Accelerometer compared with questionnaire measures of physical activity in relation to body size and composition: a large cross-sectional analysis of UK biobank. BMJ Open. 2019;9(1):e024206.
29. Patel AV, Hildebrand JS, Campbell PT, Teras LR, Craft LL, McCullough ML, et al. Leisure-time spent sitting and site-specific cancer incidence in a large U.S. Cohort Cancer Epidemiol Biomarkers Prev. 2015;24(9):1350–9.
30. Sanchez-Bayona R, Gardeazabal I, Romanos-Nanclares A, Fernandez-Lazaro CI, Alvarez-Alvarez I, Ruiz-Canela M, et al. Leisure-time physical activity, sedentary behavior, and risk of breast cancer: results from the SUN ('Seguimiento Universidad De Navarra') project. Prev Med. 2021;148:106535.
31. Cao J, Eshak ES, Liu K, Muraki I, Cui R, Iso H, et al. Television viewing time and breast cancer incidence for Japanese premenopausal and postmenopausal women: the JACC study. Cancer Res Treat. 2019;51(4):1509–17.
32. Huerta JM, Molina AJ, Chirlaque MD, Yepes P, Moratalla-Navarro F, Moreno V, et al. Domain-specific patterns of physical activity and risk of breast cancer sub-types in the MCC-Spain study. Breast Cancer Res Treat. 2019;177(3):749–60.
33. Nomura SJO, Dash C, Sheppard VB, Bowen D, Allison M, Barrington W, et al. Sedentary time and postmenopausal breast cancer incidence. Cancer Causes Control. 2017;28(12): 1405–16.
34. Nomura SJ, Dash C, Rosenberg L, Palmer J, Adams-Campbell LL. Sedentary time and breast cancer incidence in African American women. Cancer Causes Control. 2016;27(10):1239–52.
35. Boyle T, Fritschi L, Kobayashi LC, Heyworth JS, Lee DG, Si S, et al. Sedentary work and the risk of breast cancer in premenopausal and postmenopausal women: a pooled analysis of two case-control studies. Occup Environ Med. 2016;73(11):735–41.
36. Levi F, Pasche C, Lucchini F, La Vecchia C. Occupational and leisure time physical activity and the risk of breast cancer. Eur J Cancer. 1999;35(5):775–8.
37. Cohen S, Matthews CE, Bradshaw P, Lipworth L, Buchowski MS, Signorello LB, et al. Sedentary behavior, physical activity, and likelihood of breast cancer among black and white women: a report from the southern community cohort study. Cancer Prev Res. 2013;6(6): 566–76.
38. George SM, Irwin ML, Matthews CE, Mayne ST, Gail MH, Moore SC, et al. Beyond recreational physical activity: examining occupational and household activity, transportation activity, and sedentary behavior in relation to postmenopausal breast cancer risk. Am J Public Health. 2010;100(11):2288–95.
39. Lahmann PH, Friedenreich CM, Schuit AJ, Salvini S, Allen NE, Key TJ, et al. Physical activity and breast cancer risk: the European prospective investigation into cancer and nutrition. Cancer Epidemiol Biomark Prev. 2007;16(1):36–42.

40. Lynch BM, Courneya KS, Friedenreich CM. A case-control study of lifetime occupational sitting and likelihood of breast cancer. Cancer Causes Control. 2013;24(6):1257–62.
41. Mathew A, Gajalakshmi V, Balakrishnan R, Kanimozhi VC, Brennan P, Binukumar BP, et al. Physical activity levels among urban and rural women in South India and the risk of breast cancer: a case-control study. Eur J Clin Nutr. 2009;18(5):368–76.
42. Rosenberg L, Palmer JR, Bethea TN, Ban Y, Kipping-Ruane K, Adams-Campbell LL. A prospective study of physical activity and breast cancer incidence in African-American women. Cancer Epidemiol Biomark Prev. 2014;23:2522.
43. Ekenga CC, Parks CG, Sandler DP. A prospective study of occupational physical activity and breast cancer risk. Cancer Causes Control. 2015;26(12):1779–89.
44. Peplonska B, Lissowska J, Hartman TJ, Szeszenia-Dabrowska N, Blair A, Zatonski W, et al. Adulthood lifetime physical activity and breast cancer. Epidemiology. 2008;19(2):226–36.
45. Catsburg C, Kirsh VA, Soskolne CL, Kreiger N, Bruce E, Ho T, et al. Associations between anthropometric characteristics, physical activity, and breast cancer risk in a Canadian cohort. Breast Cancer Res Treat. 2014;145(2):545–52.
46. Keum N, Cao Y, Oh H, Smith-Warner SA, Orav J, Wu K, et al. Sedentary behaviors and light-intensity activities in relation to colorectal cancer risk. Int J Cancer. 2016;138(9):2109–17.
47. Eaglehouse YL, Koh WP, Wang R, Aizhen J, Yuan JM, Butler LM. Physical activity, sedentary time, and risk of colorectal cancer: the Singapore Chinese health study. Eur J Cancer Prev. 2017;26(6):469–75.
48. Nunez C, Nair-Shalliker V, Egger S, Sitas F, Bauman A. Physical activity, obesity and sedentary behaviour and the risks of colon and rectal cancers in the 45 and up study. BMC Public Health. 2018;18(1):325.
49. Gorczyca AM, Eaton CB, LaMonte MJ, Garcia DO, Johnston JD, He K, et al. Association of physical activity and sitting time with incident colorectal cancer in postmenopausal women. Eur J Cancer Prev. 2018;27(4):331–8.
50. Quang N, Hien NQ, Quang NT, Chung NT. Active lifestyle patterns reduce the risk of colorectal cancer in the north of Vietnam: a hospital-based case-control study. Cancer Control. 2019;26(1):1073274819864666.
51. Park SY, Wilkens LR, Haiman CA, Le Marchand L. Physical activity and colorectal cancer risk by sex, race/ethnicity, and subsite: the multiethnic cohort study. Cancer Prev Res (Phila). 2019;12(5):315–26.
52. Friedenreich CM, Norat T, Steindorf K, Boutron-Ruault MC, Pischon T, Mauir M, et al. Physical activity and risk of colon and rectal cancers: the European prospective investigation into cancer and nutrition. Cancer Epidemiol Biomark Prev. 2006;15(12):2398–407.
53. Howard RA, Freedman DM, Park Y, Hollenbeck A, Schatzkin A, Leitzmann MF. Physical activity, sedentary behavior, and the risk of colon and rectal cancer in the NIH-AARP diet and health study. Cancer Causes Control. 2008;19(9):939–53.
54. Steindorf K, Tobiasz-Adamczyk B, Popiela T, Jedrychowski W, Penar A, Matyja A, et al. Combined risk assessment of physical activity and dietary habits on the development of colorectal cancer. A hospital-based case-control study in Poland. Eur J Cancer Prev. 2000;9: 309–16.
55. Johnsen NF, Christensen J, Thomsen BL, Olsen A, Loft S, Overvad K, et al. Physical activity and risk of colon cancer in a cohort of Danish middle-aged men and women. Eur J Epidemiol. 2006;21(12):877–84.
56. Tavani A, Braga C, La Vecchia C, Conti E, Filiberti R, Montella M, et al. Physical activity and risk of cancers of the colon and rectum: an Italian case-control study. Br J Cancer. 1999;79 (11–12):1912–6.
57. Levi F, Pasche C, Lucchini F, Tavani A, La Vecchia C. Occupational and leisure-time physical activity and the risk of colorectal cancer. Eur J Cancer Prev. 1999;8(6):487–93.
58. Arem H, Irwin ML, Zhou Y, Lu L, Risch H, Yu H. Physical activity and endometrial cancer in a population-based case-control study. Cancer Causes Control. 2011;22(2):219–26.

59. Friberg E, Mantzoros CS, Wolk A. Physical activity and risk of endometrial cancer: a population-based prospective cohort study. Cancer Epidemiol Biomark Prev. 2006;15(11): 2136–40.
60. Friedenreich CM, Cook LS, Magliocco AM, Duggan MA, Courneya KS. Case-control study of lifetime total physical activity and endometrial cancer risk. Cancer Causes Control. 2010;21 (7):1105–16.
61. Moore SC, Gierach GL, Schatzkin A, Matthews CE. Physical activity, sedentary behaviours, and the prevention of endometrial cancer. Br J Cancer. 2010;103(7):933–8.
62. George SM, Moore SC, Chow W, Schatzkin A, Hollenbeck A, Matthews CE. A prospective analysis of prolonged sitting time and risk of renal cel carcinoma among 300,000 older adults. Ann Epidemiol. 2011;21(10):787–90.
63. Steindorf K, Friedenreich C, Linseisen J, Rohrmann S, Rundle A, Veglia F, et al. Physical activity and lung cancer risk in the European prospective investigation into cancer and nutrition cohort. Int J Cancer. 2006;119(10):2389–97.
64. Bak H, Christensen J, Lykke Thomsen B, Tjonneland A, Overvad K, Loft S, et al. Physical activity and risk for lung cancer in a Danish cohort. Int J Cancer. 2005;116:439–45.
65. Lam TK, Moore SC, Brinton LA, Smith L, Hollenbeck AR, Gierach GL, et al. Anthropometric measures and physical activity and the risk of lung cancer in never-smokers: a prospective cohort study. PLoS One. 2013;8(8):e70672.
66. Ukawa S, Tamakoshi A, Wakai K, Noda H, Ando M, Iso H. Prospective cohort study on television viewing time and incidence of lung cancer: findings from the Japan collaborative cohort study. Cancer Causes Control. 2013;24(8):1547–53.
67. Wang A, Qin F, Hedlin H, Desai M, Chlebowski R, Gomez S, et al. Physical activity and sedentary behavior in relation to lung cancer incidence and mortality in older women: the Women’s Health Initiative. Int J Cancer. 2016;139(10):2178–92.
68. Rees-Punia E, Patel AV, Fallon EA, Gapstur SM, Teras LR. Physical activity, sitting time, and risk of myelodysplastic syndromes, acute myeloid leukemia, and other myeloid malignancies. Cancer Epidemiol Biomark Prev. 2019;28(9):1489–94.
69. Xiao Q, Yang HP, Wentzensen N, Hollenbeck A, Matthews CE. Physical activity in different periods of life, sedentary behavior, and the risk of ovarian cancer in the NIH-AARP diet and health study. Cancer Epidemiol Biomark Prev. 2013;22(11):2000–8.
70. Zhang M, Xie X, Lee AH, Binns CW. Sedentary behaviours and epithelial ovarian cancer risk. Cancer Causes Control. 2004;15(1):83–9.
71. Ukawa S, Tamakoshi A, Mori M, Ikehara S, Shirakawa T, Yatsuya H, et al. Association between average daily television viewing time and the incidence of ovarian cancer: findings from the Japan collaborative cohort study. Cancer Causes Control. 2018;29(2):213–9.
72. Hildebrand JS, Gapstur SM, Gaudet MM, Campbell PT, Patel AV. Moderate-to-vigorous physical activity and leisure-time sitting in relation to ovarian cancer risk in a large prospective US cohort. Cancer Causes Control. 2015;26(11):1691–7.
73. Lee AH, Su D, Pasalich M, Wong YL, Binns CW. Habitual physical activity reduces risk of ovarian cancer: a case-control study in southern China. Prev Med. 2013;57(Suppl):S31–3.
74. Lynch BM, Friedenreich CM, Kopciuk KA, Hollenbeck AR, Moore SC, Matthews CE. Sedentary behavior and prostate cancer risk in the NIH-AARP diet and health study. Cancer Epidemiol Biomark Prev. 2014;23(5):882–9.
75. Orsini N, Bellocco R, Bottai M, Pagano M, Andersson SO, Johansson JE, et al. A prospective study of lifetime physical activity and prostate cancer incidence and mortality. Br J Cancer. 2009;101(11):1932–8.
76. Van Hoang D, Lee AH, Pham NM, Binns CW. Prostate cancer risk reduced by physical activity even among men with prolonged sitting time: a study from Vietnam. Asia Pac J Public Health. 2018;30(3):227–34.
77. Huerta JM, Chirlaque MD, Molina AJ, Amiano P, Martín V, Fernández-Villa T, et al. Physical activity domains and risk of gastric adenocarcinoma in the MCC-Spain case-control study. PLoS One. 2017;12(7):e0179731.

78. Troeschel AN, Hartman TJ, Flanders WD, Akinyemiju T, Judd S, Bostick RM. A novel evolutionary-concordance lifestyle score is inversely associated with all-cause, all-cancer, and all-cardiovascular disease mortality risk. Eur J Nutr. 2021;60(6):3485–97.
79. Patel AV, Maliniak ML, Rees-Punia E, Matthews CE, Gapstur SM. Prolonged leisure time spent sitting in relation to cause-specific mortality in a large US cohort. Am J Epidemiol. 2018;187(10):2151–8.
80. Lee JY, Ryu S, Cheong E, Sung KC. Association of Physical Activity and Inflammation with all-cause, cardiovascular-related, and cancer-related mortality. Mayo Clin Proc. 2016;91(12): 1706–16.
81. Dunstan DW, Barr ELM, Healy GN, Salmon J, Shaw JE, Balkau B, et al. Television viewing time and mortality: the Australian diabetes, obesity and lifestyle study (AusDiab). Circulation. 2010;121:384–91.
82. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009;41(5):998–1005.
83. Keadle SK, Moore SC, Sampson JN, Xiao Q, Albanes D, Matthews CE. Causes of death associated with prolonged TV viewing: NIH-AARP diet and health study. Am J Prev Med. 2015;49(6):811–21.
84. Kim Y, Wilkens LR, Park SY, Goodman MT, Monroe KR, Kolonel LN. Association between various sedentary behaviours and all-cause, cardiovascular disease and cancer mortality: the multiethnic cohort study. Int J Epidemiol. 2013;42(4):1040–56.
85. Matthews CE, Cohen SS, Fowke JH, Han X, Xiao Q, Buchowski MS, et al. Physical activity, sedentary behavior, and cause-specific mortality in black and white adults in the southern community cohort study. Am J Epidemiol. 2014;180(4):394–405.
86. Seguin R, Buchner DM, Liu J, Allison M, Manini T, Wang CY, et al. Sedentary behavior and mortality in older women: the women's health initiative. Am J Prev Med. 2014;46(2):122–35.
87. Wijndaele K, Brage S, Besson H, Khaw KT, Sharp SJ, Luben R, et al. Television viewing time independently predicts all-cause and cardiovascular mortality: the EPIC Norfolk study. Int J Epidemiol. 2011;40(1):150–9.
88. Ricci C, Freisling H, Leitzmann MF, Taljaard-Krugell C, Jacobs I, Kruger HS, et al. Diet and sedentary behaviour in relation to cancer survival. A report from the national health and nutrition examination survey linked to the U.S. mortality registry. Clin Nutr. 2020;39(11): 3489–96.
89. Arem H, Pfeiffer RM, Engels EA, Alfano CM, Hollenbeck A, Park Y, et al. Pre- and postdiagnosis physical activity, television viewing, and mortality among patients with colorectal cancer in the National Institutes of Health-AARP diet and health study. J Clin Oncol. 2015;33(2):180–8.
90. Campbell PT, Patel AV, Newton C, Jacobs E, Gapstur SM. Associations of recreational physical activity and leisure time spent sitting with colorectal cancer survival. J Clin Oncol. 2013;31(7):876–85.
91. Cao Y, Meyerhardt JA, Chan AT, Wu K, Fuchs CS, Giovannucci EL. Television watching and colorectal cancer survival in men. Cancer Causes Control. 2015;26(10):1467–76.
92. Schmid D, Behrens G, Arem H, Hart C, Herr W, Jochem C, et al. Pre- and post-diagnosis physical activity, television viewing, and mortality among hematologic cancer survivors. PLoS One. 2018;13(1):e0192078.
93. Schmid D, Matthews CE, Leitzmann MF. Physical activity and sedentary behavior in relation to mortality among renal cell cancer survivors. PLoS One. 2018;13(6):e0198995.
94. Ukawa S, Tamakoshi A, Wakai K, Kurozawa Y. Associations of daily walking and television viewing time with liver cancer mortality: findings from the Japan collaborative cohort study. Cancer Causes Control. 2014;25(7):787–93.
95. Friedenreich CM, Wang Q, Neilson HK, Kopciuk KA, McGregor SE, Courneya KS. Physical activity and survival after prostate cancer. Eur Urol. 2016;70(4):576–85.
96. Lauby-Secretan B, Scoccianti C, Loomis D, Grosse Y, Bianchini F, Straif K. Body fatness and cancer—viewpoint of the IARC working group. N Engl J Med. 2016;375(8):794–8.

97. Júdice PB, Hamilton MT, Sardinha LB, Zderic TW, Silva AM. What is the metabolic and energy cost of sitting, standing and sit/stand transitions? Eur J Appl Physiol. 2016;116(2): 263–73.
98. Johannsen DL, Welk GJ, Sharp RL, Flakoll PJ. Differences in daily energy expenditure in lean and obese women: the role of posture allocation. Obesity. 2007;16(1):34–9.
99. Levine JA, Lanningham-Foster LM, McCrady SK, Krizan AC, Olson LR, Kane PH, et al. Interindividual variation in posture allocation: possible role in human obesity. Science. 2005;307(5709):584–6.
100. Ekelund U, Brage S, Besson H, Sharp S, Wareham NJ. Time spent being sedentary and weight gain in healthy adults: reverse or bidirectional causality? Am J Clin Nutr. 2008;88:612–7.
101. Schmid D, Leitzmann MF. Association between physical activity and mortality among breast cancer and colorectal cancer survivors: a systematic review and meta-analysis. Ann Oncol. 2014;25(7):1293–311.
102. Ten Have TR, Joffe MM. A review of causal estimation of effects in mediation analyses. Stat Methods Med Res. 2012;21(1):77–107.
103. Pedersen BK, Febbraio MA. Muscles, exercise and obesity: skeletal muscle as a secretory organ. Nat Rev Endocrinol. 2012;8(8):457–65.
104. Renehan AG, Zwahlen M, Egger M. Adiposity and cancer risk: new mechanistic insights from epidemiology. Nat Rev Cancer. 2015;15(8):484–98.
105. McTiernan A. Mechanisms linking physical activity with cancer. Nat Rev Cancer. 2008;8: 205–11.
106. Drummond AE, Swain CTV, Brown KA, Dixon-Suen SC, Boing L, van Roekel EH, et al. Linking physical activity to breast cancer via sex steroid hormones, part 2: the effect of sex steroid hormones on breast cancer risk. Cancer Epidemiol Biomark Prev. 2021;31:28.
107. Neilson HK, Friedenreich CM, Brockton NT, Millikan RC. Physical activity and postmenopausal breast cancer: proposed biologic mechanisms and areas for future research. Cancer Epidemiol Biomark Prev. 2009;18(1):11–27.
108. Kendall A, Folkerd EJ, Dowsett M. Influences on circulating oestrogens in postmenopausal women: relationship with breast cancer. J Steroid Biochem Mol Biol. 2007;103:99–109.
109. Lukanova A, Kaaks R. Endogenous hormones and ovarian cancer: epidemiology and current hypotheses. Cancer Epidemiol Biomark Prev. 2005;14(1):98–107.
110. Pou KM, Massaro JM, Hoffman U, Vasan RS, Maurovich-Horvat P, Larson MG, et al. Visceral and subcutaneous adipose tissue volumes are cross-sectionally related to markers of inflammation and oxidative stress. The Framingham Heart Study. Ciculation. 2007;116:1234–41.
111. Friedenreich CM, Neilson HK, Lynch BM. State of the epidemiologic evidence on physical activity and cancer prevention. Eur J Cancer. 2010;46:2593–604.
112. Dallal CM, Brinton LA, Matthews CE, Pfeiffer RM, Hartman TJ, Lissowska J, et al. Association of active and sedentary behaviors with postmenopausal estrogen metabolism. Med Sci Sports Exerc. 2016;48(3):439–48.
113. Tworoger SS, Missmer SA, Eliassen AH, Barbieri RL, Dowsett M, Hankinson SE. Physical activity and inactivity in relation to sex hormone, prolactin, and insulin-like growth factor concentrations in premenopausal women - exercise and premenopausal hormones. Cancer Causes Control. 2007;18(7):743–52.
114. Xue F, Michels KB. Diabetes, metabolic syndrome, and breast cancer: a review of the current evidence. Am J Clin Nutr. 2007;86(Suppl):823S–35S.
115. Stephens BR, Granados K, Zderic TW, Hamilton MT, Braun B. Effects of 1 day of inactivity on insulin action in healthy men and women: interaction with energy intake. Metabolism. 2011;60(7):941–9.
116. Henson J, Davies MJ, Bodicoat DH, Edwardson CL, Gill JM, Stensel DJ, et al. Breaking up prolonged sitting with standing or walking attenuates the postprandial metabolic response in postmenopausal women: a randomized acute study. Diabetes Care. 2016;39(1):130–8.

117. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012;55(11):2895–905.
118. Vigneri R. Diabetes: diabetes therapy and cancer risk. Nat Rev Endocrinol. 2009;5(12):651–2.
119. Coussens LM, Werb Z. Inflammation and cancer. Nature. 2002;420(6917):860–7.
120. Antuna-Puente B, Feve B, Fellahi S, Bastard J-P. Adipokines: the missing link between insulin resistance and obesity. Diabetes Metab. 2008;34:2–11.
121. Hamilton MT, Healy GN, Dunstan DW, Zderic TW, Owen N. Too little exercise and too much sitting: inactivity physiology and the need for new recommendations on sedentary behavior. Curr Cardiovasc Risk Rep. 2008;2:293–8.
122. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105–13.
123. Henson J, Yates T, Edwardson CL, Khunti K, Talbot D, Gray LJ, et al. Sedentary time and markers of chronic low-grade inflammation in a high risk population. PLoS One. 2013;8(10): e78350.
124. Lynch BM, Friedenreich CM, Winkler EA, Healy GN, Vallance JK, Eakin EG, et al. Associations of objectively assessed physical activity and sedentary time with biomarkers of breast cancer risk in postmenopausal women: findings from NHANES (2003-2006). Breast Cancer Res Treat. 2011;130(1):183–94.
125. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardiometabolic biomarkers in US adults: NHANES 2003-06. Eur Heart J. 2011;32(5):590–7.
126. Hamer M, Smith L, Stamatakis E. Prospective association of TV viewing with acute phase reactants and coagulation markers: English longitudinal study of ageing. Atherosclerosis. 2015;239(2):322–7.
127. Fung TT, Hu FB, Yu J, Chu NF, Spiegelman D, Tofler GH, et al. Leisure-time physical activity, television watching, and plasma biomarkers of obesity and cardiovascular disease risk. Am J Epidemiol. 2000;152(12):1171–8.
128. Bassett JK, Swain CTV, Hodge AM, Mahmood S, Csizmadi I, Owen N, et al. Calibration of the active Australia questionnaire and application to a logistic regression model. J Sci Med Sport. 2021;24(5):474–80.
129. Mahmood S, Nguyen NH, Bassett JK, MacInnis RJ, Karahalios A, Owen N, et al. A quantitative bias analysis to estimate measurement error-related attenuation of the association between self-reported physical activity and colorectal cancer risk. Int J Epidemiol. 2020;49(1): 153–61.
130. Hernán MA, Sauer BC, Hernández-Díaz S, Platt R, Shrier I. Specifying a target trial prevents immortal time bias and other self-inflicted injuries in observational analyses. J Clin Epidemiol. 2016;79:70–5.
131. Ballard-Barbash R, Hunsberger S, Alciati MH, Blair SN, Goodwin PJ, McTiernan A, et al. Physical activity, weight control, and breast cancer risk and survival: clinical trial rationale and design considerations. J Natl Cancer Inst. 2009;101(9):630–43.
132. Lynch BM, Dixon-Suen SC, Ramirez Varela A, Yang Y, English DR, Ding D, et al. Approaches to improve causal inference in physical activity epidemiology. J Phys Act Health. 2020;17(1):80–4.
133. Robins JM, Hernan MA, Brumback B. Marginal structural models and causal inference in epidemiology. Epidemiology. 2000;11(5):550–60.
134. Davey Smith G, Hemani G. Mendelian randomization: genetic anchors for causal inference in epidemiological studies. Hum Mol Genet. 2014;23(R1):R89–98.
135. Doherty A, Smith-Byrne K, Ferreira T, Holmes MV, Holmes C, Pulit SL, et al. GWAS identifies 14 loci for device-measured physical activity and sleep duration. Nat Commun. 2018;9(1):5257.
136. Willetts M, Hollowell S, Aslett L, Holmes C, Doherty A. Statistical machine learning of sleep and physical activity phenotypes from sensor data in 96,220 UK biobank participants. Sci Rep. 2018;8(1):7961.

137. Dixon-Suen SC, Lewis SJ, Martin RM, English DR, Boyle T, Giles GG, et al. Physical activity, sedentary time and breast cancer risk: a Mendelian randomization study. Br J Sports Med. 2022;56(20):1157–70.
138. Greenland S, Pearl J, Robins JM. Causal diagrams for epidemiologic research. Epidemiology. 1999;10(1):37–48.

Chapter 10
Sedentary Behaviour and Depression

Mark Hamer and Lee Smith

Abstract Depressive symptoms are known to adversely influence longevity and well-being. In particular, depression is independently associated with cardiovascular disease and all-cause mortality and is often co-morbid with chronic diseases that can worsen their associated health outcomes. Several decades of evidence suggest that regular participation in exercise/physical activity promotes positive mood state, has anti-depressive effects, and can protect individuals from developing depression. More recently, researchers have turned their attention to the effects of sedentary behaviours on mental health. Sedentary leisure pursuits, such as viewing television, films, and playing video games, are generally perceived to be enjoyable and relaxing. It is therefore somewhat of a paradox that epidemiological data suggest sedentary behaviour may be a risk factor for depression independently from physical activity. In this overview, we examine new epidemiological evidence for an association between sedentary behaviour and depressive symptoms and discuss biologically plausible mechanisms. In summary, the area of sedentary behaviour and mental health is an emerging area, but the lack of gold-standard experimental data makes causal inference challenging.

What Is New?
- Evidence on sedentary and mental health largely comes from observational population studies.

(continued)

M. Hamer (✉)
Faculty Medical Sciences, Institute Sport, Exercise and Health, University College London, London, UK
e-mail: m.hamer@ucl.ac.uk

L. Smith
Centre for Health Performance and Wellbeing, Anglia Ruskin University, Cambridge, UK
e-mail: Lee.Smith@aru.ac.uk

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_10

- More recent work has deployed device-based assessments of sedentary time to overcome some of the limitations of self-report.
- Data from new cross-sectional studies have observed associations between greater device-assessed sedentary time and higher risk of depressive symptoms, but longitudinal data are lacking.

10.1 Introduction

Mental illness is now recognised as a serious health risk and accounts for approximately 14% of the global burden of disease. Depression, one of the most common mental disorders, ranks third among disorders responsible for global disease burden and will rank first in high-income countries by 2030 [1]. Prospective studies have demonstrated that clinical and sub-clinical depression in initially healthy individuals relates to greater risk of future cardiovascular disease (CVD), diabetes, and mortality [2–4]. Depressive symptoms are a risk factor for poor prognosis in patients with existing coronary heart disease [5]. In a meta-analysis of prospective cohort studies [6], depression also predicted a 29% increase in cancer incidence and an 8% reduction in cancer survival. In addition, observational data from 60 countries has demonstrated that depression produces the greatest decrement in health compared with other chronic diseases, and the co-morbid state of depression incrementally worsens health compared with depression alone [7].

The prevention and treatment of depression is a crucial public health issue, although we presently have a limited understanding of the risk factors and optimal intervention strategies. Depression and stress-related disorders have various modes of treatment, including pharmacotherapy, psychotherapy, and lifestyle or behavioural modification. However, evidence shows that pharmacotherapy is only effective in about one-third of patients, and some only have a partial response to treatment [8], prompting the need to identify other forms of treatment. Several decades of evidence suggest that regular exercise/physical activity has anti-depressive effects in patients and is associated with lower risk of developing depression in initially healthy individuals [9, 10]. More recently, researchers have turned their attention to the effects of sedentary behaviours on mental health. Sedentary leisure pursuits, such as viewing television (TV), films, playing video games, etc., are generally perceived to be enjoyable and relaxing. It is therefore somewhat of a paradox that emerging data, largely from observational studies, suggest sedentary behaviour may be a risk factor for depression independently from physical activity. This chapter presents an overview of the evidence linking sedentary behaviour with depressive symptoms and discusses the plausibility of the findings.

10.2 Epidemiological Evidence on Sedentary Behaviour and Depression

10.2.1 Evidence in Adults

The epidemiological evidence in this area has largely come from cross-sectional studies, and stronger longitudinal evidence is generally lacking. In a recent systematic review and meta-analysis, twenty-four studies were identified, totalling nearly 200,000 study participants [11]. Depression was defined in several ways, including self-reported doctor's diagnosis, use of antidepressant medication, or interview or validated psychometric tools using depression rating scales. The pooled risk estimate showed that participants in the highest versus non-occasional/occasional sedentary behaviour groups were at 25% increased risk of depressive symptoms although effect estimates were somewhat attenuated when only longitudinal studies were included. The analyses also uncovered significant heterogeneity and variable study quality. For example, some studies did not adjust for key confounding variables such as physical activity, and dietary intake was often poorly measured or not included in analyses. Since crude measures of sedentary behaviour were used in most of the included studies, it was not possible to examine dose–response patterns.

Several longitudinal studies have been published, although the results have been generally inconsistent. For example, several studies have demonstrated an association between self-reported TV/computer time [12] and TV time alone [13] with higher risk of depression at follow-up. In another recent prospective study, the association between sedentary behaviour and depressive symptoms was only apparent among individuals who did not meet the current physical activity guidelines [14]. Other longitudinal studies have produced conflicting findings. In one of the most robust studies to date that included four assessments at different time points over 10 years follow-up, total sitting time was not prospectively associated with depressive symptoms using lagged mixed effect modelling [15]. Instead, physical activity was the main factor in predicting depression over follow up. Data in over 6000 men and women from the English Longitudinal Study of Ageing demonstrated cross-sectional associations between higher TV viewing and greater depressive symptoms, although TV did not predict changes in symptoms over follow-up, suggesting that the difference in depressive scores persisted but did not increase over time [16]. Interestingly, in that study, TV viewing time, but not computer use, was associated with higher depressive symptoms. Thus, it is difficult to tease apart if the effects are being driven by physiological processes linked to excessive sitting or the contrasting environmental and social contexts in which they occur. For example, passive activities such as TV viewing may encourage a greater volume of prolonged sitting; conversely, internet use may encourage social interaction. Other recent work has shown possible links between interruptions in sedentary time and mental health [17]. Another issue to consider is reverse causation in that depression may, in part, drive increases in sedentary habits. Several studies have provided evidence to support this notion [18, 19]. Thus, associations between sedentary time and depression are likely to be bi-directional.

A major weakness of this area has been the reliance on self-reported measures of sedentary time; self-report can cause biases, which might be particularly marked in depression as some of the somatic symptoms have conceptual overlap with sedentary behaviour. Physical activity can be assessed objectively using accelerometers, which are devices that measure body movements in terms of acceleration. These data can be used to accurately assess the time spent across different parts of the physical activity continuum ranging from highly vigorous activity to sleeping. Relatively few studies have examined associations between device-assessed sedentary time and mental health, although the literature has been steadily evolving [20–28] (see Table 10.1). Among the nine studies published to date, six observed relationships between greater sedentary time and higher odds of depressive symptoms, whilst two reported null associations, and one found increased symptoms if sedentary time was replaced by light activity. It should be noted that all but one were cross-sectional studies; thus, the direction of the association remains unclear. The associations between sedentary time and mental health are largely independent of moderate-to-vigorous-intensity activity but may in part be explained by differences in the ratio of sedentary to light-intensity activity. Modifying the balance between sedentary time and light-intensity activity could therefore be beneficial for mental health, as suggested by other recent studies [29, 30]. Evidence from randomised controlled trials also suggests more favourable effects of undertaking lighter to moderate intensity exercise on positive mood/fatigue symptoms as opposed to vigorous exercise [31, 32]. Inconsistent findings might be attributable to different cut-off points adopted when interpreting data from accelerometers, and thus the development of definitive guidelines tackling these issues is required. In addition, accelerometer devices are limited in that they cannot be worn for all activities such as swimming and contact sports, and defining ‘non-wear’ time can therefore be problematic. Thus, self-report and objective measures both have their advantages, and an optimal method is to combine both approaches.

10.2.2 Evidence in Young People

Capturing mental health in children is more challenging as assessments often use proxy measures from parents and teachers. However, given that sedentary habits appear to track from childhood into adulthood [33], childhood exposure represents a crucial period. Recent evidence from a meta-analysis included twelve cross-sectional studies and four longitudinal studies involving a total of 127,714 children and adolescents [34]. Overall, sedentary behaviour was associated with a modest 12% increased risk of depression, although the pooled effect estimate from longitudinal studies was non-significant, and heterogeneity was high. In addition, the associations were context specific, and pooled effects were significant only for computer/internet use and not for other forms of sedentary time including TV or video games. The high

Table 10.1 Summary of evidence from observational cohort studies on device-assessed sedentary behaviour and depressive symptoms

Study	Cohort/study design characteristics	Measures	Key findings
Vallance et al. (2011)	2005–2006 US National Health and Nutrition Examination Survey, cross-sectional ($n = 2862$, aged 45.7 years, 50.2%♀)	Hip-mounted Actigraph; Patient Health Questionnaire-9	In overweight/obese participants only, those in quartile 4 (most sedentary) had 3.0-fold higher odds for depression
Hamer et al. (2014)	2008 Health Survey for England, cross-sectional ($n = 1947$; age 50 years; 51.9% ♀)	Hip-mounted Actigraph; General Health Questionnaire	Highest tertile of sedentary behaviour associated with 1.7-fold increased odds of depression
Yasunaga et al. (2018)	Cross-sectional, Japan ($n = 276$; age 74.4 years; 38% ♀)	Hip mounted active style Pro HJA-350IT; 15-item Geriatric Depression Scale	Sedentary behaviour associated with higher depressive scores
Chu et al. (2018)	The Singapore health 2 study, cross-sectional ($n = 703$; age 45 years; 55%♀)	Hip-mounted Actigraph; Kessler Screening Scale and General Health Questionnaire	Highest tertile of sedentary behaviour associated with 1.9-fold increased odds of depression
Dillon et al. (2018)	Primary care sample, Ireland, cross-sectional ($n = 2047$; age 59.6 years; 53.9% ♀)	Wrist-worn GENEActiv; Centre for Epidemiologic Studies Depression scale	No associations between sedentary and depressive symptoms
Okely et al. (2019)	Lothian Birth Cohort 1936 ($n = 271$), West of Scotland Twenty-071950s ($n = 309$) and 1930s ($n = 118$) cohorts. Cross-sectional (age range 65–83 years)	Thigh-mounted ActivPAL; Hospital Anxiety and Depression Scale	Symptoms of depression positively associated with sedentary time in the LBC1936 and twenty-071950s cohort
Konopka et al. (2020)	Maastricht study, Netherlands, prospective ($n = 2082$; age 60.1 years; 48.8%♀)	Thigh mounted ActivPAL; 9-item Patient Health Questionnaire (measured annually over 4 years of follow-up)	No associations between sedentary and depressive symptoms
Tully et al. (2020)	Community-dwelling men and women aged ≥65 years from Denmark, Spain, Germany, and Northern Ireland (n = 1360; age 75.1 years)	Hip-mounted Actigraph; Hospital and Anxiety Depression Scale	Substituting 30 minutes of sedentary with light PA was associated with increased depression
Biddle et al. (2021)	Patient cohort, UK, cross-sectional ($n = 1574$; age 59.1 years; 48.6%♀)	Thigh mounted ActivPAL; Hospital Anxiety and Depression Scale	Total and prolonged sitting is associated with 14% increased odds of depression

degree of heterogeneity possibly reflects reporting biases in addition to the significant limitations discussed earlier. In one of the largest studies to date containing over half a million adolescents from 42 European and North American countries, detrimental associations between screen time and mental well-being started when screen time exceeded 1 h per day [35]. There are little longitudinal data with extended follow-up to explore how childhood sedentary behaviours related to mental health in adulthood. In a recently published study using data from the 1970 British Cohort study, higher screen time at the age of 16 was associated with depressive symptoms at the age of 42, although the association was attenuated after adjustment for covariates [36]. Thus, it is possible that screen time in adolescence is a marker for other lifestyle factors and socioeconomic circumstances that have important life course influences on mental health. Recent longitudinal studies incorporating device-based assessment of sedentary time have reported conflicting findings [37, 38]. Another important use of birth cohort studies is to investigate the issue of reverse causality that might be in operation. Indeed, a recent study using the 1958 birth cohort showed that the bi-directional association between physical activity and depression is modified by age in that it is more persistent during adult life in the direction from activity to depressive symptoms, whereas depressive symptoms in early adulthood may be a barrier to activity [39].

Taken together, the epidemiological evidence largely suggests sedentary behaviour within certain contexts is an emerging risk factor for depressive symptoms. These data should be interpreted in light of several limitations including potential for residual confounding and lack of gold standard experimental data.

10.3 Plausible Mechanisms

There are several biological pathways that might explain the observed associations between sedentary behaviours and depression, although to date there is little empirical evidence available. Thus, in this section, we will outline various hypothesised mechanisms largely drawn from the literature in exercise and psychobiology.

10.3.1 The Immune System

There has been much interest in the association between depressive symptoms and inflammatory risk markers [40]. Several studies have reported elevated concentrations of various inflammatory markers in differing populations reporting depressive symptoms, including the medically healthy [41, 42], elderly [43–45], and patients with acute coronary symptoms or existing CVD risk factors [46, 47]. Experimental work has also demonstrated a link between inflammation and mood. Using a vaccination model to induce a mild inflammatory challenge, greater increases in negative mood were observed after vaccine compared with placebo among

30 healthy male volunteers [48]. In addition, negative changes in mood following vaccination were significantly correlated with increases in interleukin (IL)-6 production. Notably, no significant symptoms of nausea were reported, so it cannot be argued that negative mood arose because the participants were feeling ill.

A large amount of interest has also focused on the potential effects of exercise/inactivity and inflammatory responses. It has been argued that the increases in circulating IL-6 that is observed after an acute bout of exercise promote an anti-inflammatory environment by increasing IL-1 receptor antagonist and IL-10 synthesis, while inhibiting pro-inflammatory markers such as tumour necrosis factor-alpha (TNF-α) [49]. The cytokines released during exercise are thought to originate from exercising skeletal muscle, which work in a hormone-like fashion exerting specific endocrine effects on various organs and signalling pathways [50]. Unlike IL-6 release during acute mental stress, which appears to be dependent on activation of the NFκB signalling pathway [51], intramuscular IL-6 expression is regulated by a network of signalling cascades that are likely to involve the CA^{2+}/NFAT and glycogen/p38 MAPK pathways. This might partly explain why exercise-induced IL-6 release is not acting as a strong pro-inflammatory agent. This hypothesis might also explain why a large number of observational studies have demonstrated an inverse association between regular physical activity and various pro-inflammatory markers in humans [52]. In addition, we demonstrated longitudinal associations between sedentary behaviour and increases in various acute phase reactants and coagulation markers in older adults over a four-year follow-up [53]. Some of the effects of inactivity may be partly explained through the accumulation of visceral adiposity, which is an important production site for acute phase reactants and IL-6.

Given the described relationship between both mood and sedentary behaviour with inflammatory pathways, it is feasible to hypothesise that the link between sedentary behaviour and risk of depressive symptoms might be partly explained by an underlying inflammatory mechanism. However, in an observational study of 5000 men and women, the association between sedentary behaviour and depressive symptoms was largely explained through lack of physical activity, smoking, and alcohol, but not by C-reactive protein (CRP) or body mass index [54].

10.3.2 Neurobiology

The anti-inflammatory effects of exercise might also be relevant at a neurobiological level, since alterations in neurotransmitter function involving serotonin, norepinephrine, and dopamine are known to induce depression and are targets for currently available psychopharmacological treatments. Exercise is thought to alter serotonin metabolism, release endogenous opioids, and increase central noradrenergic neurotransmission, which may all contribute to antidepressant and anxiolytic effects. The dopaminergic system is thought to play a key role in depression, and polymorphisms of the dopamine D2 receptor gene have also been implicated in physical activity behaviour [55]. Further research has focused on the hippocampus, where exercise-induced neurogenesis and growth factor expression have been proposed as potential mediators [56]. Exercise has been linked with several growth factors, such as brain-derived neurotrophic factor (BDNF) and insulin-like growth factor (IGF-1), which might mediate the protective and therapeutic effects of exercise on depression. Studies have shown that an acute bout of exercise increases peripheral levels of serum BDNF in an intensity dose-dependent fashion, but resting levels of BDNF do not seem to be affected by long-term exercise training [57], suggesting that other compensatory mechanisms might be at play. The BDNF hypothesis has yet to be tested in relation to sedentary behaviour. There is also evidence to suggest that the pro-inflammatory cytokines impair some of the growth factor signalling pathways in the brain [58]; thus, pro-inflammatory actions of excess sedentary behaviour may again be important.

10.3.3 Hypothalamic Pituitary Adrenal (HPA) Axis

The interaction of the immune system with the HPA axis and the autonomic nervous system plays a crucial role in mental health. Following mental stress, the sensitivity of the immune system to dexamethasone inhibition (a synthetic version of the hormone cortisol that has potent anti-inflammatory properties) is reduced, as manifested by a reduction in this hormone's capacity to suppress the production of inflammatory cytokines [59]. In endurance-trained individuals, however, an acute bout of exercise has been shown to increase tissue sensitivity to glucocorticoids, which is thought to act as a mechanism to prevent an excessive muscle inflammatory reaction [60]. HPA axis dysregulation and cortisol hyper-secretion has been implicated in mental health and some studies have shown lower stress-induced cortisol responses in physically trained individuals compared to the untrained [61, 62], suggesting that physical activity may act as a buffer against exaggerated or sustained stress responses. Nevertheless, in a study of objectively assessed physical activity levels and cortisol responses to acute mental stress, no associations were found [63]. There is currently very little evidence on sedentary behaviour and HPA function, although recent work in a cohort of older adults suggested null associations between self-reported TV viewing and cortisol levels measured from hair [64].

10.3.4 Psychosocial Mechanisms

Several non-biological mechanisms may also exist. For example, passive sedentary activities such as TV viewing might encourage social isolation and limit the development of social networks known to be linked with depression.

In summary, there is mounting evidence to suggest the detrimental effects of excess sedentary time on mental health, although plausible biological mechanisms are currently lacking. There are numerous data showing associations between sedentary time and cardio-metabolic risk factors [53, 65]; thus, the underlying mechanisms might partly act through these pathways.

10.4 Experimental Evidence

Experimental trials have demonstrated favourable effects of exercise training on reducing depressive symptoms, with effect sizes ranging from 1.03 to 0.58, respectively [66]. There are, however, limited experimental data on the effects of sedentary behaviour. The exercise withdrawal paradigm represents a possible experimental model to investigate the links between sedentary behaviour, mood, and the underlying biology. We and others have hypothesised that mood disturbances caused by replacing regular exercise with sedentary behaviour might act as a mild inflammatory stimulus. However, recent studies have been unable to confirm this hypothesis. Several studies, including one of our own that have successfully induced an increased negative mood following several weeks of exercise withdrawal, did not find any changes in a range of inflammatory markers, such as IL-6, CRP, TNF-α, fibrinogen, and soluble intracellular adhesion molecule-1 [67, 68]. Similarly, one-week withdrawal from exercise in highly active men did not elicit any substantial changes in CRP, IL-6, TNF-α, and circulating leukocyte concentration [69]. Healthy men who reduced their daily step count by 85% for two weeks developed impaired glucose tolerance, attenuation of postprandial lipid metabolism, and a 7% increase in intra-abdominal fat mass, although plasma cytokines and muscular expression of TNF-α was not altered [70]. However, another study reported that reduced parasympathetic nervous activity as measured by heart rate variability was predictive of negative mood following exercise withdrawal [71].

In a further study, we investigated the impact of exercise withdrawal on psychophysiological responses to mental stress.. However, responses to laboratory-induced stress tasks are not meaningful in themselves, they reflect the way that people respond to stress in daily life, and this method can sometimes detect differences that might not otherwise be seen under resting conditions. Although the effects of cytokines are often thought to be transient, they may provoke a time-dependent sensitisation so that the response to a later cytokine or stressor stimulus is enhanced, resulting in an increased vulnerability to depressed mood [72]. We experimentally manipulated sedentary time by asking a group of habitual exercisers to replace their regular exercise training with sedentary activities for two weeks [73]. The adherence to the intervention was mixed, as indicated by objective accelerometry physical activity records, but on average sedentary time increased by 32 min/day during the experimental condition compared to control, that closely mirrored increases in mood disturbances. In particular, increases in sedentary behaviour caused a reduction in vigour, greater fatigue, and a general increase in somatic symptoms compared to control conditions (see Fig. 10.1). In participants with greater mood disturbances, we observed significantly higher inflammatory responses to mental stress compared to those with low or no mood disturbance. In the same study, cortisol responses to

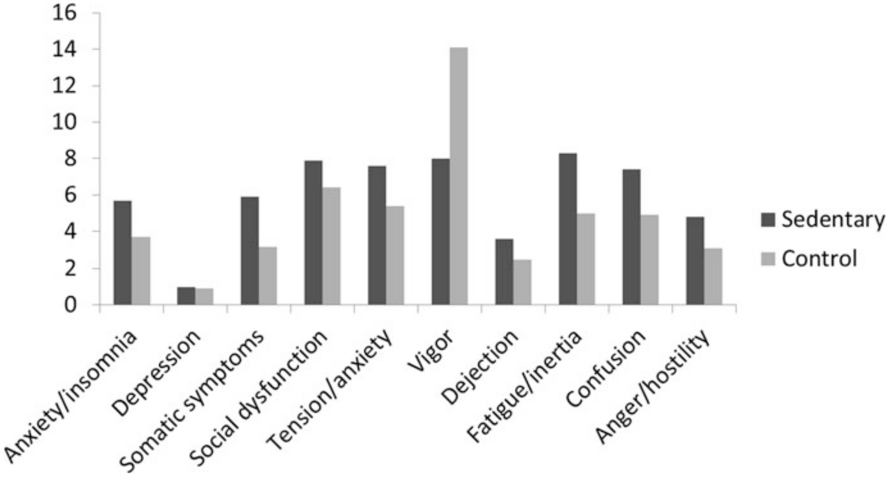

Fig. 10.1 The effect of a two-week sedentary intervention on mood symptoms and psychological distress measured using Profile of Mood States and General Health Questionnaire, respectively

mental stress were higher in the intervention phase compared to the control period with a significant difference emerging at 20 minutes post-stress. These results, although preliminary, suggest that psychobiological factors may in part mediate the effects of sedentary behaviours on mental health.

10.5 Summary

The link between common sedentary activities and mental health is somewhat paradoxical. Many people choose to spend large amounts of time in screen-based activities, for example, watching TV, films, etc., which are generally viewed as being pleasurable and relaxing. The emerging science, however, suggests that exposure to sedentary lifestyles is associated with greater risk of depressive symptoms and poor well-being. These associations appear to be stronger for certain domains of sedentary behaviour; thus, context is an important aspect to consider in future work. To date, the evidence has been largely generated from observational population studies, and experimental work is lacking. More recent work has deployed device-based assessments of sedentary time to overcome some of the limitations of self-report. Current evidence should be interpreted in light of several limitations including the potential for residual confounding and lack of gold-standard experimental data. Some evidence suggests that sedentary time directly influences psychobiological responses, including adaptations to the immune system, HPA axis, and autonomic nervous system, which might be a plausible mechanism underlying the links between sedentary behaviour and adverse mental health.

References

1. Cuijpers P, Beekman AT, Reynolds CF 3rd. Preventing depression: a global priority. JAMA. 2012;307(10):1033–4.
2. Kuper H, Marmot M, Hemingway H. Systematic review of prospective cohort studies of psychosocial factors in the etiology and prognosis of coronary heart disease. Semin Vasc Med. 2002;2:267–314.
3. Knol MJ, Twisk JW, Beekman AT, Heine RJ, Snoek FJ, Pouwer F. Depression as a risk factor for the onset of type 2 diabetes mellitus. A meta-analysis. Diabetologia. 2006;49:837–45.
4. Pan A, Sun Q, Okereke OI, Rexrode KM, Hu FB. Depression and risk of stroke morbidity and mortality: a meta-analysis and systematic review. JAMA. 2011;306(11):1241–9.
5. Barth J, Schumacher M, Herrmann-Lingen C. Depression as a risk factor for mortality in patients with coronary heart disease: a meta-analysis. Psychosom Med. 2004;66:802–13.
6. Chida Y, Hamer H, Wardle J, Steptoe A. Do psychosocial stress-related factors contribute to cancer incidence and survival? Nature Clin Prac Oncol. 2008;5:466–75.
7. Moussavi S, Chatterji S, Verdes E, Tandon A, Patel V, Ustun B. Depression, chronic diseases, and decrements in health: results from the World Health Surveys. Lancet. 2007;370:851–8.
8. Trivedi MH, Rush AJ, Wisniewski SR, Nierenberg AA, Warden D, Ritz L, Norquist G, Howland RH, Lebowitz B, PJ MG, Shores-Wilson K, Biggs MM, Balasubramani GK, Fava M, STAR*D Study Team. Evaluation of outcomes with citalopram for depression using measurement-based care in STAR*D: implications for clinical practice. Am J Psych. 2006;163: 28–40.
9. Cooney GM, Dwan K, Greig CA, et al. Exercise for depression. Cochrane Database Syst Rev. 2013;9:CD004366.
10. Mammen G, Faulkner G. Physical activity and the prevention of depression: a systematic review of prospective studies. Am J Prev Med. 2013;45(5):649–57.
11. Zhai L, Zhang Y, Zhang D. Sedentary behaviour and the risk of depression: a meta-analysis. Br J Sports Med. 2015;49(11):705–9.
12. Sanchez-Villegas A, Ara I, Guillén-Grima F, Bes-Rastrollo M, Varo-Cenarruzabeitia JJ, Martínez-González MA. Physical activity, sedentary index, and mental disorders in the SUN cohort study. Med Sci Sports Exerc. 2010;40:827–34.
13. Lucas M, Mekary R, Pan A, Mirzaei F, O'Reilly EJ, Willett WC, Koenen K, Okereke OI, Ascherio A. Relation between clinical depression risk and physical activity and time spent watching television in older women: a 10-year prospective follow-up study. Am J Epidemiol. 2011;174:1017–27.
14. Sui X, Brown WJ, Lavie CJ, West DS, Pate RR, Payne JP, Blair SN. Associations between television watching and car riding behaviors and development of depressive symptoms: a prospective study. Mayo Clin Proc. 2015;90(2):184–93.
15. van Uffelen JG, van Gellecum YR, Burton NW, Peeters G, Heesch KC, Brown WJ. Sitting-time, physical activity, and depressive symptoms in mid-aged women. Am J Prev Med. 2013;45 (3):276–81.
16. Hamer M, Stamatakis E. Prospective study of sedentary behavior, risk of depression, and cognitive impairment. Med Sci Sports Exerc. 2014;46(4):718–23.
17. Hallgren M, Nguyen TT, Owen N, Vancampfort D, Smith L, Dunstan DW, Andersson G, Wallin P, Ekblom-Bak E. Associations of interruptions to leisure-time sedentary behaviour with symptoms of depression and anxiety. Transl Psychiatry. 2020;10(1):128.
18. Brunet J, Sabiston CM, O'Loughlin E, Chaiton M, Low NC, O'Loughlin JL. Symptoms of depression are longitudinally associated with sedentary behaviors among young men but not among young women. Prev Med. 2014;60:16–20.
19. Gardner B, Iliffe S, Fox KR, Jefferis BJ, Hamer M. Sociodemographic, behavioural and health factors associated with changes in older adults' TV viewing over 2 years. Int J Behav Nutr Phys Act. 2014;11:102.

20. Vallance JK, Winkler EA, Gardiner PA, Healy GN, Lynch BM, Owen N. Associations of objectively-assessed physical activity and sedentary time with depression: NHANES (2005-2006). Prev Med. 2011;53:284–8.
21. Hamer M, Coombs N, Stamatakis E. Associations between objectively assessed and self-reported sedentary time with mental health in adults: an analysis of data from the health survey for England. BMJ Open. 2014;4(3):e004580.
22. Yasunaga A, Shibata A, Ishii K, Koohsari MJ, Oka K. Cross-sectional associations of sedentary behaviour and physical activity on depression in Japanese older adults: an isotemporal substitution approach. BMJ Open. 2018;8(9):e022282.
23. Chu AHY, van Dam RM, Biddle SJH, Tan CS, Koh D, Müller-Riemenschneider F. Self-reported domain-specific and accelerometer-based physical activity and sedentary behaviour in relation to psychological distress among an urban Asian population. Int J Behav Nutr Phys Act. 2018;15(1):36.
24. Dillon CB, McMahon E, O'Regan G, Perry IJ. Associations between physical behaviour patterns and levels of depressive symptoms, anxiety and well-being in middle-aged adults: a cross-sectional study using isotemporal substitution models. BMJ Open. 2018;8(1):e018978.
25. Okely JA, Čukić I, Shaw RJ, Chastin SF, Dall PM, Deary IJ, Der G, Dontje ML, Skelton DA, Gale CR, Seniors USP team. Positive and negative well-being and objectively measured sedentary behaviour in older adults: evidence from three cohorts. BMC Geriatr. 2019;19(1):28.
26. Konopka MJ, Köhler S, Stehouwer CDA, Schaper NC, Henry RMA, van der Kallen CJH, Savelberg HHCM, Eussen SJPM, Dagniele PC, van Dongen MCJM, Schram MT, Koster A. Accelerometer-derived sedentary time and physical activity and the incidence of depressive symptoms - The Maastricht Study. Psychol Med. 2020;52(13):1–8.
27. Tully MA, McMullan I, Blackburn NE, Wilson JJ, Bunting B, Smith L, Kee F, Deidda M, Giné-Garriga M, Coll-Planas L, Dallmeier D, Denkinger M, Rothenbacher D, Caserotti P. Sedentary behavior, physical activity, and mental health in older adults: an isotemporal substitution model. Scand J Med Sci Sports. 2020;30(10):1957–65.
28. Biddle SJH, Henson J, Davies MJ, Khunti K, Sutton S, Yates T, Edwardson CL. Device-assessed total and prolonged sitting time: associations with anxiety, depression, and health-related quality of life in adults. J Affect Disord. 2021;287:107–14.
29. Buman MP, Hekler EB, Haskell WL, Pruitt L, Conway TL, Cain KL, Sallis JF, Saelens BE, Frank LD, King AC. Objective light-intensity physical activity associations with rated health in older adults. Am J Epidemiol. 2010;172:1155–65.
30. Mekary RA, Lucas M, Pan A, et al. Isotemporal substitution analysis for physical activity, television watching, and risk of depression. Am J Epidemiol. 2013;178(3):474–83.
31. Moses J, Steptoe A, Mathews A, Edwards S. The effects of exercise training on mental well-being in the normal population: a controlled trial. J Psychosom Res. 1989;33:47–61.
32. Puetz TW, Flowers SS, O'Connor PJ. A randomized controlled trial of the effect of aerobic exercise training on feelings of energy and fatigue in sedentary young adults with persistent fatigue. Psychother Psychosom. 2008;77:167–74.
33. Smith L, Gardner B, Hamer M. Childhood correlates of adult TV viewing time: a 32-year follow-up of the 1970 British cohort study. J Epidemiol Community Health. 2015;69(4):309–13.
34. Liu M, Wu L, Yao S. Dose-response association of screen time-based sedentary behaviour in children and adolescents and depression: a meta-analysis of observational studies. Br J Sports Med. 2015 Nov 9;50(20):1252–8.
35. Khan A, Lee E-Y, Rosenbaum S, Khan SR, Tremblay MS. Dose-dependent and joint associations between screen time, physical activity, and mental wellbeing in adolescents: an international observational study. Lancet Child Adolescent Health. 2021;5(10):729–38. https://doi.org/10.1016/S2352-4642(21)00200-5.
36. Hamer M, Yates T, Sherar LB, Clemes SA, Shankar A. Association of after school sedentary behaviour in adolescence with mental wellbeing in adulthood. Prev Med. 2016;87:6–10.

37. Hamer M, Patalay P, Bell S, Batty GD. Change in device-measured physical activity assessed in childhood and adolescence in relation to depressive symptoms: a general population-based cohort study. J Epidemiol Community Health. 2020;74(4):330–5.
38. Kandola A, Lewis G, Osborn DPJ, Stubbs B, Hayes JF. Depressive symptoms and objectively measured physical activity and sedentary behaviour throughout adolescence: a prospective cohort study. Lancet Psychiatry. 2020;7(3):262–71.
39. Pinto Pereira SM, Geoffroy MC, Power C. Depressive symptoms and physical activity during 3 decades in adult life: bidirectional associations in a prospective cohort study. JAMA Psychiatry. 2014;71(12):1373–80.
40. Irwin MR, Miller AH. Depressive disorders and immunity: 20 years of progress and discovery. Brain Behav Immun. 2007;21:374–83.
41. Liukkonen T, Silvennoinen-Kassinen S, Jokelainen J, Räsänen P, Leinonen M, Meyer-Rochow VB, Timonen M. The association between C-reactive protein levels and depression: results from the northern Finland 1966 birth cohort study. Biol Psychiatry. 2006;60:825–30.
42. Panagiotakos DB, Pitsavos C, Chrysohoou C, Tsetsekou E, Papageorgiou C, Christodoulou G, Stefanadis C, ATTICA study. Inflammation, coagulation, and depressive symptomatology in cardiovascular disease-free people; the ATTICA study. Eur Heart J. 2004;25:492–9.
43. Kop WJ, Gottdiener JS, Tangen CM, Fried LP, McBurnie MA, Walston J, Newman A, Hirsch C, Tracy RP. Inflammation and coagulation factors in persons $>$ 65 years of age with symptoms of depression but without evidence of myocardial ischemia. Am J Cardiol. 2002;89: 419–24.
44. Penninx BW, Kritchevsky SB, Yaffe K, Newman AB, Simonsick EM, Rubin S, Ferrucci L, Harris T, Pahor M. Inflammatory markers and depressed mood in older persons: results from the health, aging and body composition study. Biol Psychiatry. 2003;54:566–72.
45. Bremmer MA, Beekman AT, Deeg DJ, Penninx BW, Dik MG, Hack CE, Hoogendijk WJ. Inflammatory markers in late-life depression: results from a population-based study. J Affect Disord. 2008;106:249–55.
46. Empana JP, Sykes DH, Luc G, Juhan-Vague I, Arveiler D, Ferrieres J, PRIME Study Group, et al. Contributions of depressive mood and circulating inflammatory markers to coronary heart disease in healthy European men: the Prospective Epidemiological Study of Myocardial Infarction (PRIME). Circulation. 2005;111:2299–305.
47. Pizzi C, Manzoli L, Mancini S, Costa GM. Analysis of potential predictors of depression among coronary heart disease risk factors including heart rate variability, markers of inflammation, and endothelial function. Eur Heart J. 2008;29:1110–7.
48. Wright CE, Strike PC, Brydon L, Steptoe A. Acute inflammation and negative mood: mediation by cytokine activation. Brain Behav Immun. 2005;19:345–50.
49. Febbraio MA, Pedersen BK. Muscle-derived interleukin-6: mechanisms for activation and possible biological roles. FASEB J. 2002;16:1335–47.
50. Pedersen BK. Exercise-induced myokines and their role in chronic diseases. Brain Behav Immun. 2011;25:811–6.
51. Bierhaus A, Wolf J, Andrassy M, Rohleder N, Humpert PM, Petrov D, Ferstl R, von Eynatten M, Wendt T, Rudofsky G, Joswig M, Morcos M, Schwaninger M, McEwen B, Kirschbaum C, Nawroth PP. A mechanism converting psychosocial stress into mononuclear cell activation. PNAS. 2003;100:1920–5.
52. Hamer M. The relative influences of fitness and fatness on inflammatory factors. Prev Med. 2007;44:3–11.
53. Hamer M, Smith L, Stamatakis E. Prospective association of TV viewing with acute phase reactants and coagulation markers: English longitudinal study of ageing. Atherosclerosis. 2015;239(2):322–7.
54. Hamer M, Poole L, Messerli-Bürgy N. Television viewing, C-reactive protein, and depressive symptoms in older adults. Brain Behav Immun. 2013;33:29–32.

55. Simonen RL, Rankinen T, Perusse L, Leon AS, Skinner JS, Wilmore JH, Rao DC, Bouchard C. A dopamine D2 receptor gene polymorphism and physical activity in two family studies. Physiol Behav. 2003;78:751–7.
56. Cotman CW, Berchtold NC, Christie LA. Exercise builds brain health: key roles of growth factor cascades and inflammation. Trends Neurosci. 2007;30:464–72.
57. Knaepen K, Goekint M, Heyman EM, Meeusen R. Neuroplasticity - exercise-induced response of peripheral brain-derived neurotrophic factor: a systematic review of experimental studies in human subjects. Sports Med. 2010;40:765–801.
58. Tong L, Balazs R, Soiampornkul R, Thangnipon W, Cotman CW. Interleukin-1beta impairs brain derived neurotrophic factor-induced signal transduction. Neurobiol Aging. 2008;29: 1380–93.
59. Rohleder N, Schommer NC, Hellhammer DH, Engel R, Kirschbaum C. Sex differences in glucocorticoid sensitivity of proinflammatory cytokine production after psychosocial stress. Psychosom Med. 2001;63:966–72.
60. Duclos M, Gouarne C, Bonnemaison D. Acute and chronic effects of exercise on tissue sensitivity to glucocorticoids. J Appl Physiol. 2003;94:869–75.
61. Rimmele U, Seiler R, Marti B, Wirtz PH, Ehlert U, Heinrichs M. The level of physical activity affects adrenal and cardiovascular reactivity to psychosocial stress. Psychoneuroendocrinology. 2009;34:190–8.
62. Traustadóttir T, Bosch PR, Matt KS. The HPA axis response to stress in women: effects of aging and fitness. Psychoneuroendocrinology. 2005;30:392–402.
63. Poole L, Steptoe A, Wawrzyniak AJ, Bostock S, Mitchell ES, Hamer M. Associations of objectively measured physical activity with daily mood ratings and psychophysiological stress responses in women. Psychophysiology. 2011;48(8):1165–72.
64. Jackson SE, Firth J, Grabovac I, Koyanagi A, Stubbs B, Soysal P, Willmott A, Yang L, Smith L. Sedentary behaviour and chronic stress in old age: a cross-sectional analysis of TV viewing and hair cortisol concentrations. Psychoneuroendocrinology. 2019;109:104375.
65. Healy GN, Winkler EA, Owen N, Anuradha S, Dunstan DW. Replacing sitting time with standing or stepping: associations with cardio-metabolic risk biomarkers. Eur Heart J. 2015;36 (39):2643–9.
66. Rethorst CD, Wipfli BM, Landers DM. The antidepressive effects of exercise: a meta-analysis of randomized trials. Sports Med. 2009;39:491–511.
67. Poole L, Hamer M, Wawrzyniak AJ, Steptoe A. The effects of exercise withdrawal on mood and inflammatory cytokine responses in humans. Stress. 2011;14(4):439–47.
68. Kop WJ, Weinstein AA, Deuster PA, Whittaker KS, Tracy RP. Inflammatory markers and negative mood symptoms following exercise withdrawal. Brain Behav Immun. 2008;22:1190–6.
69. Lund AJ, Hurst TL, Tyrrell RM, Thompson D. Markers of chronic inflammation with short-term changes in physical activity. Med Sci Sports Exerc. 2011;43:578–83.
70. Krogh-Madsen R, Thyfault JP, Broholm C, Mortensen OH, Olsen RH, Mounier R, Plomgaard P, van Hall G, Booth FW, Pedersen BK. A 2-wk reduction of ambulatory activity attenuates peripheral insulin sensitivity. J Appl Physiol. 2010;108:1034–40.
71. Weinstein AA, Deuster PA, Kop WJ. Heart rate variability as a predictor of negative mood symptoms induced by exercise withdrawal. Med Sci Sports Exerc. 2007;39:735–41.
72. Anisman H, Merali Z. Cytokines, stress and depressive illness: brain-immune interactions. Ann Med. 2003;35:2–11.
73. Endrighi R, Steptoe A, Hamer M. The effect of experimentally induced sedentariness on mood and psychobiological responses to mental stress. Br J Psychiatry. 2015 Aug 20;208(3):245–51.

Chapter 11
Sedentary Behaviour and Adiposity

Carmen Jochem, Daniela Schmid, and Michael F. Leitzmann

Abstract Obesity is thought to represent an intermediate variable in the pathway linking sedentary behaviour to the development of chronic disease, yet its role in the sedentary behaviour context has not been resolved. A large number of cross-sectional studies, prospective studies, and randomised controlled trials have examined the potential obesogenic effect of prolonged sedentary behaviour in children and adolescents, where television viewing has been the focus of the majority of studies. Although numerous studies have investigated the association between sedentary behaviour and adiposity, the evidence remains unclear whether prolonged time spent sedentary is associated with adiposity in children and adolescents. The association may be partly explained by unhealthy eating behaviour associated with television viewing. Furthermore, the current literature provides insufficient evidence for a positive relation between sedentary behaviour and adiposity among adults. Future prospective studies and randomised controlled trials using device-based measures to assess sedentary behaviour are needed to clarify the role of obesity in the sedentary behaviour context.

What Is New?

- The evidence regarding the association between sedentary behaviour and adiposity in children and adolescents remains inconsistent.

(continued)

C. Jochem (✉) · M. F. Leitzmann
Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany
e-mail: carmen.jochem@ukr.de; michael.leitzmann@ukr.de

D. Schmid
Department of Public Health, Health Services Research and Health Technology Assessment, UMIT – University for Health Sciences, Medical Informatics and Technology, Hall in Tirol, Austria
e-mail: Daniela.Schmid@umit-tirol.at

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_11

- Whereas cross-sectional studies indicate a positive relationship between sedentary behaviour and adiposity in children and adolescents, many prospective studies do not confirm this association.
- Based on randomised controlled trials, there seems to be no evidence for a causal association between sedentary behaviour and adiposity in children and adolescents.
- Evidence for an association between sedentary behaviour and adiposity in adults and elderly adults from observational and interventional studies remains inconclusive.
- Further studies using device-based methods are needed to draw more definitive conclusions about the associations between sedentary behaviour and adiposity in different population groups.

11.1 Introduction

Globally, the prevalence of overweight and obesity in young people and adults is alarmingly high, with approximately 39 million overweight children under 5 years of age and more than 1.9 billion overweight adults, of which over 650 million adults are obese [1–3]. During the past several decades, the number of overweight children and adults has risen dramatically [1]. Low- and middle-income countries have been particularly affected, where the number of overweight children has more than doubled since 1990, from 7.5 million to 15.5 million. The proportion of overweight and obese adults increased from 28.8% to 36.9% between 1980 and 2013 in men and from 29.8% to 38.0% in women, worldwide [1]. In 2016, 39% of men and 40% of women were overweight [3].

According to the Global Burden of Diseases study, approximately 23% children and adolescents in developed countries were overweight or obese in 2013 (compared to 16% in 1980) [1]. In developing countries, approximately 13% boys and girls were overweight or obese in 2013 (compared to 8% in 1980). In developing countries, the rates of overweight and obesity are higher in women, whereas in developed countries, the prevalence of overweight and obesity is higher in men. Considering rates of obesity only, women exhibit higher rates in both developed and developing countries [1]. Whereas rising trends in children's and adolescent's body mass index (BMI) have plateaued at high levels in many high-income countries, trends are accelerating in parts of Asia [4]. Worldwide, overweight or obesity (i.e., a BMI $\geq$ 25 kg/m^2) is responsible for an estimated 160 million global disability-adjusted life-years (DALYs) and 5.02 million deaths [5]. Overweight and obesity increase the risk of a number of chronic diseases, including coronary heart disease, ischemic stroke, type 2 diabetes mellitus, and certain types of cancers [6, 7].

Overweight and obesity during childhood are associated with adult adiposity [8]. Thus, overweight and obesity in children and young people is a global public health issue of great relevance. In 2014, the World Health Organization established the Commission on Ending Childhood Obesity [9] to develop a comprehensive set of recommendations to prevent and address childhood obesity. One of the main recommendations of the commission is to reduce sedentary behaviours and to promote physical activity in children and adolescents.

In the past decade, numerous observational and intervention studies investigated the relation between sedentary behaviour and adiposity. The following chapter provides an overview of the main findings of these investigations, followed by a brief discussion of potential biologic mechanisms involved. For further details on the prevalence and correlates of sedentary behaviour, please refer to Chap. 2.

11.2 Sedentary Behaviour in Relation to Adiposity in Children and Adolescents

Numerous reviews and meta-analyses examined the association between sedentary behaviour and adiposity in children and adolescents [10–36]. A selection of systematic reviews and meta-analyses that have summarised the available information on sedentary behaviour and adiposity in childhood and adolescence published since 2010 is presented in Table 11.1.

11.2.1 Relationship Between Sedentary Behaviour and Adiposity: Evidence from Observational Studies

Numerous observational studies investigated the relationship between sedentary behaviour and adiposity in children and adolescents. The findings of these observational studies have been summarised by various systematic reviews and meta-analyses. In 2017, Biddle and colleagues published an umbrella systematic review of systematic reviews and meta-analyses that aimed to provide a comprehensive overview of the inconsistent literature on sedentary behaviour and adiposity in children and adolescents [19]. Findings from a total of 29 systematic reviews and meta-analyses were summarised. Of these, 19 reviews reported data from observational studies (cross-sectional: $N = 4$; prospective: $N = 5$; both: $N = 10$). In sum, systematic reviews that synthesised results from cross-sectional studies indicated weak positive relations of television viewing and screen time to adiposity in children and adolescents. Furthermore, there was some evidence for a positive association with computer use. However, reviews that summarised the findings from longitudinal studies showed less consistent results—depending on different measures of exposure and outcome used. For both cross-sectional and longitudinal study designs, there seems to be no evidence for an association between total sedentary time and adiposity in children and adolescents when sedentary behaviour was assessed objectively (i.e., using accelerometers).

Table 11.1 Overview of the main findings of recent reviews and meta-analyses of observational studies and intervention trials on the association between sedentary behaviour and adiposity in children and adolescents published between 2010 and 2021

Author, year (Reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
Alanazi et al. (2021) [10]	Systematic Review including 16 studies (9 studies on SB & adiposity: 2 case–control, 7 cross-sectional studies)	5–12 years	Self-/parent-reported or objectively measured	Objectively measured	TV watching; screen time	Six studies showed a positive relationship between SB and adiposity. Three studies found no associations with adiposity outcomes.
Podnar et al. (2020) [11]	Systematic review and meta-analysis including 146 intervention studies (2 SB only interventions; 6 SB + physical fitness interventions; 37 SB + PA interventions)	6–12 years	SB intervention	Objectively measured	SB interventions	Interventions targeting physical fitness + SB were not successful in favourably affecting BMI (SMD = −0.01; 95% CI = −0.09 to 0.07). Interventions PA + SB favourably affected BMI (SMD = −0.07; 95% CI = −0.13 to −0.00), and BMI z-score (SMD = −0.06; 95% CI = −0.09 to −0.03). Overall, including SB to a PA-or physical fitness-intervention did not lead to increases in the effectiveness compared to PA- or physical fitness-only interventions.
		0–7 years			Screen time	

Li et al. (2020) [12]	Meta-analysis and systematic review including 23 studies (9 studies on the association between screen time and adiposity)		Parent-reported or objectively measured	Objectively measured		Screen time exceeding ≥1 h/d or ≥ 2 h/d was associated with overweight/obesity among toddlers and preschoolers. Two studies showed a positive relationship between excessive screen time and sedentary activities.
Shao et al. (2020) [13]	Systematic review including 17 studies from China (12 cross-sectional studies; 2 case-control studies; 3 cohort studies)	6–18 years	Self-/parent-reported	Self-/parent-reported or objectively measured	Screen time, homework, reading, writing, etc.	Most cross-sectional studies (11 out of 12 studies) showed a positive relationship between SB (especially screen-based SB) and adiposity in Chinese children. All case–control studies and two out of three cohort studies showed the same association.
D'Souza et al. (2020) [14]	Systematic review including 28 studies (22 cross-sectional studies; 6 cohort studies); 27 studies included SB	5–12 years	Self-/parent-reported or objectively measured	Self-/parent-reported or objectively measured	All sedentary behaviours, PA, diet, and sleep	Clustering unhealthy lifestyle patterns (high SB, low PA, unhealthy diet) was often associated with increased risk of adiposity compared to healthy and mixed patterns.
		3–18 years	SB intervention	Objectively measured	Prolonged sedentary time (the duration of sedentary	More prolonged sedentary time > 15 minutes

(continued)

Table 11.1 (continued)

Author, year (Reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
Wijndaele et al. (2019) [15]	Meta-analysis including cross-sectional data from 14 studies				time accumulated in bouts >15 minutes and > 30 minutes	was associated with higher standardised BMI and waist circumference. However, these associations disappeared after adjustment for MVPA.
Marker et al. (2019) [16]	Meta-analysis including 15 studies on children and adolescents	Children and adolescents	Self-/parent-reported or objectively measured	Self-/parent-reported or objectively measured	Sedentary video gaming	There was no statistically significant relationship between non-active video game use and body mass in adolescents, $\hat{\rho} = 0.01$, 95% CI [−0.21, 0.23], or children, $\hat{\rho} = 0.09$, 95% CI [−0.07, 0.25].
Zabatiero et al. (2018) [17]	Systematic review and meta-analysis including 4 studies in children	Overweight or obese children aged between 6 and 12 years	Objectively measured	Objectively measured	All sedentary behaviours	Interventions aimed at reducing SB significantly reduced BMI in children with overweight or obesity (SMD = −0.09; 95% CI = −0.18 to −0.00).
Poitras et al. (2017) [18]	Systematic review including 60 studies with adiposity as health outcome (13 cohort studies; 2 case-	0–4 years	Self-/parent-reported or objectively measured	Self-/parent-reported or objectively measured	All sedentary behaviours (especially screen time)	Associations between objectively measured total sedentary time and adiposity were predominantly null. Associations

	control studies; 47 cross-sectional studies; 1 RCT)					between screen-based SB and adiposity were largely null or unfavourable.
Biddle et al. (2017) [19]	Systematic review of 29 systematic reviews and meta-analyses (including both observational and intervention studies)	≤18 years	Self-reported or objectively measured	Self-reported or objectively measured	All sedentary behaviours	Small associations between SB and adiposity from cross-sectional evidence, but less evidence for an association between SB and adiposity from longitudinal studies. Objectively measured SB showed no association with adiposity. There is no evidence for a causal association between SB and adiposity in children and adolescents.
Van Ekris et al. (2016) [20]	Meta-analysis including 9 cohort studies	≤18 years	Self-/parent-reported or objectively measured	Objectively measured	TV watching; screen time	TV watching: Pooled effect for each additional hour of baseline TV viewing per day was not significantly related to follow-up BMI ($\beta = 0.01$, 95% CI = [−0.002 to 0.02]).
	Meta-analysis including 5 cohort studies	≤18 years	Self-/parent-reported or objectively measured	Objectively measured	computer use/game time	Computer use/game time: Pooled effect for each additional hour of baseline computer use per day was not

(continued)

Table 11.1 (continued)

Author, year (Reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
						significantly related to follow-up BMI ($\beta = 0.00$, 95% CI = [−0.004 to 0.01]. No evidence for a relationship with BMI/BMI z-score or WC/WC z-score.
Cliff et al. (2016) [21]	Meta-analysis including 27 cross-sectional studies and 13 prospective studies	2–18 years	Objectively measured	Objectively measured	Total sedentary time	Pooled effect size based on cross-sectional studies: $r = 0.07$ (95% CI = 0.00–0.13).
Azevedo et al. (2016) [22]	Meta-analysis including 67 randomised controlled trials and non-randomised controlled trials (6 SB only interventions; 10 SB + PA interventions; 51 SB + other behaviour interventions)	0–17 years	SB intervention	Objectively measured	SB intervention	Pooled mean reduction in BMI and BMI z-score in mixed-weight populations: standardised mean difference = −0.060 (95% CI = −0.098 to −0.022). Pooled estimate for an overweight or obese population: standardised mean difference = −0.255 (95% CI = −0.400 to −0.109).
Zhang et al. (2015) [23]	Meta-analysis including 14 cross-sectional studies	1–18 years	Self-reported	Objectively measured or	TV watching	OR of childhood obesity for highest vs. lowest time of TV watching

				self-reported		1.47 (95% CI = 1.33–1.62). Boys: OR 1.30 (95% CI = 1.16–1.45) Girls: OR 1.26 (95% CI = 1.11–1.41) Linear dose–response relation for TV watching and childhood obesity ($P < 0.001$) (12 studies included); risk increased by 13% for each 1 h/day increment in TV watching.
Tanaka et al. (2014) [24]	Review including 3 longitudinal studies	Data not provided	Objectively measured	Objectively assessed	All sedentary behaviours	Little evidence on the influence of changes in sedentary behaviour on changes in adiposity (inconsistent findings of the 3 underlying studies)
Liao et al. (2014) [25]	Meta-analysis including 25 randomised controlled trials (5 SB only interventions; 10 SB + PA interventions; 10 SB + PA + diet interventions)	≤18 years	SB intervention	BMI; BMI z-score	TV watching and other screen-based activities	Mean BMI reduction for the intervention groups was 0.10 kg/m^2 greater compared to the control groups. Effect sizes were not significantly different from zero for SB only interventions ($g = -0.154$, $p = 0.129$), SB + PA interventions ($g = -0.089$, $p = 0.125$), and SB + PA + diet

(continued)

Table 11.1 (continued)

Author, year (Reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
						interventions ($g = -0.060$, $p = 0.214$).
Pate et al. (2013) [26]	Review including 4 prospective cohort studies	5–18 years	Objectively measured	Objectively assessed	All sedentary behaviours	Limited prospective evidence yields mixed findings on whether sedentary behaviour is associated with excessive fatness in children and adolescents.
LeBlanc et al. (2012) [27]	Review including 9 prospective cohort studies +1 randomised trial	0–4 years	Parent-reported	Objectively assessed	TV watching	Low- to moderate-quality evidence to suggest that increased TV watching is associated with unfavourable measures of adiposity.
Prentice-Dunn et al. (2012) [28]	Review including 9 cross-sectional studies	1–18 years	Self-/parent-reported or objectively measured	Self-/parent-reported or objectively measured	TV watching; overall screen time; playing electronic games; PC use; internet use; cell phone use	Seven of nine studies assessing sedentary behaviours found a positive correlation with child weight status.
Schmidt et al. (2012) [29]	Review including 18 intervention studies measuring BMI	<12 years	Self-/parent-reported	Objectively assessed	TV viewing; video games; computer use; internet use	9 studies reported reductions in BMI for the intervention group compared to the control group.
Leung et al. (2012) [30]	Review including 12 intervention studies	6–19 years	Self-reported	No detail reported	Media use; other SB	One of the 3 SB intervention studies reported

	(3 SB only interventions; 1 PA intervention; 6 SB + PA interventions; 2 SB + PA + diet interventions)					on anthropometric measures and showed that compared to controls, intervention group had significant decreases in anthropometric measures, such as BMI (−0.45 kg/m^2; $P = 0.002$) and triceps skinfold thickness (−1.47 mm; $P = 0.002$). Interventions that focused on decreasing SB, whether alone or in combination with other strategies, such as increasing PA and improving diet, were associated with improvements in anthropometric measurements related to childhood obesity
van Grieken et al. (2012) [31]	Meta-analysis including 34 intervention studies (4 controlled trials; 30 randomised controlled trials)	0–18 years	Not reported	Not reported	Screen time activities and other sedentary behaviours (e.g., listening to music, reading)	6 of the 34 studies reported a significant effect of the intervention on BMI (kg/m^2) or BMI-z score. Post-intervention BMI: mean difference of −0.25 kg/m^2 (95% CI = −0.40 to −0.09) in favour of the intervention group. Post-intervention

(continued)

Table 11.1 (continued)

Author, year (Reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
						change-from-baseline: mean difference was −0.14 kg/m^2 (95% CI = −0.23 to −0.05) in favour of the intervention group. No significant differences in effects on BMI between single and multiple health behaviour interventions.
Costigan et al. (2012) [32]	Review including 14 cross-sectional studies and 6 longitudinal studies	12–18 years (girls)	Self-reported or objectively measured	Self-reported or objectively measured	TV watching; electronic gaming; computer use; video time; overall SB	Strong evidence for a positive relation between screen-based SB and weight status (i.e., increased BMI/body fatness, increased risk of overweight/obesity, increased odds of obesity).
te Velde et al. (2012) [33]	Review including 7 prospective studies	4–6 years	Parent-reported or objectively measured	Objectively measured	TV watching; video/computer time	Moderate evidence for a positive relation between TV watching/video/computer time and overweight.
Tremblay et al. (2011) [34]	Review + meta-analysis including 8 randomised controlled trials,	5–17 years	Self-/parent-reported or	Self-/parent-reported or	TV watching; overall screen time; playing electronic games; PC use	Effect of −0.89 kg/m^2 (95% CI = −1.67 to −0.11, $p = 0.03$) decrease

	10 intervention studies, 33 longitudinal studies, 119 cross-sectional studies		objectively measured	objectively measures		in mean BMI in the intervention group. > 2 hours of sedentary behaviour per day is associated with an increased risk for overweight/obesity. This risk increases in a dose-response manner. Each additional hour of TV viewing increased risk for obesity >2 hours/day significantly increased risk for overweight/obesity.
Chinapaw et al. (2011) [35]	Review including 26 prospective studies	Mean age at baseline varied from 3 years up to around 17 years old; Mean age at follow-up varied from 5–6 years to around 32 years old	Self-/parent-reported or objectively measured	Self/parent-reported or objectively measured	TV watching; computer use	Insufficient evidence for a longitudinal relation between self- or proxy-reported sedentary time and indicators of fat mass.
Wahi et al. (2011) [36]	Meta-analysis including 6 randomised controlled trials	≤18 years	No detail reported	No detail reported	Interventions focussed on reducing screen time	The difference in mean change in BMI in the intervention group compared with the control group was −0.10 (95% CI = −0.28 to 0.09).

Abbreviations: *BMI* body mass index, *CI* confidence interval, *PA* physical activity, *SB* sedentary behaviour, *MetS* metabolic syndrome, *MVPA* moderate-to-vigorous intensity physical activity, *SMD* standardised mean difference

To provide more detailed information, the results of selected systematic reviews and meta-analyses including observational studies will briefly be described here.

A large systematic review by Tremblay et al. found that 94 of 119 cross-sectional studies reported that greater amounts of sedentary time were related to increased risk of adiposity in school-aged children and adolescents [34]. Based on a dose–response analysis of television watching time and overweight/obesity, the review concluded that >2 hours of television viewing per day is associated with an increased risk for developing adiposity. Similarly, a review by Costigan et al. observed a positive relation between screen-based sedentary behaviour and body weight in 11 of 12 cross-sectional studies in adolescent girls, particularly for screen time exceeding 2 hours per day [32].

A meta-analysis by Zhang et al. of 14 cross-sectional studies in children and adolescents (age range 1–18 years) compared the highest with the lowest categories of television watching and reported a pooled odds ratio (OR) of adiposity of 1.47 (95% confidence interval (CI) = 1.33–1.62) [23]. When stratified by sex, a positive relation between television watching and adiposity was apparent in both boys (OR = 1.30, 95% CI = 1.16–1.45) and girls (OR = 1.26, 95% CI = 1.11–1.41). Also, effect estimates were similar among preschool children and school children. In linear dose–response analyses, each 1 h per day increment in television watching was associated with a 13% increased risk of adiposity.

In a systematic review of cross-sectional studies, Cliff et al. reported that 11 of 48 studies reported a significant positive association between objectively assessed sedentary behaviour and adiposity in children [21]. Their meta-analysis of 27 cross-sectional studies yielded a weak but statistically significant positive relation between the two ($r = 0.07$, 95% CI 0.00 to 0.13, $p = 0.024$). However, a large degree of heterogeneity between studies was noted, and statistical significance of the pooled risk estimate remained evident only in lower quality studies and those that were not adjusted for physical activity. Prentice-Dunn et al. [28] reviewed the data from nine cross-sectional studies and noted a positive association between sedentary behaviours and child weight status in seven studies that relied on self-reported sedentary behaviour, but found no relation in two studies that used objective sedentary behaviour data. The heterogeneous findings according to study quality and mode of sedentary behaviour assessment in those studies highlight the challenge in accurately capturing sedentary behaviour levels and the need to address potential confounding by unhealthy diet or insufficient physical activity.

The aforementioned review of cross-sectional studies by Prentice-Dunn and colleagues also summarised the sparse data on sedentary behaviours other than television viewing, such as playing video games, internet use, and cell phone use [28]. According to that review, three studies revealed a positive association between playing video games and adiposity [37–39], whereas one study found no association between PC use and weight [40]. One study also reported that cell phone use was not associated with adiposity unless cell phones were used to play video games [41]. That study [41] also showed a positive association between internet use and BMI in adolescents. Due to the limited number of studies that investigated the association between sedentary behaviours other than television watching and adiposity in children and adolescents, there is a need for further studies—especially of prospective design—to draw firm conclusions regarding the relation of sedentary behaviours other than television viewing to adiposity.

In addition to the impact of total sedentary time on risk for adiposity, the way sedentary time is accumulated may also be relevant. Five of six cross-sectional studies reviewed by Cliff et al. showed no statistically significant association between number of breaks in sedentary behaviour and adiposity [21]. However, one cross-sectional study [42] found that breaks in sedentary time and the number of sedentary bouts lasting 1–4 min were inversely related to BMI in children with a family history of obesity. More research is needed to determine whether avoiding prolonged uninterrupted periods of sedentary time provides protection from risk of developing obesity.

Furthermore, a meta-analysis that investigated the associations between objectively assessed sedentary behaviour and metabolic syndrome in more than 6000 children and adolescents in cross-sectional analyses showed that an increase of one hour in sedentary time per day was positively associated with the metabolic syndrome (OR = 1.28; 95% CI = 1.13–1.45) [43]. However, that association was attenuated and was rendered statistically non-significant after adjustment for moderate-to-vigorous intensity physical activity (OR = 1.14; 95% CI = 0.96–1.36).

Taken together, findings from cross-sectional studies (and from reviews summarising those studies) suggest a weak positive association between sedentary behaviour—particularly television watching in excess of 2 hours per day—and adiposity in children. However, numerous issues need to be kept in mind when interpreting the findings of those studies. Importantly, analyses were based on cross-sectional study designs that are unable to assess the directionality of the relation of sedentary behaviour to obesity; thus, the temporal relation is unclear, i.e., which came first. Also, investigations on television watching were self-reported, which may have contributed to measurement error in those studies. In addition, the cut-points for weight status and BMI were not entirely consistent across studies, making it challenging to compare and synthesise the results.

In addition to cross-sectional studies on the relationship between sedentary behaviour and adiposity in children and adolescents, a large number of prospective studies investigated this relationship and have been summarised by systematic reviews and meta-analyses.

In addition to the synthesised results of the comprehensive review by Biddle and colleagues, the results of selected systematic reviews and meta-analyses including prospective studies will briefly be described here. According to an early systematic review by Tremblay et al. of studies in children and adolescents (age range 5–17 years), 19 of 28 prospective studies found a positive association between sedentary time and risk of adiposity [34]. Consistent with this, a review by Costigan et al. of studies on girls aged 12–18 years reported a positive relation of screen-based sedentary behaviour to body weight in all six prospective studies considered [32]. A more recent meta-analysis by van Ekris et al. of studies in children less than 18 years of age combined the data from nine prospective studies and reported a statistically non-significant association between television viewing and adiposity. Likewise, the summary estimates from five prospective studies yielded no relation between computer use/game time and objectively assessed total sedentary time. However, when combining all different sedentary measures, there was evidence for a positive association with adiposity [20].

A number of studies prospectively examined the association between television watching and adiposity in toddlers and preschoolers. One systematic review by LeBlanc et al. [27] and another by te Velde et al. [33] summarised the data from prospective studies that examined the association between television watching, computer use, or computer/video gaming and measures of adiposity in toddlers and preschoolers and found low-to-moderate evidence that increased screen time is associated with greater adiposity.

A number of studies prospectively examined the association between sedentary behaviour and subsequent change in adiposity. One observational study [44] prospectively investigated the association between television watching and body fat change in children from preschool to early adolescence. By age 11, those who watched 3 or more hours of television per day as preschoolers had greater subsequent increases in body fat than those who watched less than 1.75 h of television per day. Results remained robust after controlling for baseline body fat and level of physical activity. Similarly, a prospective study found that television viewing among 3- to 4-year-olds was positively related to BMI assessed at 3 years of follow-up [45]. In contrast, a prospective study of children aged 0–6 years [46] found that increased television watching was related to increased adiposity, but that association was no longer apparent when commercialised television viewing was controlled for, suggesting that the increase in adiposity was explained by the content of the television (i.e., advertisements) and not the sedentary behaviour itself. As summarised by an early systematic review by Chinapaw et al. of 26 prospective cohort studies in children aged 3–17 years at baseline, there is insufficient evidence for a positive relation of sedentary time to markers of adiposity [35]. Focusing on high quality studies, Chinapaw et al. noted that only four of six studies on BMI and two of four studies on waist circumference, fat percentage, or skinfold thickness found a significant positive relation of sedentary time to indicators of fat mass.

Two subsequent reviews, one by Tanaka et al. [24] and the other by Pate et al. [26], summarised the data from prospective studies that used objective measures of sedentary behaviour. Two individual studies [47, 48] found no relation between sedentary time and change in adiposity. Similarly, one prospective study showed a null association between changes in sedentary time and changes in BMI or body fat mass [49]. In contrast, one prospective study found a statistically significant relation of increased sedentary behaviour to increased BMI at the 90th, 75th, and 50th percentiles between ages 9 and 15 years, independent of moderate-to-vigorous physical activity [50]. Another prospective study reported a borderline significant relation of increased time spent sedentary to increased BMI in girls but detected no association in boys [51]. The observed heterogeneity in the results of those studies may be due to differences in statistical modelling of the data, variation in the assessments of adiposity, and differences in covariates included in the models.

Since the publication of the comprehensive review of reviews by Biddle and colleagues [19], further systematic reviews and meta-analyses have summarised the relationship between sedentary behaviour and adiposity (see Table 11.1). However, those reviews and meta-analyses often included many older studies. Thus, their findings vary and the overall evidence remains inconsistent.

Taken together, there is limited prospective evidence for a relation of sedentary time or changes in sedentary time to changes in adiposity in children and adolescents.

11.2.2 Relationship Between Sedentary Behaviour and Adiposity: Evidence from Intervention Studies

Findings of intervention studies on the relation between sedentary behaviour and adiposity in children and adolescents have been summarised by various systematic reviews and meta-analyses. The systematic review of reviews and meta-analyses by Biddle and colleagues included ten reviews that focused on intervention studies [19]. Out of these, six reviews showed that sedentary behaviour interventions caused favourable changes in weight status, whereas four reviews reported inconsistent or null effects. To provide more detailed information, the results of selected systematic reviews and meta-analyses including intervention studies will briefly be described here. A meta-analysis by Azevedo et al. [22] included 67 trials and found that sedentary behaviour interventions led to a small but statistically significant reduction in BMI (standardised mean difference = −0.060 (95% CI = −0.098 to −0.022), with a more pronounced BMI reduction in overweight or obese children (standardised mean difference = −0.255, 95% CI = −0.400 to −0.109). A meta-analysis by Liao et al. [25] included 25 RCTs and reported a small but statistically significant effect of sedentary behaviour interventions on BMI reduction when studies on sedentary behaviour were combined with other interventions, including physical activity and diet (Hedge's $g = -0.073$, $p = 0.021$) but not for single sedentary behaviour interventions. By comparison, van Grieken et al. [31] in a pooled analysis of 34 intervention studies found a statistically significant BMI difference of -0.25 kg/m^2 (95% CI = −0.40 to −0.09) in favour of the intervention group for single sedentary behaviour interventions as well as for multiple health behaviour interventions. Tremblay et al. [34] combined the data from 4 RCTs and showed that interventions aimed at reducing sedentary behaviour showed a statistically significant effect on BMI reduction (-0.89 kg/m^2, 95% CI = −1.67 to −0.11). In a review of intervention studies that explored effective strategies for reducing screen time in various settings, Schmidt et al. [29] reported that nine of 18 intervention studies found a positive effect of reduced screen time on lowering BMI. This is consistent with a review by Leung et al. [30] of 12 intervention studies that reported a beneficial impact of decreasing sedentary behaviour on markers of adiposity in school-age youth.

It is important to note that most of the individual studies summarised in the above reviews and meta-analyses targeted sedentary behaviour alongside other behaviours, such as physical activity, diet, sleep, breastfeeding, or motor skills. Thus, those studies focused on the effect of multicomponent interventions and not on sedentary behaviour only. Therefore, it remains unclear whether the observed decrease in BMI reduction was due to reduced sedentary behaviour, increased physical activity, enhanced diet, or any combination thereof. It is worth pointing out that a meta-analysis by Wahi et al. [36] included six RCTs on the effect of sedentary behaviour reduction on BMI change, five of which did not have a co-intervention and found no significant BMI change (-0.10 kg/m^2 (95% CI $= -0.28$ to 0.09). Taken together, behaviour change interventions that also include a reduction in sedentary behaviours show modest effects on BMI reduction in children, but interventions that focus solely on reducing screen time may not be effective, and additional behaviours (i.e., diet and physical activity) may need to be targeted to generate significant decreases in weight.

11.2.3 Evidence Regarding the Causality of the Association Between Sedentary Behaviour and Adiposity

The inconsistency of results regarding the association between sedentary behaviour and adiposity in children and adolescents raises the question of whether and to what degree the association can be considered causal. In order to address this question, Biddle and colleagues used the Bradford Hill criteria [52] and assessed the strength of association, consistency, specificity, temporality, coherence and biological plausibility, dose-response, and experimental evidence in the reviews and meta-analyses included in their review of reviews [19]. Although these criteria might be helpful in judging causality, they may not be considered conclusive.

First, they reported weak support regarding the (consistently low) strength of association between sedentary behaviour and adiposity in children and adolescents from both observational and intervention studies. Second, the consistency of the evidence across different populations and different settings was reported to be moderate to weak, with stronger evidence for an association in children than adolescents. However, this could be explained by the larger number of studies conducted in children than adolescents, as well as by the influence of maturation and associated confounding measures of adiposity. Weak consistency was reported for measures of sedentary behaviour and markers of adiposity. Also, there was inconclusive evidence regarding sex differences. Third, Biddle and colleagues concluded that there is no evidence for specificity (i.e., whether adiposity is mainly limited to the presence of sedentary behaviour). However, this criterion is not very meaningful because adiposity is influenced by several factors. Fourth, the evidence for temporality (i.e., whether sedentary behaviour precedes the development of adiposity) was classified as weak because of mixed results from prospective studies.

Fifth, it was considered plausible and coherent with current knowledge that sedentary behaviour and the corresponding low energy expenditure could be obesogenic. However, because of the co-existence of different behaviours (e.g., TV viewing, dietary patterns, physical activity) and their potential moderating effects, the authors reported moderate evidence regarding coherence and biological plausibility. Sixth, Biddle and colleagues reported that there was evidence for a dose-response relationship (i.e., whether higher levels of sedentary behaviour are related to higher levels of adiposity), although the magnitude of this dose-response association seems to be small. Finally, experimental evidence for an effect of sedentary behaviour on changes of adiposity was judged to be weak. Certain subpopulations (such as obese children and adolescents) appeared to show stronger benefits in experimental designs.

In sum, and based on the criteria, Biddle and colleagues concluded that there is no evidence for a causal association between sedentary behaviour and adiposity in children and adolescents.

11.3 Sedentary Behaviour in Relation to Adiposity in Adults

The volume of information from reviews and meta-analyses of sedentary behaviour in relation to adiposity in adults [53–60] is less abundant than that in children and adolescents. Generally, there is less consistency in the evidence for an association between sedentary behaviour and adiposity in adults and the elderly. A selection of studies that summarised the available information on sedentary behaviour and adiposity in adults published since 2010 is presented in Table 11.2.

11.3.1 Relationship Between Sedentary Behaviour and Adiposity: Evidence from Observational Studies

In their umbrella review from 2017, Biddle et al. evaluated ten systematic reviews of observational and interventional studies related to the sedentary behaviour and obesity relation in adults [64]. Overall, the authors concluded that the available data support limited evidence for a positive association between sedentary behaviour and adiposity in adults, yet most studies showed weak associations. Their conclusion from reviews of observational studies indicates some evidence for an association between adiposity and sedentary behaviour, largely screening time, although this remains mainly inconclusive. Clearer associations were found for cross-sectional self-report studies than longitudinal studies and studies using device-based measures. Some evidence was apparent for breaks in sedentary time in relation to a more favourable BMI, and for use of a car and adiposity.

Table 11.2 Overview of the main findings of reviews and meta-analyses of observational studies and intervention trials on the association between sedentary behaviour and adiposity in adults

Author, year (reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
Hadgraft et al. (2021) [61]	52 intervention studies	≥18 years	SB intervention	Weight, BMI, WC, BF, FM	SB interventions 2 weeks and < 6 months; replacements for sedentary behaviour include primarily standing, walking, or other stepping, but also sometimes pedalling, 'incidental' exercise (likely predominantly light activities), activities of moderate or greater intensity and sometimes resistance exercise	Statistically significant pooled effects for body weight, waist circumference, and body fat percentage, and a trend towards reduced fat mass; non-statistically significant effect for BMI
Guo et al. (2019) [62]	6 cohort studies and 15 cross-sectional studies	≥18 years	Self-reported or objective	Overweight/obesity (defined according to body mass index [BMI])	Total SB and television viewing	A non-linear association between total SB and TV viewing and overweight/obesity was found. The pooled RRs for overweight/obesity for the highest versus lowest category of total SB and TV viewing were 1.38

						(95% CI 1.22–1.56) and 1.62 (95% CI 1.22–2.14), retrospectively
Campbell et al. (2018) [63]	31 prospective cohort studies. For the qualitative review; 23 prospective cohort studies for the meta-analysis and one randomised controlled trial	Adults >18 years	SB intervention	Body weight, BMI, risk of overweight (≥25 kg/m^2) or obesity (≥30 kg/m^2), waist circumference	SB was defined as wakeful seated behaviours—either upright or reclined—associated with low energy expenditure (1.5 metabolic equivalents or less) and included sitting time, TV viewing, screen time, commuting time, reading and occupational sitting; the intervention included decreases in SB, other lifestyle modifications, such as diet were possible	A significant pooled odds ratio for high versus low SB in relation to becoming overweight or obese was 1.33, 95% CI 1.11–1.60, based on six studies. Significant associations for change in SB (1 h/day increment from baseline to end of follow-up) with a very small 5-year change in waist circumference; a borderline statistically significant association between each additional hour per day change in sedentary time (over a 5-year follow-up) and change in body weight over that time; results were not essentially different for TV viewing
Biddle et al. (2017) [64]	Review of 10 systematic reviews	Adults ≥18 years	Self-reported or objective	Body weight, weight gain, BMI, waist	Total SB or domain- or type-specific sedentary	Cross-sectional observational studies

(continued)

Table 11.2 (continued)

Author, year (reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
				circumference, risk for overweight or obesity, waist-hip-ratio	behaviour (e.g., occupational sitting, TV viewing time)	showed some association between self-reported screen time (mainly TV viewing) and adiposity, but this remains inconclusive; for older adults, a small association between SB and weight status has been observed. No association was found for sedentary behaviour assessed by device-based measures and adiposity in adults; Insufficient evidence is available for sedentary behaviour and adiposity from longitudinal studies during adulthood
O'Donoghue et al. (2016) [65]	25 observational studies	Adults 18–65 years	Self-reported or objective	BMI	Total sitting time, two studies reported accelerometer data, heart rate, occupational sitting time	Seventeen showed a positive association while the others reported no association.

						The two studies that used accelerometry indicated no significant association between total sedentary time and BMI while most of the remaining studies showed a positive association. That the higher the BMI, the higher the level of sedentariness. Two studies reported a positive association between occupational sitting and BMI
Wirth et al. (2016) [53]	Review including 3 randomised controlled trials, 1 prospective study, 11 cross-sectional studies	Older adults (mean age of study sample 2′:60 years)	Self-reported or objective	BMI	Waking behaviour with an energy expenditure $ 1.5 METs whilst in a sitting or reclining posture	Mixed evidence for an association between sedentary behaviour and BMI (nine studies demonstrated a positive association)
	Review including 4 randomised controlled trials, 1 prospective study, 10 cross-sectional studies			WC		Generally no evidence for an association (eight studies demonstrated a positive association)
Chastin et al. (2015a) [54]	Review including one longitudinal study and 7 cross-sectional studies	≥65 years	Self-reported or objective	BMI, WC, BF, body weight; self-reported or objective	Total sedentary time (e.g. min/day) or time spent in sedentary domains such as	Obese adults reported greater levels of SB or TV viewing [30]. Estimated effect size

(continued)

Table 11.2 (continued)

Author, year (reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
					watching TV, screen time, occupational sitting time, time	reported were 2.5% [32] and 3.5% [66] more sedentary time and 50% higher odd ratio of TV time [30] for obese individuals
Chastin et al. (2015b) [67]	7 cross-sectional studies	≥21 years	Objective measures	BMI, WC	Breaks in total SB	A suggestive association was found for sitting breaks and BM; the results were less homogeneous und uncertain for WC
McCormack and Virk, (2014) [68]	Ten studies	≥16 years	Mostly self-reported	Mostly BMI	Time or distance travelling in a motor vehicle travel	8 out of 10 studies found a significant positive association between time or distance travelled in a motor vehicle and adiposity
Neuhaus et al. (2014) [69]	6 intervention studies	≥18 years	Overall and workplace sedentary time (assessed by device-based measures and self-reports)	Weight, BMI, WC	Workplace interventions using activity-permissive desks	Improvements were found for WC in 5 out of 6 intervention studies, but no change for other outcomes
	Review including six cross-sectional studies	2′:60 years	Self-reported or objective	Overweight/obesity		Five studies showed a positive association

de Rezende et al. (2014) [55]					Sedentary behaviour; TV watching; sitting in cars	between sedentary behaviour(s) and overweight/obesity. One study found no association between sitting >1 h/day in a car and overweight/obesity.
	Review including six cross-sectional studies			WC/WHR/abdominal obesity (self-reported or objectively measured)	Sedentary behaviour; TV watching	Five studies showed a positive relation between sedentary behaviour(s) and WC/WHR/abdominal obesity. One study found no association
Rhodes et al. (2012) [56]	Review including 32 cross-sectional studies and 10 prospective studies	Adults	Self-reported	Self-reported or objective	TV watching; computer use; leisure-time reading	TV watching: 16 of 28 studies showed a positive association between BMI and TV viewing. Computer use: two of four studies showed a positive association between computer use and BMI. Leisure-time reading: three studies found no association between leisure-time reading and BMI
Proper et al. (2011) [57]	Review including four prospective studies	Adults	Self-reported	Self-reported		Insufficient evidence for a positive relation

(continued)

Table 11.2 (continued)

Author, year (reference)	Type of publication and number and type of included studies	Age of participants	Assessment of sedentary behaviour	Assessment of adiposity	Type of sedentary behaviour	Main findings
					TV viewing; occupational sitting; sedentary behaviours	between sedentary behaviour and risk of overweight or obesity
Thorp et al. (2011) [58]	Review including 24 prospective studies	Adults	Self-reported or objective	Self-reported or objective	Sedentary behaviour	Limited evidence for a positive relation between sedentary behaviour and obesity; reasonable evidence that sedentary behaviour during childhood and adolescence predicts adulthood obesity
Van Uffelen et al. (2010) [59]	Review including ten cross-sectional studies and three prospective studies	Adults	Self-reported	Self-reported and objective	Occupational sitting	Five cross-sectional studies showed a positive relation between occupational sitting and BMI (four studies found no association, and one study showed an inverse association); one prospective study showed a positive relation, but two prospective studies found no association

SB sedentary behaviour, *BMI* body mass index, *WC* waist circumference, *WHR* waist-to-hip ratio, *BF* body fat, *FM* fat mass, *CI* confidence interval, *MET* metabolic equivalent.

A recent meta-analysis of prospective cohort studies and one randomised controlled trial by Campbell et al. showed small, inconsistent, and non-significant associations between sedentary behaviour and body weight [63]. However, the pooled ORs for high versus low sedentary behaviour in relation to becoming overweight or obese reached statistical significance (OR = 1.33, 95% CI 1.11–1.60, based on six studies). Based on the results of five studies, change in sedentary behaviour (1 h/day increment from baseline to the end of follow-up) was associated with a small but statistically significant 5-year change in waist circumference. Further, results from three studies showed a borderline statistically significant association between each additional hour per day change in sedentary time (over a 5-year follow-up) and change in body weight over that time. The randomised controlled trial reported no differences between changes in weight, BMI, and waist circumference between the intervention and control groups after 12 months of follow-up [63].

Another review by Proper et al. [57] also found insufficient evidence for a positive relation between self-reported sedentary behaviour and risk of overweight or obesity. Likewise, there is limited support for a relation of self-reported sedentary behaviour to subsequent weight gain in adults. The authors concluded that there is limited evidence for a longitudinal association of weight gain with risk of obesity.

One review by Rhodes et al. [56] summarised the data from 42 studies (32 cross-sectional studies and ten prospective studies) on different types of sedentary behaviour in relation to BMI in adults. Results showed that 19 of 28 studies reported a positive association between television viewing and BMI, three of which supported a relation in women but not men. In addition, screen viewing was associated with higher BMI in four studies, one of which supported a relation in women but not men. Further, two of four studies on computer use were positively related to BMI. In contrast, eight studies on sitting and three studies on leisure-time reading detected no association with BMI. Taken together, these findings provide some evidence for a positive relation of television and screen viewing to BMI in adults, but the associations with other sedentary behaviours appear weak.

Several systematic reviews and individual studies investigated the potential obesogenic effect of TV viewing specifically. O'Donoghue et al. [65] evaluated 25 papers on sedentary behaviour and BMI, with most of these investigating self-reported leisure screen time. Two thirds of those papers showed a positive association with BMI, while the remaining ones showed no association. Two studies using accelerometers reported no significant association between total sedentary time and BMI. Two studies reported that occupational sitting was related to a higher BMI. A systematic review by Thorp et al. [58] of 24 prospective studies used TV viewing, watching videos, using a computer, playing video games, or driving a car as exposures and used BMI, obesity, weight gain, weight maintenance, or a measure of body fat distribution (i.e., waist circumference) as endpoints. Results showed that only six of eleven prospective studies reported a positive relation of self-reported time spent in sedentary behaviour to risk for obesity. Of those six positive studies, two studies exhibited an attenuation of the formerly statistically significant association following adjustment for baseline BMI, which may be explained by the shorter duration of follow-up in those studies; one study displayed a significant association only among those with normal weight at study baseline, suggesting that sedentary behaviour and weight gain in adults are mutually reinforcing and that initial weight status may represent a significant determinant of the amount of weight gained during follow-up. Specifically, Thorp et al. [58] found a positive association between sedentary behaviour and weight gain in eight of twelve studies, only five of which remained evident after adjustment for physical activity. Examples from individual studies revealed similar positive associations with adiposity. For example, the Nurses' Health Study [70] found that each 2 hour per day increase in television viewing was associated with a 23% increased risk of obesity in women over six years of follow-up, regardless of physical activity level, dietary factors, and other covariates. Likewise, the Australian Diabetes, Obesity, and Lifestyle Study (AusDiab) reported that an increase in television viewing over five years was significantly associated with an increase in waist circumference, irrespective of physical activity level [71]. Some studies showed a positive association between television viewing and BMI or waist circumference [72–75] that was attenuated after controlling for BMI [73], physical activity [74], dietary factors [75], and other covariates [75].

In a recent dose-response meta-analysis [62], 21 observational studies were summarised to assess possible linear or non-linear associations of total sedentary behaviour or TV viewing with overweight/obesity. The pooled relative risks for overweight/obesity for the highest versus lowest category of total sedentary behaviour or TV viewing were 1.38 (95% CI: 1.22–1.56) and 1.62 (95% CI: 1.22–2.14), respectively. Furthermore, non-linear associations for overweight/obesity with total sedentary time and TV viewing time were observed.

A systematic review by van Uffelen et al. [59] examined the relation between occupational sitting time and BMI based on 12 observational studies (nine cross-sectional studies, two prospective studies, and one study with both cross-sectional and prospective data). Five of the ten cross-sectional studies revealed a positive association between sitting at work and BMI, of which two studies reported a statistically significant positive relation in men, but not women. Four studies found no association and one study reported an inverse relation. Two of the three prospective studies observed no association between occupational sitting time and BMI. The third prospective study reported that each two hour per day increment in sitting at work was suggestive of increasing risk of obesity. However, the association with obesity across different levels of sitting at work was only statistically significant for sitting beyond 40 hours per week as compared with less than one hour of sitting. It is worth noting that a large proportion of studies included in the review [59] combined sedentary behaviour with physical activity categories. Results from such studies fail to represent the true association between sedentary behaviour and adiposity because a proportion of the sedentary behaviour risk estimate may be explained by the inverse of the decreased adiposity risk brought about by physical activity [76].

One review summarised seven cross-sectional studies and three longitudinal studies [68] related to motor vehicle travel time and weight status. Of these, two longitudinal studies and six cross-sectional studies found a positive association between vehicle use and the risk of overweight and obesity, although the strength of association was not reported.

A small but growing body of data suggests that engaging in sedentary behaviour during childhood or adolescence is a predictor of obesity in adulthood. Specifically, four prospective studies reviewed by Thorp et al. [58] consistently found that sedentary behaviour during childhood or adolescence was positively associated with BMI in adulthood, independent of childhood/adolescent BMI and physical activity.

11.3.2 Relationship Between Sedentary Behaviour and Adiposity: Evidence from Intervention Studies

A recent systematic review and meta-analysis of 52 intervention studies summarised effect sizes on sedentary interventions (targeting sedentary behaviour reductions alone or combined with increases in physical activity) and body anthropometry [61]. Interventions were mostly conducted in the workplace or the community environment, with less studies conducted in healthcare, domestic, and educational settings. Pooled effect size estimates showed small but statistically significant beneficial effects on weight, waist circumference, percentage body fat, and a trend towards reduced fat mass, with no significant results observed for fat-free mass and body weight.

Neuhaus et al. [69] reviewed studies on the effectiveness of workplace interventions on adiposity, including BMI (five studies), body composition (19 studies), and body weight (nine studies). Specifically, activity-permissive workstations that either promote less sitting (e.g., standing desk), less sitting and more movement (e.g., treadmill desk), or active sitting (e.g., cycling using an ergometer while seated) were evaluated. The effects of the interventions on adiposity were modest, with only 22%, 20%, and 5% of studies showed improvements in body weight, BMI, and body composition, respectively.

11.3.3 Sedentary Behaviour in Relation to Adiposity in the Elderly

Despite a high prevalence of sedentary behaviour among the elderly [77], the relation between sedentary behaviour and adiposity among people of advanced age has been less frequently studied. A recent systematic review of 12 cross-sectional studies by de Rezende et al. [55] reported that different aspects of sedentary behaviour were relatively consistently positively associated with overweight and obesity as well as measures of body composition, such as waist circumference and waist-to-hip ratio. However, the authors of the review concluded that the evidence for a relation between sedentary behaviour and adiposity among the elderly is insufficient due to the moderate quality of available studies. A recent review of studies in adults aged 60 years or older by Wirth et al. [53] found a statistically significant positive relation of sedentary behaviour to BMI in seven of eleven cross-sectional studies, one prospective study, and one of three RCTs. In addition, the review found a statistically significant positive relation of sedentary behaviour to waist circumference in seven of ten cross-sectional studies and in one prospective study, but it detected no association in four RCTs. The authors concluded that there was mixed evidence for a positive association between BMI and sedentary behaviour and no relation with waist circumference. One cross-sectional study that examined community design relationships of body weight in older adults reported that sitting in a car was unrelated to overweight or obesity [78].

A recent systematic review by Chastin et al. investigated determinants of sedentary behaviour in the elderly [54]. Seven studies (six cross-sectional studies and one prospective study) on self-reported or accelerometer-based sedentary behaviour in relation to obesity found greater volumes of sedentary time or television viewing among obese individuals [54]. In their umbrella review summarising available systematic reviews on sedentary behaviour and adiposity, Biddle et al. [64] concluded that there is some evidence for a positive association between sedentary behaviour and adiposity among older persons; however, this relation is generally weak and is based on cross-sectional studies. Clearly, there is a need for further prospective studies using objective measures of sedentary behaviour in relation to obesity in the elderly.

11.4 Limitations of Existing Reviews and Meta-Analyses on Sedentary Behaviour in Relation to Adiposity in Children, Adolescents, Adults, and Older Adults

Although the existing literature points towards a positive association between sedentary behaviour and adiposity among children, findings need to be interpreted in the context of certain limitations. Most available data are based on cross-sectional studies, which pose a challenge regarding inference about the causality of the relation. In addition, the evidence is based mainly on television viewing time, which may not be representative of total sedentary time, particularly in children [79]. Also, the strength of the association between sedentary behaviour and adiposity may vary according to the type of sedentary behaviour (i.e., watching television, playing video games, using a computer), which has not always been taken into account. Furthermore, the majority of studies among children, adolescents, and adults are based on self-reports. Findings from such studies are more prone to measurement error and exposure misclassification than studies using device-based assessments of sedentary time and measures of adiposity [80]. Moreover, the type of assessment of adiposity has not been consistent across previous studies. In addition, the methods applied for statistical analyses vary between individual studies, which results in between-study heterogeneity complicating comparability, both on a descriptive and an analytical level.

11.5 Biologic Mechanisms

Obesity may arise from several factors, including heritability and genetic factors; hormonal conditions; and appetite and satiety disorders [81]. However, the most important factors are likely to be overeating and lack of physical activity and these factors are modifiable. One possible explanation for the observed positive association between sedentary time and obesity is that individuals who spend more time in sedentary pursuits inevitably devote less time to light intensity activity [82]. This leads to a positive energy balance and subsequent weight gain and obesity over time [83]. Recent studies have shown that individuals spending too much time sitting and not engaging in sufficient physical activity have worse health outcomes than does with high levels of physical activity [84, 85].

Moreover, it is likely that the association between sedentary time and weight gain is influenced by other factors, such as dietary intake. One study [86] found that increased energy intake, particularly energy from carbohydrates, mediated the association between television viewing and BMI in adolescents. Another study found that TV viewing was positively associated with consumption of takeaway foods cross-sectionally [87]. A study among adolescents [88] showed that television viewing was associated with a higher intake of foods containing fat and sugar and lower intakes of fruits and vegetables. Data from the European Youth Heart Study (EYHS) found that the association between television viewing and adiposity among children was attenuated following adjustment for eating while watching television [89]. Exposure to food advertising during television viewing time has been suggested to prime food consumption [90].

Whether mechanisms that control appetite and energy intake play a role in the association between sedentariness and adiposity remains speculative. Regulation of food intake and energy homeostasis is complex. Briefly, peptide YY (PYY) and glucagon-like peptide 1 (GLP-1) provide negative feedback to inhibit appetite and food intake, while ghrelin, a gastrointestinal hormone, stimulates appetite. In addition, insulin and glucagon are involved in energy homeostasis [91]. A line of research indicates that physically active persons have better control of appetite than sedentary individuals [92]. A recent experimental study [93, 94] showed that an exercise intervention among obese adolescents reduced daily energy imbalance by affecting ad libitum dinner energy consumption, whereas bed rest increased energy intake and subsequently led to a positive energy balance. These findings support the idea that the effect of exercise or sedentary behaviour on energy balance is not only related to exercise-induced energy expenditure but also involves a role of energy intake in regulating energy balance.

Obesity may also be caused by short sleep duration brought about by excessive time spent television viewing or using the computer or the internet. Also, increased time commuting to and from work, long working hours, and shift-work have all been linked to obesity via their associations with shorter sleep times [95].

Obesity is thought to represent an intermediate variable in the relation between sedentary behaviour and various disease outcomes, although this hypothesis needs to be further clarified. While some studies noted attenuations of the associations between sedentary behaviour and obesity-related diseases in models that were adjusted for BMI [96–98], other studies found that adjustment for BMI did not materially affect the results [99, 100]. Obesity induces chronic inflammation [101] and insulin resistance [102], which represent risk factors for cardiovascular disease and cancer [103].

Likewise, postmenopausal oestrogen production in adipose tissue through aromatisation of androgens may increase risk of hormone-related female cancers [104, 105]. Further, obesity is related to dyslipidaemia and hypertension [106], which pose risk for cardiovascular disease [107, 108].

Further studies are needed to clarify the biologic mechanisms potentially linking sedentary behaviour to adiposity. In addition, the role of adiposity as an intermediate variable in the relation between sedentary behaviour and chronic disease requires clarification. For detailed information on the physiologic responses to sedentary behaviour, please see Chap. 5.

11.6 Conclusion

A multitude of studies has evaluated the association between sedentary behaviour and adiposity. In children and adolescents, findings from meta-analyses and systematic reviews point towards a positive association between the two, whereas in adults, results on sedentary behaviour and adiposity are inconclusive. Further studies using objective measures of sedentary behaviours are needed to draw more definitive conclusions about the relation between sedentary behaviour and adiposity. Limiting screen time to less than two hours per day in children and adolescents appears to be a sound conclusion that can be drawn from the current scientific evidence base. To prevent the development of obesity, it is prudent to minimise sedentary behaviour and to enhance physical activity and a healthy diet in both children and adults.

References

1. Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet (London, England). 2014;384(9945):766–81.

2. UNICEF – World Health Organization – Word Bank Group. Levels and trends in child malnutrition. UNICEF – WHO – World Bank Group joint child malnutrition estimates. Key findings of the 2015 edition. New York; Geneva; Washington: UNICEF; WHO; World Bank Group.
3. World Health Organization. Obesity and overweight 2021. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight
4. N. C. D. Risk Factor Collaboration. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. Lancet (London, England). 2017;390(10113):2627–42.
5. G. B. D. Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet (London, England). 2020;396(10258):1223–49.
6. World Health Organization. Obesity. Situation and trends 2014. Available from: http://www.who.int/gho/ncd/risk_factors/obesity_text/en/.
7. Lauby-Secretan B, Scoccianti C, Loomis D, Grosse Y, Bianchini F, Straif K, et al. Body fatness and cancer—viewpoint of the IARC working group. N Engl J Med. 2016;375(8):794–8.
8. Freedman DS, Khan LK, Serdula MK, Dietz WH, Srinivasan SR, Berenson GS. The relation of childhood BMI to adult adiposity: the Bogalusa Heart Study. Pediatrics. 2005;115(1):22–7.
9. World Health Organization. Report of the commission on ending childhood obesity. Geneva, Switzerland: World Health Organization; 2016.
10. Alanazi YA, Sousa-Sa E, Chong KH, Parrish AM, Okely AD. Systematic review of the relationships between 24-hour movement behaviours and health indicators in school-aged children from Arab-speaking countries. Int J Environ Res Public Health. 2021;18(16):8640.
11. Podnar H, Juric P, Karuc J, Saez M, Barcelo MA, Radman I, et al. Comparative effectiveness of school-based interventions targeting physical activity, physical fitness or sedentary behaviour on obesity prevention in 6- to 12-year-old children: a systematic review and meta-analysis. Obes Rev. 2021;22(2):e13160.
12. Li C, Cheng G, Sha T, Cheng W, Yan Y. The relationships between screen use and health indicators among infants, toddlers, and preschoolers: a meta-analysis and systematic review. Int J Environ Res Public Health. 2020;17(19):7324.
13. Shao T, Wang L, Chen H. Association between sedentary behavior and obesity in school-age children in China: a systematic review of evidence. Curr Pharm Des. 2020;26(39):5012–20.
14. D'Souza NJ, Kuswara K, Zheng M, Leech R, Downing KL, Lioret S, et al. A systematic review of lifestyle patterns and their association with adiposity in children aged 5–12 years. Obes Rev. 2020;21(8):e13029.
15. Wijndaele K, White T, Andersen LB, Bugge A, Kolle E, Northstone K, et al. Substituting prolonged sedentary time and cardiovascular risk in children and youth: a meta-analysis within the International Children's Accelerometry database (ICAD). Int J Behav Nutr Phys Activity. 2019;16(1):96.
16. Marker C, Gnambs T, Appel M. Exploring the myth of the chubby gamer: a meta-analysis on sedentary video gaming and body mass. Soc Sci Med. 2019:112325.
17. Zabatiero J, Ng L, Clayton R, Middlemiss S, Kang K, Harrold M, et al. Effectiveness of interventions aiming at reducing sedentary behaviour in a non-surgical population with overweight or obesity: a systematic review and meta-analysis. Obes Res Clin Pract. 2019;13(2):115–28.
18. Poitras VJ, Gray CE, Janssen X, Aubert S, Carson V, Faulkner G, et al. Systematic review of the relationships between sedentary behaviour and health indicators in the early years (0–4 years). BMC Public Health. 2017;17(Suppl 5):868.
19. Biddle SJ, Garcia Bengoechea E, Wiesner G. Sedentary behaviour and adiposity in youth: a systematic review of reviews and analysis of causality. Int J Behav Nutr Phys Activity. 2017;14(1):43.

20. van Ekris E, Altenburg TM, Singh AS, Proper KI, Heymans MW, Chinapaw MJ. An evidence-update on the prospective relationship between childhood sedentary behaviour and biomedical health indicators: a systematic review and meta-analysis. Obes Rev. 2016;17(9):833–49.
21. Cliff DP, Hesketh KD, Vella SA, Hinkley T, Tsiros MD, Ridgers ND, et al. Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis. Obes Rev. 2016;17(4):330–44.
22. Azevedo LB, Ling J, Soos I, Robalino S, Ells L. The effectiveness of sedentary behaviour interventions for reducing body mass index in children and adolescents: systematic review and meta-analysis. Obes Rev. 2016;17(7):623–35.
23. Zhang G, Wu L, Zhou L, Lu W, Mao C. Television watching and risk of childhood obesity: a meta-analysis. Eur J Pub Health. 2016;26(1):13–8.
24. Tanaka C, Reilly JJ, Huang WY. Longitudinal changes in objectively measured sedentary behaviour and their relationship with adiposity in children and adolescents: systematic review and evidence appraisal. Obes Rev. 2014;15(10):791–803.
25. Liao Y, Liao J, Durand CP, Dunton GF. Which type of sedentary behaviour intervention is more effective at reducing body mass index in children? A meta-analytic review. Obes Rev. 2014;15(3):159–68.
26. Pate RR, O'Neill JR, Liese AD, Janz KF, Granberg EM, Colabianchi N, et al. Factors associated with development of excessive fatness in children and adolescents: a review of prospective studies. Obes Rev. 2013;14(8):645–58.
27. LeBlanc AG, Spence JC, Carson V, Connor Gorber S, Dillman C, Janssen I, et al. Systematic review of sedentary behaviour and health indicators in the early years (aged 0–4 years). Appl Physiol Nutr Metab. 2012;37(4):753–72.
28. Prentice-Dunn H, Prentice-Dunn S. Physical activity, sedentary behavior, and childhood obesity: a review of cross-sectional studies. Psychol Health Med. 2012;17(3):255–73.
29. Schmidt ME, Haines J, O'Brien A, McDonald J, Price S, Sherry B, et al. Systematic review of effective strategies for reducing screen time among young children. Obesity. 2012;20(7):1338–54.
30. Leung MM, Agaronov A, Grytsenko K, Yeh MC. Intervening to reduce sedentary behaviors and childhood obesity among school-age youth: a systematic review of randomized trials. J Obes. 2012;2012:685430.
31. van Grieken A, Ezendam NP, Paulis WD, van der Wouden JC, Raat H. Primary prevention of overweight in children and adolescents: a meta-analysis of the effectiveness of interventions aiming to decrease sedentary behaviour. Int J Behav Nutr Phys Activity. 2012;9:61.
32. Costigan SA, Barnett L, Plotnikoff RC, Lubans DR. The health indicators associated with screen-based sedentary behavior among adolescent girls: a systematic review. J Adolesc Health. 2013;52(4):382–92.
33. te Velde SJ, van Nassau F, Uijtdewilligen L, van Stralen MM, Cardon G, De Craemer M, et al. Energy balance-related behaviours associated with overweight and obesity in preschool children: a systematic review of prospective studies. Obes Rev. 2012;13(Suppl 1):56–74.
34. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Activity. 2011;8:98.
35. Chinapaw MJ, Proper KI, Brug J, van Mechelen W, Singh AS. Relationship between young peoples' sedentary behaviour and biomedical health indicators: a systematic review of prospective studies. Obes Rev. 2011;12(7):e621–32.
36. Wahi G, Parkin PC, Beyene J, Uleryk EM, Birken CS. Effectiveness of interventions aimed at reducing screen time in children: a systematic review and meta-analysis of randomized controlled trials. Arch Pediatr Adolesc Med. 2011;165(11):979–86.
37. Carvalhal MM, Padez MC, Moreira PA, Rosado VM. Overweight and obesity related to activities in Portuguese children, 7–9 years. Eur J Pub Health. 2007;17(1):42–6.

38. Graf C, Koch B, Dordel S, Schindler-Marlow S, Icks A, Schuller A, et al. Physical activity, leisure habits and obesity in first-grade children. Eur J Cardiovasc Prev Rehabil. 2004;11(4): 284–90.
39. Vandewater EA, Shim MS, Caplovitz AG. Linking obesity and activity level with children's television and video game use. J Adolesc. 2004;27(1):71–85.
40. Oliver M, Schluter PJ, Rush E, Schofield GM, Paterson J. Physical activity, sedentariness, and body fatness in a sample of 6-year-old Pacific children. Int J Pediatr Obes. 2011;6(2–2): e565–73.
41. Yen CF, Hsiao RC, Ko CH, Yen JY, Huang CF, Liu SC, et al. The relationships between body mass index and television viewing, internet use and cellular phone use: the moderating effects of socio-demographic characteristics and exercise. Int J Eat Disord. 2010;43(6):565–71.
42. Saunders TJ, Tremblay MS, Mathieu ME, Henderson M, O'Loughlin J, Tremblay A, et al. Associations of sedentary behavior, sedentary bouts and breaks in sedentary time with cardiometabolic risk in children with a family history of obesity. PLoS One. 2013;8(11): e79143.
43. Renninger M, Hansen BH, Steene-Johannessen J, Kriemler S, Froberg K, Northstone K, et al. Associations between accelerometry measured physical activity and sedentary time and the metabolic syndrome: a meta-analysis of more than 6000 children and adolescents. Pediatr Obes. 2020;15(1):e12578.
44. Proctor MH, Moore LL, Gao D, Cupples LA, Bradlee ML, Hood MY, et al. Television viewing and change in body fat from preschool to early adolescence: The Framingham Children’s Study. Int J Obes Relat Metab Disord. 2003;27(7):827–33.
45. Jago R, Baranowski T, Baranowski JC, Thompson D, Greaves KA. BMI from 3–6 y of age is predicted by TV viewing and physical activity, not diet. Int J Obes. 2005;29(6):557–64.
46. Zimmerman FJ, Bell JF. Associations of television content type and obesity in children. Am J Public Health. 2010;100(2):334–40.
47. Janz KF, Burns TL, Levy SM, Iowa Bone Development S. Tracking of activity and sedentary behaviors in childhood: the Iowa Bone Development Study. Am J Prev Med. 2005;29(3): 171–8.
48. Fisher A, Hill C, Webber L, Purslow L, Wardle J. MVPA is associated with lower weight gain in 8–10 year old children: a prospective study with 1 year follow-up. PLoS One. 2011;6(4): e18576.
49. Kwon S, Burns TL, Levy SM, Janz KF. Which contributes more to childhood adiposity-high levels of sedentarism or low levels of moderate-through-vigorous physical activity? The Iowa Bone Development Study. J Pediatr. 2013;162(6):1169–74.
50. Mitchell JA, Pate RR, Beets MW, Nader PR. Time spent in sedentary behavior and changes in childhood BMI: a longitudinal study from ages 9 to 15 years. Int J Obes. 2013;37(1):54–60.
51. Basterfield L, Pearce MS, Adamson AJ, Frary JK, Parkinson KN, Wright CM, et al. Physical activity, sedentary behavior, and adiposity in English children. Am J Prev Med. 2012;42(5): 445–51.
52. Hill AB. The environment and disease: association or causation? Proc R Soc Med. 1965;58: 295–300.
53. Wirth K, Klenk J, Brefka S, Dallmeier D, Faehling K, Figuls MR, et al. Biomarkers associated with sedentary behaviour in older adults: a systematic review. Ageing Res Rev. 2016 [Epub ahead of print].
54. Chastin SF, Buck C, Freiberger E, Murphy M, Brug J, Cardon G, et al. Systematic literature review of determinants of sedentary behaviour in older adults: a DEDIPAC study. Int J Behav Nutr Phys Activity. 2015;12:127.
55. de Rezende LF, Rey-Lopez JP, Matsudo VK, do Carmo Luiz O. Sedentary behavior and health outcomes among older adults: a systematic review. BMC Public Health. 2014;14:333.
56. Rhodes RE, Mark RS, Temmel CP. Adult sedentary behavior: a systematic review. Am J Prev Med. 2012;42(3):e3–28.

57. Proper KI, Singh AS, van Mechelen W, Chinapaw MJ. Sedentary behaviors and health outcomes among adults: a systematic review of prospective studies. Am J Prev Med. 2011;40(2):174–82.
58. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996–2011. Am J Prev Med. 2011;41(2):207–15.
59. van Uffelen JG, Wong J, Chau JY, van der Ploeg HP, Riphagen I, Gilson ND, et al. Occupational sitting and health risks: a systematic review. Am J Prev Med. 2010;39(4): 379–88.
60. Williams DM, Raynor HA, Ciccolo JT. A review of TV viewing and its association with health outcomes in adults. Am J Lifestyle Med. 2008;2(3):250–9.
61. Hadgraft NT, Winkler E, Climie RE, Grace MS, Romero L, Owen N, et al. Effects of sedentary behaviour interventions on biomarkers of cardiometabolic risk in adults: systematic review with meta-analyses. Br J Sports Med. 2021;55(3):144–54.
62. Guo C, Zhou Q, Zhang D, Qin P, Li Q, Tian G, et al. Association of total sedentary behaviour and television viewing with risk of overweight/obesity, type 2 diabetes and hypertension: a dose-response meta-analysis. Diabetes Obes Metab. 2020;22(1):79–90.
63. Campbell SDI, Brosnan BJ, Chu AKY, Skeaff CM, Rehrer NJ, Perry TL, et al. Sedentary behavior and body weight and composition in adults: a systematic review and meta-analysis of prospective studies. Sports Med. 2018;48(3):585–95.
64. Biddle SJH, Garcia Bengoechea E, Pedisic Z, Bennie J, Vergeer I, Wiesner G. Screen time, other sedentary behaviours, and obesity risk in adults: a review of reviews. Curr Obes Rep. 2017;6(2):134–47.
65. O'Donoghue G, Perchoux C, Mensah K, Lakerveld J, van der Ploeg H, Bernaards C, et al. A systematic review of correlates of sedentary behaviour in adults aged 18–65 years: a socio-ecological approach. BMC Public Health. 2016;16:163.
66. Marshall SJ, Biddle SJ, Gorely T, Cameron N, Murdey I. Relationships between media use, body fatness and physical activity in children and youth: a meta-analysis. Int J Obes Relat Metab Disord. 2004;28(10):1238–46.
67. Chastin SF, Egerton T, Leask C, Stamatakis E. Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. Obesity. 2015;23(9):1800–10.
68. McCormack GR, Virk JS. Driving towards obesity: a systematized literature review on the association between motor vehicle travel time and distance and weight status in adults. Prev Med. 2014;66:49–55.
69. Neuhaus M, Eakin EG, Straker L, Owen N, Dunstan DW, Reid N, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. Obes Rev. 2014;15(10):822–38.
70. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. JAMA. 2003;289(14):1785–91.
71. Wijndaele K, Healy GN, Dunstan DW, Barnett AG, Salmon J, Shaw JE, et al. Increased cardiometabolic risk is associated with increased TV viewing time. Med Sci Sports Exerc. 2010;42(8):1511–8.
72. Kronenberg F, Pereira MA, Schmitz MK, Arnett DK, Evenson KR, Crapo RO, et al. Influence of leisure time physical activity and television watching on atherosclerosis risk factors in the NHLBI Family Heart Study. Atherosclerosis. 2000;153(2):433–43.
73. Stamatakis E, Hamer M, Mishra GD. Early adulthood television viewing and cardiometabolic risk profiles in early middle age: results from a population, prospective cohort study. Diabetologia. 2012;55(2):311–20.
74. Tucker LA, Tucker JM. Television viewing and obesity in 300 women: evaluation of the pathways of energy intake and physical activity. Obesity. 2011;19(10):1950–6.

75. Cleland VJ, Schmidt MD, Dwyer T, Venn AJ. Television viewing and abdominal obesity in young adults: is the association mediated by food and beverage consumption during viewing time or reduced leisure-time physical activity? Am J Clin Nutr. 2008;87(5):1148–55.
76. Lynch BM, Boyle T. Distinguishing sedentary from inactive: implications for meta-analyses. Br J Cancer. 2014;111(11):2202–3.
77. Owen N, Salmon J, Koohsari MJ, Turrell G, Giles-Corti B. Sedentary behaviour and health: mapping environmental and social contexts to underpin chronic disease prevention. Br J Sports Med. 2014;48(3):174–7.
78. Frank L, Kerr J, Rosenberg D, King A. Healthy aging and where you live: community design relationships with physical activity and body weight in older Americans. J Phys Act Health. 2010;7(Suppl 1):S82–90.
79. Verloigne M, Van Lippevelde W, Maes L, Yildirim M, Chinapaw M, Manios Y, et al. Self-reported TV and computer time do not represent accelerometer-derived total sedentary time in 10 to 12-year-olds. Eur J Pub Health. 2013;23(1):30–2.
80. Matthews CE, Moore SC, George SM, Sampson J, Bowles HR. Improving self-reports of active and sedentary behaviors in large epidemiologic studies. Exerc Sport Sci Rev. 2012;40 (3):118–26.
81. Rosiek A, Maciejewska NF, Leksowski K, Rosiek-Kryszewska A, Leksowski L. Effect of television on obesity and excess of weight and consequences of health. Int J Environ Res Public Health. 2015;12(8):9408–26.
82. Bann D, Hire D, Manini T, Cooper R, Botoseneanu A, McDermott MM, et al. Light Intensity physical activity and sedentary behavior in relation to body mass index and grip strength in older adults: cross-sectional findings from the Lifestyle Interventions and Independence for Elders (LIFE) study. PLoS One. 2015;10(2):e0116058.
83. Hill JO, Wyatt HR, Peters JC. Energy balance and obesity. Circulation. 2012;126(1):126–32.
84. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet (London, England). 2016;388(10051):1302–10.
85. Ekelund U, Brown WJ, Steene-Johannessen J, Fagerland MW, Owen N, Powell KE, et al. Do the associations of sedentary behaviour with cardiovascular disease mortality and cancer mortality differ by physical activity level? A systematic review and harmonised meta-analysis of data from 850 060 participants. Br J Sports Med. 2019;53(14):886–94.
86. Cameron JD, Maras D, Sigal RJ, Kenny GP, Borghese MM, Chaput JP, et al. The mediating role of energy intake on the relationship between screen time behaviour and body mass index in adolescents with obesity: The HEARTY study. Appetite. 2016;107:437–44.
87. Fletcher EA, Lamb KE, McNaughton SA, Garnett SP, Dunstan DW, Baur LA, et al. Cross-sectional and prospective mediating effects of dietary intake on the relationship between sedentary behaviour and body mass index in adolescents. BMC Public Health. 2017;17(1): 751.
88. Ramos E, Costa A, Araujo J, Severo M, Lopes C. Effect of television viewing on food and nutrient intake among adolescents. Nutrition. 2013;29(11–12):1362–7.
89. Ekelund U, Brage S, Froberg K, Harro M, Anderssen SA, Sardinha LB, et al. TV viewing and physical activity are independently associated with metabolic risk in children: the European Youth Heart Study. PLoS Med. 2006;3(12):e488.
90. Harris JL, Bargh JA, Brownell KD. Priming effects of television food advertising on eating behavior. Health Psychol. 2009;28(4):404–13.
91. Rosenkilde M, Reichkendler MH, Auerbach P, Torang S, Gram AS, Ploug T, et al. Appetite regulation in overweight, sedentary men after different amounts of endurance exercise: a randomized controlled trial. J Appl Physiol. 2013;115(11):1599–609.
92. Martins C, Morgan L, Truby H. A review of the effects of exercise on appetite regulation: an obesity perspective. Int J Obes. 2008;32(9):1337–47.

93. Thivel D, Metz L, Aucouturier J, Brakoniecki K, Duche P, Morio B. The effects of imposed sedentary behavior and exercise on energy intake in adolescents with obesity. Journal of developmental and behavioral pediatrics : JDBP. 2013;34(8):616–22.
94. Hagele FA, Busing F, Nas A, Hasler M, Muller MJ, Blundell JE, et al. Appetite control is improved by acute increases in energy turnover at different levels of energy balance. J Clin Endocrinol Metab. 2019;104(10):4481–91.
95. Bayon V, Leger D, Gomez-Merino D, Vecchierini MF, Chennaoui M. Sleep debt and obesity. Ann Med. 2014;46(5):264–72.
96. Gierach GL, Chang SC, Brinton LA, Lacey JV Jr, Hollenbeck AR, Schatzkin A, et al. Physical activity, sedentary behavior, and endometrial cancer risk in the NIH-AARP Diet and Health Study. Int J Cancer. 2009;124(9):2139–47.
97. Patel AV, Feigelson HS, Talbot JT, McCullough ML, Rodriguez C, Patel RC, et al. The role of body weight in the relationship between physical activity and endometrial cancer: results from a large cohort of US women. Int J Cancer. 2008;123(8):1877–82.
98. Patel AV, Hildebrand JS, Campbell PT, Teras LR, Craft LL, McCullough ML, et al. Leisure-time spent sitting and site-specific cancer incidence in a large U.S. cohort. Cancer Epidemiol Biomarkers Prev. 2015;24(9):1350–9.
99. Hildebrand JS, Gapstur SM, Gaudet MM, Campbell PT, Patel AV. Moderate-to-vigorous physical activity and leisure-time sitting in relation to ovarian cancer risk in a large prospective US cohort. Cancer Causes Control. 2015;26(11):1691–7.
100. Friberg E, Mantzoros CS, Wolk A. Physical activity and risk of endometrial cancer: a population-based prospective cohort study. Cancer Epidemiol Biomarkers Prev. 2006;15 (11):2136–40.
101. Rodriguez-Hernandez H, Simental-Mendia LE, Rodriguez-Ramirez G, Reyes-Romero MA. Obesity and inflammation: epidemiology, risk factors, and markers of inflammation. Int J Endocrinol. 2013;2013:678159.
102. Kahn BB, Flier JS. Obesity and insulin resistance. J Clin Invest. 2000;106(4):473–81.
103. Wiebe N, Stenvinkel P, Tonelli M. Associations of chronic inflammation, insulin resistance, and severe obesity with mortality, myocardial infarction, cancer, and chronic pulmonary disease. JAMA Netw Open. 2019;2(8):e1910456.
104. Lynch BM, Neilson HK, Friedenreich CM. Physical activity and breast cancer prevention. Recent results in cancer research Fortschritte der Krebsforschung Progres dans les recherches sur le cancer 2011;186:13–42.
105. Cust AE. Physical activity and gynecologic cancer prevention. Recent results in cancer research Fortschritte der Krebsforschung Progres dans les recherches sur le cancer. 2011;186:159–185.
106. Roeters van Lennep JE, Westerveld HT, Erkelens DW, van der Wall EE. Risk factors for coronary heart disease: implications of gender. Cardiovasc Res. 2002;53(3):538–49.
107. Poss J, Custodis F, Werner C, Weingartner O, Bohm M, Laufs U. Cardiovascular disease and dyslipidemia: beyond LDL. Curr Pharm Des. 2011;17(9):861–70.
108. Franklin SS, Wong ND. Hypertension and cardiovascular disease: contributions of the Framingham Heart Study. Glob Heart. 2013;8(1):49–57.

Chapter 12
Sedentary Behaviour and Psychosocial Health Across the Life Course

Lee Smith and Mark Hamer

Abstract Psychosocial health is broadly defined to include psychological and social-psychological outcomes, interlinked with socioeconomic factors. Psychosocial health has been shown to be strongly associated with self-rated health, longevity, and heart disease. This chapter will summarise and explain the literature on sedentary behaviour and psychosocial health across the life course, with a focus on the psychosocial domains: bullying/victimisation, self-esteem, pro-social behaviour, and mental disorders (bipolar disorder, anxiety, stress). In summary, the majority of literature is in young people and has focused on concepts such as self-esteem and pro-social behaviour, suggesting an inverse relationship with sedentary behaviour. Limited research has focused on these concepts in adults. The existing literature should be interpreted in light of limited gold standard experimental data.

What Is New?

- Research on the association between sedentary behaviour and psychosocial health is still scarce.
- A narrative review on the psychological correlates of sedentary screen time behaviour among children and adolescents found that higher levels of screen time were associated with poor psychological well-being and body dissatisfaction.
- In general, higher levels of screen time seem to be associated with poorer mental health outcomes. However, associations may be influenced by screen type, sex, and age.

L. Smith (✉)
Centre for Health Performance and Wellbeing, Anglia Ruskin University, Cambridge, UK
e-mail: Lee.Smith@aru.ac.uk

M. Hamer
Institute Sport, Exercise and Health, Faculty Medical Sciences, University College London, London, UK
e-mail: m.hamer@ucl.ac.uk

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_12

12.1 Introduction

Psychosocial health is broadly defined to include psychological and social-psychological outcomes, interlinked with socioeconomic factors. There is no accepted definition in the field, although it usually includes characteristics such as self-esteem and mood, as well as affect, such as anxiety [1]. For the purpose of this chapter, the umbrella term psychosocial health is broadly defined as the mental (e.g. values, attitudes, beliefs), social (e.g. interacting with others, social support), and emotional (e.g. emotional reaction to specific scenarios) dimensions of what it means to be healthy. It also encompasses how past experiences influence these dimensions in present scenarios. There is a growing body of literature in the area of psychosocial health that demonstrates its importance for physical health. Not only has psychosocial health been found to be associated with self-rated health and longevity [2, 3], but a review by Hemingway and Marmot [4] concluded that prospective cohort studies provide strong evidence that some psychosocial domains are independent aetiological and prognostic factors for coronary heart disease.

12.2 Sedentary Behaviour and Psychosocial Health in Young Children

The newborn brain develops rapidly through the initial years of life and considerable plasticity exists during this period [5, 6]. Thus, it is likely that sustained exposure to specific media content during the initial years of life impacts on the developing brain. Few studies have investigated associations between sedentary behaviour and psychosocial health in young children (0–7 years). A review collated and summarised the literature between sedentary behaviour and health in this age group, and just six observational studies were identified on psychosocial health [7]. The review showed that exposure to screen time before the age of 3 years is negatively associated with attention and language [8–10]. Interestingly, one longitudinal study found that each additional hour of television (TV) viewing per day at age 4 years was associated with a small increase in subsequent bullying in grade school (OR = 1.06, 95% CI = 1.02–1.11) [11]. Another study showed that every additional hour of television exposure at 29 months corresponded to a 10% unit increase in victimisation by classmates [12]. Little else is currently known on sedentary behaviour and psychosocial health in young children. It is possible that associations between the amount of TV exposure and psychosocial outcomes in this age group might be derived from reduced active interaction between young children and their caregivers (Fig. 12.1). The limited but significant literature in this area provides a rationale for further investigation using experimental designs.

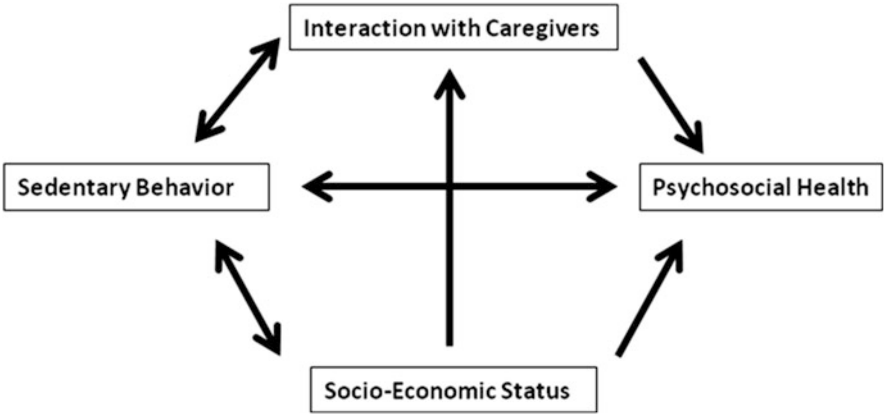

Fig. 12.1 The association between young children's and young people's sedentary behaviour and psychosocial health via socioeconomic status and interaction with caregivers

12.3 Sedentary Behaviour and Self-Esteem in Young People

Self-esteem reflects a person's overall subjective emotional evaluation of his or her own worth. It is a judgement of oneself as well as an attitude towards the self. In brief, it is the opinion one holds over one's self. Self-esteem is often seen to be the single most important measure of psychological well-being [1]. A review collated and evaluated all studies on sedentary behaviour and health outcomes in young people aged between 5 and 17 years [13] and identified 14 studies that investigated the association between TV viewing and self-esteem. The majority of identified studies were observational ($n = 11$). Seven cross-sectional studies found that high screen time was associated with low self-esteem and decreased perception of self-worth (a sub-domain of self-esteem). Studies suggest that a dose–response relationship exists. For example, Russ et al. [14] found 8% greater odds of concern about self-esteem with each additional hour of screen time. However, the cross-sectional literature is inconsistent: two studies found the reverse relationship [15, 16] and two found no association [17, 18]. This conflicting literature may be explained by differences in sample characteristics between studies and/or different measures of exposure and outcome variables. The current review identified two interventions that aimed to examine the effects of reducing sedentary behaviour on self-esteem and self-worth [19, 20]. In these studies, changes in TV viewing were inversely related with physical self-worth and global self-esteem [19]. A plausible explanation for this inverse association is that those who have low self-esteem may find challenging activities (e.g. physical activity) less enjoyable as they may be difficult for them, and thus may prefer more passive sedentary activities (i.e. TV viewing and computer gaming). Alternatively, performing challenging activities as opposed to TV viewing may yield high levels of self-esteem.

12.4 Sedentary and Pro-social Behaviour in Young People

Positive pro-social behaviour is voluntary behaviour intended to benefit others and may include helping, sharing, donating, cooperating, and volunteering. The study of sedentary behaviour and pro-social behaviour in young people often investigates negative behaviours such as bullying, victimisation, and aggression. Tremblay et al. [13] identified 18 observational studies (17 cross-sectional studies and one longitudinal study) that examined the relationship between sedentary activities and various domains of pro-social behaviour. The cross-sectional studies found similar findings. Those who watched less TV were more emotionally stable, sensitive, imaginative, outgoing, self-controlled, intelligent, moralistic, college bound, and less likely to be aggressive or to engage in less risky behaviour. Interestingly gender differences were observed. One study showed that increased TV viewing was associated with increased aggression in girls but not boys [16], whereas two studies found that increased computer use was associated with behavioural problems in boys but not girls [21, 22]. The one longitudinal study found that watching greater than 2 h of TV per day (at ages 30–33 months and 5.5 years) was a significant risk factor for behavioural problems (aggressive behaviour, attention problems) [23]. One plausible explanation for the inverse association between sedentary activities and pro-social behaviour is that those who view scenes of violence (common on TV and in computer games) have an increased probability of "aggressive" behaviour and at least a temporary decrease in pro-social behaviour per se [24]. This may also explain observed gender differences. Girls may watch aggressive programmes on TV and boys may play aggressive video games. Thus, TV viewing may have a strong negative influence on pro-social behaviour in girls and computer use in boys.

12.5 Sedentary Behaviour, Socioeconomic Status, and Psychosocial Health in Young People

Another important issue relates to gradients in social circumstances. Young people from lower socioeconomic status (SES) families spend the greatest amount of time in sedentary behaviours [25]. For example, Henning Brodersen and colleagues [26] analysed data from a 5-year longitudinal study of 5863 students aged 11–12 years. Sedentary behaviour levels were greater in students from lower SES neighbourhoods ($p < 0.001$). The difference between the higher and lower SES groups averaged 2.29 (standard error (SE) = 0.318) hours per week in boys and 4.09 (SE = 0.49) hours per week in girls. This difference did not change over the 5 years of the study. A review on SES and antisocial behaviour identified 133 studies and found that lower family SES was associated with higher levels of antisocial behaviour [27]. Family background/circumstances might drive many of the associations seen in relation to sedentary behaviour and psychosocial health in young people. The potential confounding influences of the association between sedentary behaviour and psychosocial health via SES is demonstrated in Fig. 12.1.

12.6 Sedentary Behaviour and Psychosocial Health in Adults

Few studies have investigated psychosocial health and sedentary behaviour in adults [7]. Those that have investigated such associations have predominantly focused on mental disorders (bipolar disorder, anxiety, stress). For example, Sanchez-Villegas and colleagues [28] assessed the association between sedentary behaviour and mental disorders over 6 years in a large cohort of university graduates. Participants who spent more than 42 h a week watching TV and/or using the computer, compared to those spending less than 10.5 h, were significantly more likely to have a mental disorder. However, a review of studies investigating sedentary behaviour and psychosocial health in older adults revealed conflicting findings [29]. One identified study investigated board game use and reading (two domains of sedentary behaviour) and found that older adults who participated in these activities were less likely to develop dementia compared to those who did not [30]. Another study demonstrated that sedentary time per se was negatively associated with psychosocial wellbeing [31]. Finally, one study found that the highest quartile of sitting time, compared to the lowest, was significantly and negatively associated with mental health and social functioning, after controlling for leisure time physical activity [32]. These conflicting findings suggest that the association between sedentary behaviour and domains of psychosocial health may be context specific, dependent on the cognitive demand of the task. For example, board games and reading may require high levels of cognition whereas sedentary behaviour per se may require low levels. It has been suggested that people with higher educational levels are more resistant to the effects of dementia as a result of having cognitive reserve and increase complexity of neuronal synapses [33]. Similarly, participation in cognitively challenging sedentary activities (reading, board games) may lower the risk of mental disorders [34, 35].

12.7 Influence of Physical Activity on the Sedentary and Psychosocial Health Association

There is a large body of literature on associations between physical activity levels and psychosocial health. Briefly, the literature suggests that regular participation in physical activity is beneficial for many psychosocial health outcomes such as anxiety, mood, and self-esteem and has both a positive and negative effect on pro-social behaviour [1, 36]. Increased physical activity may be associated with psychosocial health for several reasons such as achieving goals, becoming more competent, achieving mastery, having increased social desirability, and developing self-preservation strategies and social reinforcement. In addition, sports/physical activity provides an alternative to occupy a time void where delinquent behaviour could take place [36]. It may therefore be that identified associations between sedentary behaviour and psychosocial health are not driven by sedentary behaviour per se but by the absence of physical activity. Future research may wish to investigate whether associations between sedentary behaviour and psychosocial health are modified or altered by level of physical activity.

12.8 Summary

Psychosocial health is an umbrella term and includes a large number of variables. This chapter has specifically focused on several areas relevant to sedentary behaviour (bullying/victimisation, self-esteem, pro-social behaviour, and mental disorders) at various stages in the life course. Currently, there is a limited body of literature that investigates psychosocial health and sedentary behaviour across the life course. The majority of literature focuses on young people where sedentary behaviours have been adversely linked to self-esteem and pro-social behaviour. Limited research has focused on this concept in adults, other than the studies that have investigated mental disorders. A major limitation of the evidence is that few studies have intervened to investigate if psychosocial health can be improved through the reduction of sedentary behaviour. It is likely that interventions need to be tailored to each domain of psychosocial health and specific age group. The observed associations between sedentary behaviour and psychosocial health may not be driven by sedentary behaviour per se but by the absence of physical activity. Moreover, associations may be confounded by SES and other potentially important factors. Sedentary behaviour and psychosocial health is potentially an important but currently understudied area. Gold standard experimental studies are needed before inferences and recommendations can be made.

References

1. Biddle S. Exercise and psychosocial health. Res Q Exerc Sport. 1995;66(4):292–7.
2. Klabbers G, Bosma H, Kempen GI, Benzeval M, Van den Akker M, van Eijk JT. Do psychosocial profiles predict self-rated health, morbidity and mortality in late middle-aged and older people? J Behav Med. 2014;37(3):357–68.
3. Anstey K, Luszcz M, Andrews G. Psychosocial factors, gender and late-life mortality. Ageing Int. 2002;27(2):73–89.
4. Hemingway H, Marmot M. Psychosocial factors in the aetiology and prognosis of coronoary heart disease: systematic review of prospective cohort studies. BMJ. 1999;318(7196):1460–7.

5. Barkovich AJ, Kjos BO, Jackson DE Jr, Norman D. Normal maturation of the neonatal and infant brain: MR imaging at 1.5 T. Radiology. 1988;166(1 Pt 1):173–80.
6. Yamada H, Sadato N, Konishi Y, Muramoto S, Kimura K, Tanaka M, et al. A milestone for normal development of the infantile brain detected by functional MRI. Neurology. 2000;55(2): 218–23.
7. Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. Appl Physiol Nutr Metab. 2010;35(6):725–40.
8. Christakis DA, Zimmerman FJ, DiGiuseppe DL, McCarty CA. Early television exposure and subsequent attentional problems in children. Pediatrics. 2004;113(4):708–13.
9. Zimmerman FJ, Christakis DA, Meltzoff AN. Associations between media viewing and language development in children under age 2 years. J Pediatr. 2007;151(4):364–8.
10. Zimmerman FJ, Christakis DA. Children's television viewing and cognitive outcomes: a longitudinal analysis of national data. Arch Pediatr Adolesc Med. 2005;159(7):619–25.
11. Zimmerman FJ, Glew GM, Christakis DA, Katon W. Early cognitive stimulation, emotional support, and television watching as predictors of subsequent bullying among grade-school children. Arch Pediatr Adolesc Med. 2005;159(4):384–8.
12. Pagani LS, Fitzpatrick C, Barnett TA, Dubow E. Prospective associations between early childhood television exposure and academic, psychosocial, and physical well-being by middle childhood. Arch Pediatr Adolesc Med. 2010;164(5):425–31.
13. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Activity. 2011;8:98.
14. Russ SA, Larson K, Franke TM, Halfon N. Associations between media use and health in US children. Acad Pediatr. 2009;9(5):300–6.
15. Neumark-Sztainer D, Goeden C, Story M, Wall M. Associations between body satisfaction and physical activity in adolescents: implications for programs aimed at preventing a broad spectrum of weight-related disorders. Eat Disord. 2004;12(2):125–37.
16. Dominick JR. Videogames, television violence, and aggression in teenagers. J Commun. 1984;34(2):136–47.
17. Ohannessian CM. Media use and adolescent psychological adjustment: an examination of gender differences. J Child Fam Stud. 2009;18(5):582–93.
18. Wiggins JD. Self-esteem, earned grades, and television viewing habits of students. The School Counsellor. 1987;35(2):128–33.
19. Goldfield GS, Mallory R, Parker T, Cunningham T, Legg C, Lumb A, et al. Effects of modifying physical activity and sedentary behavior on psychosocial adjustment in overweight/obese children. J Pediatr Psychol. 2007;32(7):783–93.
20. Simon C, Wagner A, DiVita C, Rauscher E, Klein-Platat C, Arveiler D, et al. Intervention centred on adolescents' physical activity and sedentary behaviour (ICAPS): concept and 6-month results. Int J Obes Relat Metab Disord. 2004;28(Suppl 3):S96–S103.
21. Leatherdale ST, Wong SL. Modifiable characteristics associated with sedentary behaviours among youth. Int J Pediatr Obes. 2008;3(2):93–101.
22. Sakamoto A. Video game use and the development of sociocognitive abilities in children: three surveys of elementary school students. J Appl Social Psychol. 1994;24(1):21–42.
23. Mistry KB, Minkovitz CS, Strobino DM, Borzekowski DL. Children's television exposure and behavioral and social outcomes at 5.5 years: does timing of exposure matter? Pediatrics. 2007;120(4):762–9.
24. Anderson CA, Bushman BJ. Effects of violent video games on aggressive behavior, aggressive cognition, aggressive affect, physiological arousal, and prosocial behavior: a meta-analytic review of the scientific literature. Psychol Sci. 2001;12(5):353–9.
25. Salmon J, Tremblay MS, Marshall SJ, Hume C. Health risks, correlates, and interventions to reduce sedentary behavior in young people. Am J Prev Med. 2011;41(2):197–206.

26. Brodersen NH, Steptoe A, Boniface DR, Wardle J. Trends in physical activity and sedentary behaviour in adolescence: ethnic and socioeconomic differences. Br J Sports Med. 2007;41(3): 140–4.
27. Piotrowska PJ, Stride CB, Croft SE, Rowe R. Socioeconomic status and antisocial behaviour among children and adolescents: a systematic review and meta-analysis. Clin Psychol Rev. 2015;35:47–55.
28. Sanchez-Villegas A, Ara I, Guillen-Grima F, Bes-Rastrollo M, Varo-Cenarruzabeitia JJ, Martinez-Gonzalez MA. Physical activity, sedentary index, and mental disorders in the SUN cohort study. Med Sci Sports Exerc. 2008;40(5):827–34.
29. De Rezende LF, Rey-Lopez JP, Matsudo VK, Luiz DC, O. Sedentary behavior and health outcomes among older adults: a systematic review. BMC Public Health. 2014;14:333.
30. Verghese J, Lipton RB, Katz MJ, Hall CB, Derby CA, Kuslansky G, et al. Leisure activities and the risk of dementia in the elderly. N Engl J Med. 2003;348(25):2508–16.
31. Buman MP, Hekler EB, Haskell WL, Pruitt L, Conway TL, Cain KL, et al. Objective light-intensity physical activity associations with rated health in older adults. Am J Epidemiol. 2010;172(10):1155–65.
32. Balboa-Castillo T, Leon-Munoz LM, Graciani A, Rodriguez-Artalejo F, Guallar-Castillon P. Longitudinal association of physical activity and sedentary behavior during leisure time with health-related quality of life in community-dwelling older adults. Health Qual Life Outcomes. 2011;9:47.
33. Katzman R. Education and the prevalence of dementia and Alzheimer's disease. Neurology. 1993;43(1):13–20.
34. Rogers RL, Meyer JS, Mortel KF. After reaching retirement age physical activity sustains cerebral perfusion and cognition. J Am Geriatr Soc. 1990;38(2):123–8.
35. Laurin D, Verreault R, Lindsay J, MacPherson K, Rockwood K. Physical activity and risk of cognitive impairment and dementia in elderly persons. Arch Neurol. 2001;58(3):498–504.
36. Nieman P. Psychosocial aspects of physical activity. Paediatr Child Health. 2002;7(5):309–12.

Chapter 13
Sedentary Behaviour and Ageing

Dawn A. Skelton, Juliet A. Harvey, Calum F. Leask, and Jennifer Scott

Abstract This chapter focuses on the prevalence and amount of sedentary behaviour in older adults with a range of functional limitations, distinguishing the differences between those who live independently with those who live in residential settings or who are subject to enforced sedentary behaviour, such as those in hospital. The associations of prolonged sedentary behaviour with both physical and mental health are less researched than in adults or children but show a clear pattern of increased mortality, reduced function, frailty, mental health, and longevity. Evidence on interventions to reduce sedentary behaviour in older adults is still scarce and studies show only small effect sizes, have short or no follow up beyond the intervention period and are often in combination with efforts to increase physical activity. Clearly more work in this vulnerable population, especially in those transitioning to frailty, is warranted.

D. A. Skelton (✉)
Research Centre for Health (ReaCH), School of Health and Life Sciences, Glasgow Caledonian University, Glasgow, UK
e-mail: Dawn.Skelton@gcu.ac.uk

J. A. Harvey
NHS Greater Glasgow & Clyde, Glasgow, UK
e-mail: juliet.harvey@ggc.scot.nhs.uk

C. F. Leask
Lead for Evaluation, NHS Grampian, Aberdeen, UK
e-mail: calum.leask@nhs.scot

J. Scott
NHS Lanarkshire & School of Health and Life Sciences, Glasgow Caledonian University, Glasgow, UK
e-mail: Jennifer.Scott@gcu.ac.uk

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_13

What Is New?

- Systematic reviews and meta-analyses have continued to examine the relationship between sedentary behaviour and bone health, cognitive function, obesity, and activities of daily living in older adults. For bone health, findings vary across studies and differ by gender. Low levels of sedentary behaviour appear to be beneficial for cognitive function and for the ability to complete activities of daily living.
- The effectiveness of interventions aimed at reducing sedentary time in community-dwelling older adults has been summarised by a number of systematic reviews and meta-analyses, showing mixed results. Whereas some systematic reviews concluded that there is no evidence or limited evidence for the effectiveness of interventions to reduce sedentary behaviour, other reviews found small but significant reductions in sedentary behaviour.

13.1 Prevalence of Sedentary Behaviour in Older Adults

Prevalence of sedentary behaviour varies by living status and by functional level of older adults [1, 2]. Prevalence of sedentary behaviour depends on the type of measurement of sedentary behaviour (self-report vs objective measures) and even in objective measurement, the type of monitor, the epochs over which data is collected, and the positioning of the monitor (see Chap. 3 for more detail). In older adults, the Seniors USP Team looked at a systematic comparative validation of self-report measures of sedentary time against an objective measure (activPAL) [3]. All self-report measures showed under-reporting, poor accuracy compared with the objective measure, with very wide limits of agreement and poor precision (random error $>$ 2.5 h). The type of assessment used by the tool, whether direct, proxy, or a composite measure, influenced the measurement characteristics. For self-report, the best combination for precision and reduced data loss were proxy measures (television time) and single item direct measures, using a visual analogue scale, to assess the proportion of the day spent sitting. Interestingly, the recall period (e.g., previous week) had little influence on measurement characteristics [3]. The same group examined reliability, minimal detectable change, and responsiveness to change of sedentary behaviour measures using a systematic set of six subjective tools and one objective tool (activPAL3c), over 14 days [4]. Relative reliability (Intra Class Correlation coefficients-ICC), absolute reliability (SEM), MDC, and the relative responsiveness (Cohen's d effect size (ES) and Guyatt's Responsiveness coefficient (GR)) were calculated for each of the different tools and ranked for different study designs. ICC ranged from 0.414 to 0.946, SEM from 36.03 to 137.01 min, MDC from 1.66 to 8.42 hours, ES from 0.017 to 0.259 and GR from 0.024 to 0.485. Objective (device-based) average day per week measurement was ranked as most responsive in a clinical practice setting, but a one-day measurement ranked highest in quasi-experimental, longitudinal, and controlled trial study designs, and television viewing (previous week recall) was ranked as the most responsive subjective measure in all study designs [4].

13.1.1 Community-Dwelling Older Adults

Globally, almost 60% of older adults self-report sitting for more than 4 hours of their waking day [1]. When objectively measured, 67% of the older population are sedentary for more than 8.5 hours of their waking day [1, 5]. When objective data from a number of studies are weighted and pooled, a mean of 9.4 hours (ranging from 8.5–10.7 hours) per day is measured [6]. From the available studies, the UK and USA record the highest levels of sedentary behaviour at approximately 11 hours per day [7–10]. For more information on the prevalence and correlates of sedentary behaviour in older adults, please refer to Sects. 2.2.5 and 2.3.2.

In older adults, there is little difference in sedentary behaviour trends between sexes [11], although females are more likely to accumulate their sedentary time in shorter bouts and therefore more likely to break up prolonged periods of sitting than males [12]. In twin studies, there is a suggestion, however, that environment is more important in the gender aetiology of sitting [13]. In a Finnish cohort of older individuals, women sat less than men and older age was associated with less sitting time [13]. There is a trend of increased sedentary behaviour with increasing age, with both device-based measurement (Fig. 13.1) and via self-reported (Fig. 13.2) sedentary time [14–21]. Reading time and screen time are exceptions to the trend, the lower levels of screen time are likely to be due to low computer technology literacy and availability at this age [14, 15, 17].

13.1.2 Assisted Care and Nursing Care Settings

Sedentary behaviour is particularly prevalent in those older adults living in residential care settings. Some of this sedentary time is due to physical and mental health conditions, but there is a culture of risk avoidance and of ‘caring’ to the point of staff and residents avoiding movement, as seen in hospital settings [22]. One study in the UK found that care home residents spent on average 79% of their day sedentary, 14% in low activity, 6% in light activity, and 1% in moderate-to-vigorous activity [23]. Residents spend a median of 12.4 hours sitting/lying (with 73% of this accumulated in unbroken bouts of ≥30 minutes), only 1.9 hours standing and 214 minutes stepping in their waking day [24]. Potential barriers for implementing interventions to increase physical activity or reduce sedentary behaviour in these settings have been reviewed [25] and include resident health status, lack of space for physical activity, and staffing and funding constraints.

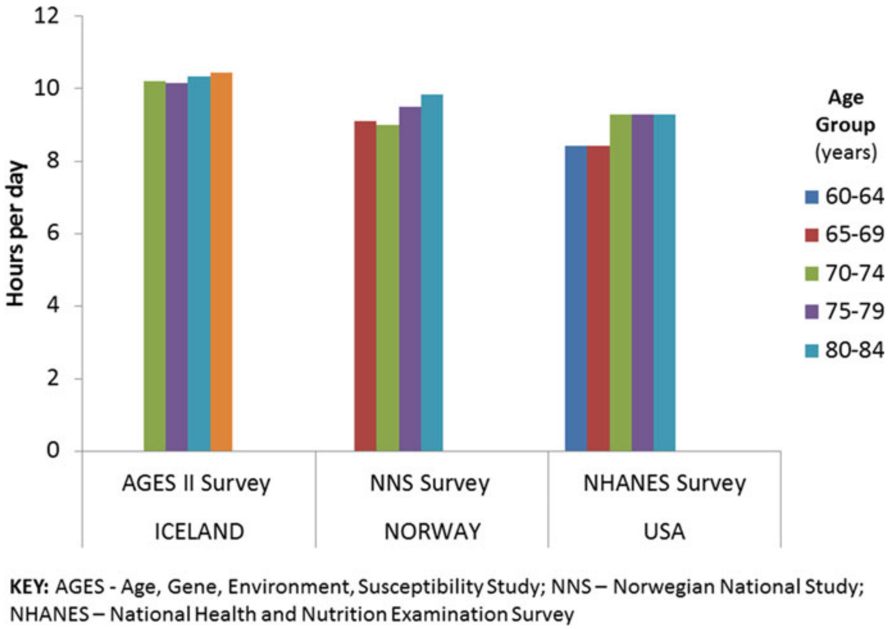

Fig. 13.1 Sedentary behaviour measured by accelerometry (>60 year by age group), adapted from Harvey et al. [12]

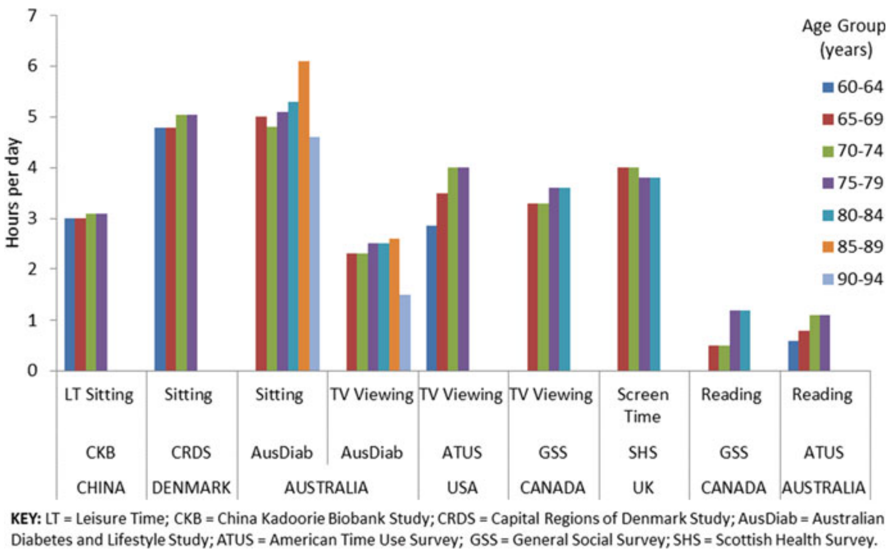

Fig. 13.2 Sedentary behaviour by various methods of self-report (>60 years by age group), adapted from Harvey et al. [12]

13.1.3 Hospital Settings

In few settings can the impact of prolonged inactivity in older adults be observed more acutely than in hospitalised inpatients. Bed rest or sedentary behaviour in hospital is ubiquitous, with older patients spending the majority of time during their hospitalisation in bed. For example, one study using accelerometers on patients aged 65 and older, who were not delirious, did not have dementia, and were able to walk in the 2 weeks before admission, showed that 83% of the hospital stay was spent lying in bed and 13% sitting by the side of the bed [26]. Grant et al. [27] found ward-based older patients spend as few as 76 mins per day in an upright position. A review of 42 studies reporting the activity levels of acutely admitted medical and surgical patients found they spent between 93% and 98.8% of their admission sitting or lying down [28]. Low inpatient mobility can result in functional decline, higher medical complications and increased mortality [2].

It has been suggested that alternatives to hospitalisation, such as providing acute-level hospital services to older medical patients in their own homes ('Hospital at Home'), may pose less risk of physical functional decline by allowing more physical activity than the traditional ward-based inpatient environment [29]. Such delivery models may achieve this by imposing fewer restrictions on mobility and allowing more opportunity to continue to perform their regular activities of daily living (ADLs) [30]. A recent study examined sedentary behaviour in a matched cohort of older inpatients versus those receiving hospital care in their own homes found that whilst sedentary behaviours were similar, the latter group spent more time sitting and less time lying down, and were significantly more physically active in terms of walking duration and step count [2]. A systematic review of the physical activity levels of acutely ill older adults in Hospital at Home settings, prior to Ramsey's study, found no studies of hospital at home participants but found that participants in studies of hospital patients who would have met criteria to be treated at home only undertook 882 steps a day, accounting for only 6.6% of their day in standing [31]. This sedentary behaviour seen in hospital can lead to an increase in sedentary behaviour once the person leaves hospital as well, as shown in one case study where the older adult wore an accelerometer before a broken shoulder, while she was in hospital and when she returned home [32].

13.2 What, Why, and With Whom Are Older Adults Sedentary

Health behaviour theories, such as the socio-ecological model and dual process theory, state that individuals' choices and behaviours are determined by the context of both their physical and social environment [33, 34]. The SITONAUMY consensus taxonomy has defined the context of sedentary behaviour to have several distinct facets, including what (the specific activity), why (the purpose), and with whom (the social setting) [35]. In order to understand the context of sedentary behaviour in older adults, a mixed use of objective activity monitoring and time-lapse photography has been shown to be acceptable to older people [36]. Leask et al. [37] objectively measured the context of sedentary behaviour in older adults by using a body-worn time-lapse camera in combination with an activPAL monitor to quantify older adults' sedentary periods. Palmer et al. [38] did in-depth interviews with older people about what they do when they are sedentary.

13.2.1 What Older Adults Are Doing When Sedentary

The majority of older adults' sedentary time is non-screen time (63.9%), with 36.1% of sedentary time in front of a screen [37]. The main non-screen-based sedentary activities include reading (22.9%), eating (7.4%), and driving (7.4%) (Fig. 13.3). Of screen-based periods, television viewing, computer/laptop usage, and using small devices comprise 84%, 9.6%, and 5.9% of time respectively. When interviewed, older adults described many different leisure time, household, transport, and occupational sitting and non-sitting activities [38]. The distinction between being busy/not busy was more important to older people than sitting/not sitting, and informed their judgments about high-value 'purposeful' (social, cognitively active, restorative) sitting and low-value 'passive' sitting [38].

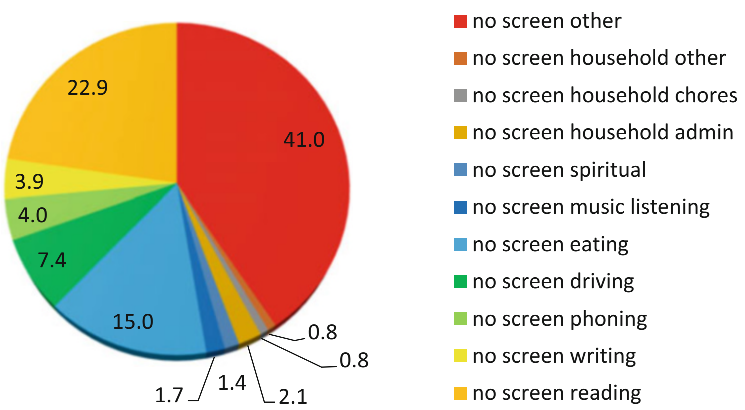

Fig. 13.3 Distribution of the non-screen-based sedentary time (% of day) in older adults (≥65 years), adapted from Leask et al. [38]

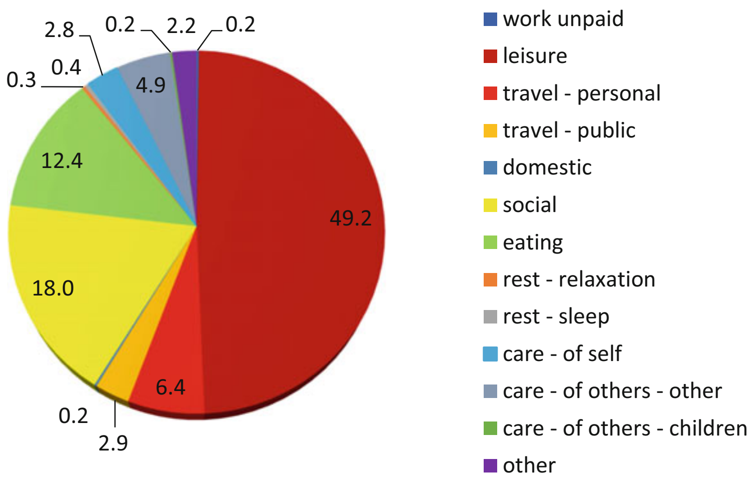

Fig. 13.4 Distribution of the purpose of sedentary time (% of day) in older adults (≥65 years), adapted from Leask et al. [38]

13.2.2 Why Older Adults Are Sedentary?

The purpose for older adults' sedentary time, as defined by a researcher and viewed on the time-lapse camera, were predominantly leisure (49.2%), social (18%), and eating (12.4%) (Fig. 13.4) [37]. Although older adults spend a large percentage of sedentary bouts in public and personal travel, these facets do not account for large percentages of sedentary time (6.4% and 2.9% respectively) [37].

13.2.3 With Whom Are Older Adults Sedentary?

Data shows that older adults are predominately sedentary alone (56.9% of time), however, time is also spent with their friends (11.4%) and family (21.3%) [39]. When interviewed, other people around them and access to leisure facilities were associated with lower sedentary behaviour in the views of older people [38].

13.2.4 What Do Older Adults Perceive as the Reasons for Their Sedentary Behaviour?

In order to understand why older adults think they are sedentary, in a mixed-methods study, 30 older adults (mean age 74 years) were asked to recollect their believed reasons for (breaking) sedentary behaviour and these were compared with their actual reasons after looking at the images [40]. The most frequent reasons that the older adults believed kept them sedentary were television/radio (48.3%), fatigue (34.5%), and health status (31.0%). However, the factors most often mentioned as actual reasons following viewing images were eating/drinking (96.6%), television/radio (89.7%), and reading/crosswords (75.9%). Domestic chores (55.2%), walking (37.9%), and socialising (20.7%) were most often mentioned as reasons that people believed made them break their sedentary behaviour, and these reasons have been reported elsewhere in qualitative work with older adults [41]. Yet, the factors that were most often mentioned as actual reasons were domestic chores (86.2%), food/tea preparation (82.8%), and performing simple tasks (75.9%) [40]. This difference between perceived reasons and actual reasons for either prolonged sitting or breaking up sitting may be useful in tailoring interventions on an individual basis.

More recently, interviews with 44 older people showed that people often positioned sitting as a moral practice, distinguishing between 'good' (active/'busy') and 'bad' (passive/'not busy') sitting. This allowed them to align themselves with acceptable (worthwhile) forms of sitting and distance themselves from other people whose sitting they viewed as less worthwhile [42]. However, some participants also described needing to sit more as they got older. The findings suggest that some public health messaging may lead to stigmatisation around sitting [42].

13.3 Effects of Sedentary Behaviour in Older Adults

13.3.1 Mortality and Life Expectancy

There is strong evidence that a relationship exists between sedentary behaviour and mortality in both men and women from all-causes and cardiovascular disease [39, 43] (see also Chaps. 8 and 14). A recent meta-analysis and meta-regression analysis of eleven cohorts ($n = 38{,}141$ participants) showed that comparing the most sedentary with the least sedentary groups of participants resulted in a pooled hazard ratio of 2.44 (95% confidence interval (CI) 1.82–3.25) with clear dose–response relationships between total sedentary behaviour, steps per day and mortality risk [44].

The ability to break prolonged periods of sitting will be affected by ability to rise from a chair easily and one review of mortality showed that those taking the longest to rise have nearly a two-fold increase in risk of mortality compared to those who rise easily [45]. Three of the studies also reported effect estimates from comparisons of people unable to do chair rises with those in the fastest quarter; the summary hazard ratio for mortality from a meta-analysis of these three results suggested that those unable to do chair rises had the highest rates of mortality [45].

Katzmarzyk and Lee [46] examined the effect of self-reported sedentary behaviour on life expectancy in the USA and found expected gains in life expectancy of 2 years for reducing sitting to less than 3 hours daily and a gain of 1.38 years by reducing television viewing to less than 2 hours. Indeed, long periods of sitting are associated with a bigger waist-to-hip ratio and therefore an increased risk of metabolic syndrome and stroke [47]. There is a positive and escalating linear association between sedentary bout length and waist circumference in older adults, with the odds of being abdominally obese rising by 48% for each 1 hour sedentary bout increment [48]. Longitudinal studies and cross-sectional studies have indicated a relationship between high levels of sedentary behaviour and incidence of: metabolic syndrome, diabetes, obesity, cardiovascular disease, high cholesterol, gallstone disease, and certain cancers (ovarian, colon, endometrial and possibly breast cancer and renal cell carcinoma) [5, 39, 43, 47, 49, 50].

A recent systematic review of sedentary behaviour and obesity ($n = 638{,}000$ adults and older adults) found elevated rates of sedentary behaviour in people with obesity but that the range of different measures, methods, and cut-off points used in the measurement of sedentary behaviour made risk estimates difficult [51]. Telomere length is associated with a healthy lifestyle and longevity and a physical activity intervention that reduced self-reported sitting time in sedentary overweight older individuals showed that telomere lengthening was significantly associated with reduced sitting time [52].

Another potential reason for reduced longevity is the link between higher sedentary behaviour and arteriosclerosis (arterial stiffness and cardio-ankle vascular index) [53]. A review of outcomes of sedentary behaviour in older people concluded that there was an association between sedentary time and geriatric-relevant health outcomes, but that the body of longitudinal evidence was insufficient yet to determine a dose–response relationship or a threshold for clinically relevant risk [54].

13.3.2 Quality of Life and Activities of Daily Living

A number of studies have now shown associations with sedentary behaviour and quality of life [55–58].

Higher physical activity and lower sedentary behaviour, in a large review, are associated with better ability to complete activities of daily living (ADL) and instrumental ADL (IADL) in 6 longitudinal studies and overall results of cross-sectional studies ($n = 24$) supported these associations. However, the effect sizes were relatively small [59]. In a large nationally representative sample of older people who completed self-reported sedentary behaviour in 6 domains (watching television, using a computer/tablet, talking to friends or family members, doing hobby or other activities, transportation, and resting/napping) health outcomes were analysed [60]. Those aged over 80 who had high levels of sedentary time, which was not mentally stimulating, had more difficulties of activities of daily living, more problems limiting activities, and lower cognitive function than those who had lower levels of sedentary behaviour or those who engaged in cognitively stimulating sedentary behaviour [60]. Continence is sometimes a reason given for being less active (not being too far from a toilet), and urgency urinary incontinence is significantly associated with increased average duration sedentary behaviour bouts, but not stress urinary incontinence [61].

The lack of mobilisation and prevalent sedentary behaviour is one of the main reasons for the dramatic loss of ability to perform activities of daily living seen in older people following hospital admission, a phenomenon that may be referred to as 'hospital-associated deconditioning' or 'post-hospital syndrome' [62]. Up to 30% of acutely hospitalised older adults will experience a loss of independence in activities of daily living such as dressing, eating, and maintaining hygiene and continence following admission [63].

13.3.3 Muscle Strength and Physical Function

Even healthy adults can experience significant physiological changes from prolonged immobility, as found by a study conducted with a group of healthy older adults placed on bed rest for 10 days [64]. This study observed a significant decrease in muscle protein synthesis, strength, and lower extremity and whole-body mass. All measures of lower extremity strength were significantly lower after bed rest including isotonic knee extensor strength, stair-climbing power and maximal aerobic capacity. Interestingly this led to a reduction in voluntary physical activity after bed rest, and the percentage of time spent inactive increased [65].

In those living in residential care settings, total time in sedentary behaviour was associated with sarcopenia [66]. 'Acute sarcopenia' is a related concept, manifesting as a rapid reduction in muscle mass and function, caused by a combination of the inflammatory burden and endocrine dysregulation associated with acute illness, together with muscle disuse resulting from prolonged bed rest [67]. Sarcopenia can result in mobility problems, falls, loss of independence, and impaired ability to perform daily activities [68]. Lower sedentary behaviour is associated with better upper and lower body muscle strength and power [69]. In a cross-sectional study of older men and women who had self-reported total sitting and television viewing time recorded alongside total body and regional lean mass and fat mass (dual-energy X-ray absorptiometry), lower limb muscle strength and power, sarcopenia was associated with total sitting time and lower total body muscle mass and lower leg muscle mass were associated with television viewing time [70]. Indeed, for each 1-hour increment in total sitting time the risk of sarcopenia increased by 33% [70].

Sedentary behaviour has been associated with diminished physical function over time [71, 72]. Objectively measured sedentary behaviour is associated with worse physical function measured using the Short Physical Performance Battery, balance task scores, 400 m walk time, chair stand time, and gait speed [73]. Even in young old age (60–64 years), time spent sedentary is associated with lower grip strength and lower timed up and go speed [74]. Self-reported television time was positively related to 400 m walk time [73] and prolonged television viewing has been related to reduced grip strength, in contrast to use of the internet, which showed a positive relationship [75].

A longitudinal study of 5408 middle-aged and older people showed that over a 3-year period, greater sedentary time was significantly associated with poorer chair stand and timed walk scores [76]. High sedentary time in combination with low physical activity levels (but not in combination with high moderate-to-vigorous physical activity (MVPA) levels) was associated with poorer physical function compared with the reference group (low sedentary time/high MVPA, suggesting that the effects of sedentary behaviour on function might be mediated by the individuals being fairly active when they are not sitting [76]. By substituting 30 minutes of sedentary time with 30 minutes of MVPA improvements in chair stands (β −0.57) and timed walk (β −0.36) were seen. Similar, but less robust findings, were observed for reallocations of sedentary time to light-intensity physical activity [76].

Another large study looked at the associations of replacing sedentary behaviour with physical activity of different intensities on the physical function of over 80 s living in long-term care facilities. It found that reallocation of sedentary behaviour to light-intensity physical activity (and greater intensity) was associated with less time in the Timed Up and Go Test and higher levels of grip strength [77].

Breaking up sedentary time has been associated with better physical function in older adults. Using the Senior Fitness Test composite score, those older adults who broke their sedentary behaviour more (even after adjusting for total sedentary time and moderate-to-vigorous physical activity) performed better [78]. Indeed, one recent sedentary behaviour intervention, which did not show any effect on total sedentary time in those living in residential settings, did show improved physical function (timed up and go and chair rise) after participants set goals to reduce waking day sitting bouts to a maximum of 30–60 minutes over a ten-week intervention period [79].

13.3.4 Frailty and Falls

Frailty is strongly associated with sedentary behaviour [80, 81] and sedentary behaviour (>7 hours per day measured on self-report) can be a potential marker in the screening of frailty in community-dwelling older adults [82]. Examination of large health survey data and objective monitoring suggests those most sedentary have higher levels of frailty, high activity of daily living disability and have higher healthcare usage [81]. A recent systematic review looking at objectively measured sedentary behaviour showed a small effect size ($\beta = 0.100$ [0.001, 0.249]) of sedentary behaviour on frailty, with measures of physical activity (total, steps, sit-to-stand transitions and energy expenditure) having a greater effect size ($\beta = -0.272$ [−0.381, −0.107]) [83]. In another large cross-sectional analysis, those with sitting time < 4 h/day (measured using IPAQ self-report) with those with a sitting time of ≥8 h/day were significantly more likely to be diagnosed with frailty (Odds ratio (OR), 3.140) [84]. Each one unit increase in sitting time (h/day) was related to average 1.114 (units on frailty index) increase in prevalence of frailty. This study found positive associations of physical activity and frailty but that excess sitting time may counteract the beneficial effects of physical activity on frailty [84].

Finally, in terms of falls, a recent systematic review has shown that although fear of falling is associated with greater sedentary behaviour, associations with falls or fractures showed inconsistent effect directions [85]. Fallers spend more time sedentary than non-fallers (22 minutes per day extra in men), and if they also experience fear of falling, there is an additional 45 minutes of sedentary time per day [86].

13.3.5 Bone Health

A systematic review found two prospective and five cross-sectional observational studies which had examined the association between bone health and sedentary behaviour in older adults [87]. Findings were varied and suggested differences in genders. In women, four studies reported significant positive associations of sedentary behaviour with bone mineral density at different sites, but two found significant negative associations. However, studies which examined men reported negative or no associations. The differences seen could be due to the different anatomical sites considered, the different methods used to measure sedentary behaviour, and the varied quality of the studies. Recently, in Mexico, older participants with higher levels of moderate-to-vigorous physical activity levels had higher total bone mineral density and also cortical thickness [88]. One study considering self-reported sedentary behaviour in 77,206 women and looking at fracture risk over 14 years found, after controlling for covariates and total physical activity, sedentary time was positively associated with total fracture risk (>9.5 h/d vs <6.5 h/d: HR, 1.04) [89].

13.3.6 Mental Health and Cognition

Sitting, television time, and screen time have all been associated with negative mental health outcomes and reduced levels of cognition [75, 90]. Sedentary pastimes have also been associated with executive dysfunction [91]. Interestingly, fallers are known to have executive dysfunction and fear of falling is associated with high sedentary time in older adults [73].

High television viewing has been related to lower psychological well-being and depression [11], mood disorder and sense of belonging to community [92] and long periods of sitting are associated with depression and social isolation [47]. In order to see if the link between sedentary behaviour and depression was related to underlying inflammatory processes, Hamer et al. [93] looked at C-reactive protein and self-reported television viewing time. Those older adults who watch more television had higher C-reactive protein and higher levels of depression. A longitudinal cohort study looking at incident depressive symptoms in older adults over a 15-month period showed a strong association with incident depression and sitting for over 4 or

8 hours compared with sitting under 4 hours [94]. In a large cross-sectional study in China, people who were sedentary for greater than 6 hours a day were three times more likely to report depression than those who reported sitting for less than 6 hours per day [95]. There is an association between loneliness and sedentary time [96]. There does not appear to be any relationship between sedentary behaviour and personality traits [97]. In two cohorts in Scotland, there was no association between well-being or symptoms of anxiety and sedentary outcomes but depression was associated with sedentary time [98]. Attitudes to ageing in the 70s did not predict sedentary behaviour 7 years later [99]. In the same cohorts, there was no evidence that objectively measured sedentary time was associated with measures of cognitive ability at different time points in life, including cognitive change from childhood to older age [100].

The association of sedentary behaviour with mental health is not simple. Several sedentary activities were found to be positively associated with self-reported measures of psychosocial wellness in middle-aged and older adults [101]. Among respondents not diagnosed with a mood disorder, positive associations were noted for crosswords/puzzles and listening to radio/music or playing an instrument. Satisfaction with life was positively associated with computer use and a sense of belonging was consistently positively associated with sedentary activities [101]. In older adults providing care reduced sedentary time is seen compared to those not providing care [102].

Not all sitting is bad, with certain sedentary tasks such as computer use, playing games, and completing craft projects being positively associated with cognition [47, 75, 90]. In a review of 45 articles with 15,817 older adults, Rojer et al. [103] found that lower objectively measured sedentary behaviour was associated with better global cognitive function. In a 15-year prospective study, the risk of dementia was examined against sedentary behaviour and no relationship was observed [104]. However, one study looking at cerebral blood flow in older adults has found that sedentary time may act as a behavioural risk factor for blood flow dysfunction in those at generic risk of Alzheimer's disease [105]. For further detail on the association between sedentary behaviour and psychosocial health in older adults, please refer to Chap. 12.

13.4 Acute Effects of Sedentary Behaviour in Older Adults

Lack of movement during long periods of sitting might temporally affect function, due to increased joint stiffness and decreased neuronal input, making it difficult to stand and, therefore, engage in upright activity [106]. When temperatures are above or below normal, the effects of even short periods of sitting can be marked. One study showed that women, aged 70 years and older, sitting in a cold room (15 °C) for just 45 minutes, led to an average loss of 5% of explosive muscle power leading to a reduced sit-to-stand velocity (10%) and 3.5% slower walking speed [107]. The same research group also looked at older women sitting in a hot (30 °C) room for

45 minutes and saw a marked increase in postural hypotension, increased blood pressure, and reduced stamina [108].

13.4.1 Who Should We Target?

Although increasing age is associated with higher sedentary behaviour, biological age, as indexed by extrinsic or intrinsic epigenetic age acceleration, does not appear to be associated with sedentary behaviour [109]. High levels of sitting time in older adults is associated with being single, living in an urban area, and having post high school education in women [110]. Adverse socioeconomic circumstance and lower education has been related to screen-based activities [17]. In two cohorts of older people, a range of socioeconomic position measures and social disadvantage were associated with increased sedentary time [111]. In one cohort of older people, those most deprived on the Carstairs measure spent 6.5% more of their waking time sedentary than the least deprived. However, for employed older people, the relationship was much weaker. For example, in terms of social class differences, the most disadvantaged spent 5.7% more waking time sedentary, whereas among the employed, there was no difference [111]. Some of this relationship of sedentary time with social and economic disadvantage may be affected by the relationship seen between fear of crime and perceived absence of services to support activity [102].

It certainly seems as if targeting those with a low socioeconomic status, those not using the internet, those with a higher body mass index (BMI) status and those with poorer cognitive function and the presence of depressive symptoms will help in public health terms as it is these older adults who, over time, increase their sedentary behaviour over a two-year period [112, 113].

13.5 Barriers and Facilitators to Reducing Sedentary Behaviour in Older People

Older adults perceive the breaking up of prolonged periods of sitting as more achievable than increasing moderate-to-vigorous physical activity and so interventions should focus on the perceived ease of these interventions and the potential positive benefits of breaking up prolonged sitting [114]. Understanding what the barriers and facilitators to engaging in an intervention to reduce sedentary behaviour is important to uptake and adherence.

Table 13.1 Motivators and barriers to reducing sedentary behaviour in older adults (data from qualitative and quantitative studies)

Motivators		Barriers	
Personal motivators	• Good health (cognition, less co-morbidities, better functional ability). • Desire to improve health. • Awareness of sedentary behaviour. • Monitoring Standing fits lifestyle. • Easy to make standing a habit. • Curious about their sedentary behaviour. • Reducing sedentary behaviour is a self-competition. • Notice positive impacts. • Sense of achievement. • Enjoy being more active during breaks. • Locus of control. • Self-efficacy for physical activity.	Personal barriers	• Health barriers (body mass index, smokers, depressive symptoms, cognition, polypharmacy, functional difficulties). • Enjoy sedentary activities. • Feel active so do not see sitting as problematic. • Difficulty conceptualising or applying sedentary behaviour distinct from physical activity. • Lack of time. • Fatigue/lack of energy. • Pain. • Sitting habits hard to break. • Lower socioeconomic status. • Depression. • Poor perceived health.
Social motivators	• Encouragement from others.	Social barriers	• Inappropriate amount/type of social support. • Social pressure. • Ageist stereotyping.
Environment motivators	• Adaptable home or work environment.	Environment barriers	• Unadaptable environment.
Program motivators	• Activity monitors are a reminder. • Feedback was interesting. • Positive experiences with health coaches. • Goals helpful and appropriate. • Timers/alarms to remind to stand. • Self-log provides accountability. • Workbooks had useful information and ideas.	Program barriers	• No accountability for self-logs. • Difficulty with goal setting feedback hard to interpret. • Health coach calls too long. • Intervention too short. • Reminders were agitating or hard to use.

Adapted from qualitative studies: [35, 38, 42, 79, 114, 115] and quantitative studies: [112, 113, 116, 117]

13.5.1 Community-Dwelling Older People

There is emerging literature as to the motivators and barriers to reducing sedentary behaviour (as opposed to increasing physical activity) in older adults (Table 13.1), which will be able to help guide sedentary behaviour interventions. A series of semi-structured interviews with a group of overweight and obese older individuals showed that motivators to reducing sedentary behaviour were the desire to improve health, newly acquired knowledge of sedentary behaviour, the ease of incorporating sedentary behaviour reduction into current lifestyle, an adaptable environment and the use of reminders or prompts [115]. The barriers included existing health conditions, the enjoyment of sedentary activities, unadaptable environments or social contexts, fatigue and difficulty in understanding sedentary behaviour reduction as distinct from physical activity. Other barriers include pain, social pressure and a lack of energy [35], abnormal BMI, smoking, and polypharmacy [116]. Because sitting is ubiquitous and occurs throughout the day, there may be unique aspects involved in changing sedentary behaviour compared with physical activity in older adults. It is likely that strategies involving built environment changes or prompts are key [118], although much of the previous work on this has involved providing sit–stand workstations or treadmill desks to reduce workplace sitting which may be less relevant to older adults who are retired or working part time. Certainly, older adults perceive sedentary behaviour interventions as being easier to incorporate into daily life than physical activity interventions, but note that the development of new routines, the encouragement of family members and awareness of the culture of sitting in older people and a willingness to challenge this were important [115].

In younger people (aged 20–64 years) there is an energy cost to the sit-to-stand transition (VO_2 for sit-to-stand transition 3.86 ml kg^{-1} min^{-1}); however, the metabolic cost of the sit-to-stand transition is only 0.32 kcal min^{-1} above sitting, so the modest energetic cost (compared to exercise), regardless of gender or body composition should be a public health message to interrupt sitting frequently [119]). Indeed, sit-to-stand transitions could be seen as small bouts of functional training that are achievable for older adults that are not able to engage in exercise programmes requiring a greater energy cost. This alongside the known association of chair rise ability and mortality [45] and improvements in sit-to-stand ability with repeated sit-to-stand practice [79] could be a good motivator for older people to break prolonged periods of sitting. The notion that minimising and/or breaking up sedentary behaviour could contribute to a more active lifestyle captured the attention of older adults and was motivating in terms of being readily achievable and capable of being instigated instantly without cost or pre-planning in one qualitative study [114]. However, the notion of balancing active and non-active periods in order to provide sufficient rest resonated particularly with those adults aged 75+ years, and those with long-term health conditions and learning disabilities, highlighting an example of where interventions need to be tailored to each individual and consider their needs and preferences [114].

The involvement of older adults in the design of a sedentary behaviour intervention is likely to improve acceptability and uptake. A group of older people have been involved in the co-creation of a sedentary behaviour intervention and have developed a daily diary which allows personalisation based on individual preferences, understanding personal behavioural assets to break up prolonged sitting, action planning and reviewing their perceptions of change over time [120]. In a series of focus groups with older people, they suggested that a good strategy to help older people break up long periods of sitting was to use the activities of daily routine and reasons why individuals already naturally interrupting their sedentary behaviour, in other words, look to an 'asset-based approach' [41]. These assets were categorised into 5 sub-themes: physical assets (e.g., standing up to reduce stiffness); psychological assets (e.g., standing up to reduce feelings of guilt); interpersonal assets (e.g., standing up to answer the phone); knowledge assets (e.g., standing up due to knowing the benefits of breaking sedentary behaviour), and activities of daily living assets (e.g., standing up to get a drink).

13.5.2 Assisted Care and Nursing Care Settings

The fit between someone's abilities and the demands of the environment (person-environment fit) appears important to residents' engagement in activity and ability or willingness to displace sitting time with physical activity [121]. Environmental demands can include the distance between rooms that people visit, closeness of call-bells to their bed or seat, handrail placement, floor coverings, places to sit along corridors, nothing to look at along corridors, height of chairs, and tilt of seat of chairs [121]. Lower staffing levels can lead to a later time of getting up and dressed, lack of time to engage residents in movement and prompts to move, or even help out of a chair so they can move, and some staff understand the value of re-enablement and invite residents to help with chores or encourage them to use the communal area for eating, for example, and others do not [121]. At the personal level, many residents are multimorbid, frail and there is a high level of dementia and depression in these settings, all of which impact on engagement in activity or willingness to break up sedentary behaviour. Some do not want to 'waste' carers time, some look on being in a care home as a time to 'rest' or prepare for 'death' [122].

13.5.3 Hospital Settings

The barriers to inpatient mobility have been explored and a number of factors have been identified that contribute to the sedentary behaviour of inpatients. Risk aversion from both a patient, clinician and institutional perspective, in particular with regard to falls, is one such factor. Resnick et al. [22] found that optimising physical activity of patients was a low priority for the nurses with patient safety taking precedence.

Given that up to 10% of older adults experience a fall during hospitalisation this concern is well founded [123], yet activity restriction may instead result in increased fall risk by contributing to deconditioning and functional loss [124]. However, fear of falling in patients in a hospital setting is also important, with one study showing fear of falling led to patients curtailing their activity in hospital [125]. Further barriers to movement include environmental factors such as a lack of assistive mobility aids, tethering to medical equipment, unfamiliar surroundings and the design of hospital beds/wards, patient factors such as feeling ill, being unmotivated to move and feeling like a burden on staff when seeking support to be active [126, 127]. Reducing sedentary behaviour in hospital inpatients is influenced by a range of complex and multi-level factors. Organisational and clinical leadership is required to build a culture and climate in which staff feel empowered to overcome barriers and promote and facilitate reduced sedentary behaviour in their patients [128].

13.6 Interventions to Reduce Sedentary Behaviour in Older People

Despite the potential health benefits (Table 13.2), Studies on interventions to reduce sedentary behaviour in older adults are still in their infancy compared to interventions aimed at increasing physical activity [134]. A consensus statement on research priorities for sedentary time in older people has called for research to assess the

Table 13.2 Potential effects of sedentary behaviour interventions in older adults (data from qualitative and quantitative studies)

Physical Health	Mental Health	Other
Easier to move around	General feelings of better health and well-being	Increase in devoted physical activity time, especially daily walking
Reduced stiffness	Improvements to overall mood	Heightened awareness of sedentary behaviour in his/her own life
Better balance	More alert throughout the day	Heightened awareness of how much sedentary behaviour is encouraged in society
Improved walking speed	Improved concentration	Increase in daily light activity levels, such as household chores
Improved chronic pain management	Reduced depressive symptoms	Increased standing time and standing activities
Better sleep quality		Increased breaks in prolonged sitting time (sit-to-stand transitions)
Less fatigue		Reduced TV time
Better perceived health		Changes in amount of socialisation
Lengthened telomere length		Self-efficacy for physical activity
		Increased walking

Adapted from qualitative studies: [79, 115] and quantitative studies [52, 117, 129–133] impact that reducing sedentary time, or breaking up prolonged bouts of sedentary time, has on geriatric-relevant health outcomes, in particular to consider dose–response relationships [135]. For more information on approaches to decrease sedentary behaviour among older adults, please refer to Chap. 19.

13.6.1 Community-Dwelling Older Adults

The last five years has seen a growth in number of studies focussing on reducing sedentary behaviour, mostly short term and with a variety of methods of measuring and reporting sedentary time. One review considered 17 studies in a narrative review and 8 within a meta-analysis ($n = 1024$ participants) and concluded that although the interventions significantly reduced sedentary time, the overall effect was small ($d = -0.25$, 95% CI [−0.50, 0.00]) [6]. Another review specifically focussing on reducing non-occupational sedentary behaviour found no studies in older adults [136]. A Cochrane systematic review and meta-analysis found, in 7 studies ($n = 397$) with majority female and highly educated participants, in high income countries, that interventions may reduce sedentary time (mean difference (MD) − 44.91 min/day, 95% CI [−93.13 to 3.32] but they could not pool evidence on the effect of interventions on breaks in sedentary behaviour or time spent in specific domains such as TV time, as data from only one study were available for these outcomes [134]. This review also showed little evidence for improved physical function, fitness, blood pressure or glucose blood levels and no data on cognitive function or adverse events. Most interventions were theory-driven and employed multiple strategies, including education, self-monitoring, and goal setting [134, 137, 138]. Both reviews recommended that future research should recruit larger samples, use device-based measures of sedentary time, include measures of time spent in specific sedentary behaviours, duration and number of breaks in sedentary time and that practitioners should employ diverse sedentary behaviour-specific strategies (as opposed to increasing physical activity) to encourage older adults to reduce time spent sedentary [134, 137, 138]. Chastin et al. [134] also called for interventions that aimed at modifying the environment, policy, and social and cultural norms.

Inconsistent results from studies may be confounded by different levels of function and frailty that may affect motivation and ability to reduce sedentary behaviour. An 8-week sedentary behaviour intervention (‘On your feet to earn your seat’ booklet with 16 tips to reduce sedentary behaviour) in assisted living facilities and in community-dwelling older adults (>6 hours per day self-reported sitting) showed an effect on reported sitting time only in the community-dwelling older adults [129].

There have been a large number of mobile health technology studies published in the area of physical activity but less specifically on reducing sedentary behaviour. A scoping review of mHealth applications with potential to support older adults to reduce sedentary behaviour found only 3 studies which had reducing sedentary behaviour as a target but these often aided self-regulation of physical activity rather than sedentary behaviour and most sedentary behaviour outcomes were inconclusive [139]. King et al. [130] used mobile phone applications over an 8-week period to successfully promote reducing sedentary behaviour in aging adults (average age = 59.1 years). Three behaviour change apps to promote regular physical activity and reduce sedentary behaviour, based on three distinct motivational frames drawn from behavioural science theory and evidence, were used. Following their 8-week behavioural adoption period, there was a significant decrease in discretionary television viewing, with average television viewing time being reduced by 29.1 minutes [130].

13.6.2 Assisted Care and Nursing Care Settings

Recent studies aimed at reducing sedentary behaviour in care home residents have shown mixed results. A cluster-randomised trial, in 10 Dutch Care Homes, of a re-enablement programme targeting sedentary behaviour in those receiving care at home over a 12-month period, found no changes in sedentary time and was not cost-effective compared to usual care [140].

An intervention, lasting 3 months, involving activity monitoring feedback and motivation consultations (one per month) in residents living in assisted care facilities, showed no changes to total sitting time but did show improvements in the 30 second sit-to-stand and timed-up and go tests of function [79]. Sedentary behaviour was highly variable throughout the study within individuals, reflecting health and other personal issues in this frail group. Those who had vibrational feedback (set to vibrate at personalised time periods) had better outcomes than those who just received feedback each month from the activity monitors [79].

One pilot RCT in 4 care homes in two European Countries looked at the implementation of the Get Ready intervention, delivered by a staff champion one-to-one with the care home resident and a family member [141]. The intervention, with six face-to-face sessions over a twelve-week period showed a decrease in daily hours spent sitting (Cohen's $d = 0.36$) and improvements in health-related quality of life, fear of falling, and habitual gait speed compared to usual care. However, this needs confirmation in a definitive trial [141].

13.6.3 Hospital Settings

A number of public health campaigns encouraging continued inpatient mobility have gained recognition both in hospitals and on social media platforms. Examples include '#endPJparalysis' [142] and the Johns Hopkins Activity and Mobility Promotion '#everyBODYmoves' campaign [143]. The aim of such initiatives is to prevent deconditioning by encouraging and facilitating patients to go about their usual daily activities as far as safely possible. A large Delphi consensus study has recently produced recommendations on physical activity for inpatients, emphasising the importance of reducing prolonged periods of lying and sitting, and incorporating opportunities for physical activity into the daily care, of older patients, with a focus on promoting function, independence, and activities of daily living [144].

Numerous interventions have been trialled to reduce inpatient sedentary behaviour and the incidence of functional decline, including patient education, early mobilisation, encouraging patients to get up, dressed and perform their usual daily activities, individual patient activity plans, group activity sessions, supervised ambulation, medication reviews, and comprehensive geriatric assessment [145, 146]. Evidence for the efficacy of such interventions is limited however. A systematic review, comparing interventions to reduce hospital-associated deconditioning with standard care, identified seven randomised controlled trials, based in acute medical wards, which investigated increasing physical activity through education, changing healthcare practice, and/or changing ward environments [146]. The review indicated such interventions may be beneficial in reducing the risk of decline in ADL score by 4% at discharge, residing in a nursing home between 1–3 months post-discharge by 8%, and mortality at 1 month post-discharge by 23%, however the evidence was appraised as low quality [146]. More high-quality research is required to support the introduction of interventions in clinical practice.

13.7 Conclusions

Sedentary behaviour is extremely prevalent in community-dwelling older adults and is even greater in those admitted to hospital or those living in residential settings. Although some sedentary activities are cognitively enhancing, the poor long-term health outcomes of those with prolonged sitting periods in the day are clear and independent of physical activity. Interventions to reduce sedentary behaviour appear more acceptable to older people than interventions aimed at increasing moderate-to-vigorous activity. Current evidence suggests that interventions aimed at personal factors show only a minimal decrease in sedentary behaviour but the potential for some functional improvements in those more frail. There is a need for interventions to consider environment, social context, culture and policy. More work in the older population, particularly those transitioning into frailty, is needed.

References

1. Harvey JA, Chastin SF, Skelton DA. Prevalence of sedentary behavior in older adults: a systematic review. Int J Environ Res Public Health. 2013;10(12):6645–61.
2. Ramsey KA, Loveland P, Rojer AGM, Denehy L, Goonan R, Marston C, et al. Geriatric rehabilitation inpatients Roam at home! A matched cohort study of objectively measured

physical activity and sedentary behavior in home-based and hospital-based settings. J Am Med Dir Assoc. 2021;22(12):2432–9 e1.
3. Chastin SFM, Dontje ML, Skelton DA, Cukic I, Shaw RJ, Gill JMR, et al. Systematic comparative validation of self-report measures of sedentary time against an objective measure of postural sitting (activPAL). Int J Behav Nutr Phys Act. 2018;15(1):21.
4. Dontje ML, Dall PM, Skelton DA, Gill JMR, Chastin SFM, Seniors USPT. Reliability, minimal detectable change and responsiveness to change: Indicators to select the best method to measure sedentary behaviour in older adults in different study designs. PLoS One. 2018;13(4):e0195424.
5. Stamatakis E, Davis M, Stathi A, Hamer M. Associations between multiple indicators of objectively-measured and self-reported sedentary behaviour and cardiometabolic risk in older adults. Prev Med. 2012;54(1):82–7.
6. Harvey JA, Chastin SF, Skelton DA. How sedentary are older people? A systematic review of the amount of sedentary behavior. J Aging Phys Act. 2015;23(3):471–87.
7. Hamer M, Kivimaki M, Steptoe A. Longitudinal patterns in physical activity and sedentary behaviour from mid-life to early old age: a substudy of the Whitehall II cohort. J Epidemiol Community Health. 2012;66(12):1110–5.
8. Bann D, Hire D, Manini T, Cooper R, Botoseneanu A, McDermott MM, et al. Light Intensity physical activity and sedentary behavior in relation to body mass index and grip strength in older adults: cross-sectional findings from the Lifestyle Interventions and Independence for Elders (LIFE) study. PLoS One. 2015;10(2):e0116058.
9. Sartini C, Wannamethee SG, Iliffe S, Morris RW, Ash S, Lennon L, et al. Diurnal patterns of objectively measured physical activity and sedentary behaviour in older men. BMC Public Health. 2015;15:609.
10. Withall J, Stathi A, Davis M, Coulson J, Thompson JL, Fox KR. Objective indicators of physical activity and sedentary time and associations with subjective well-being in adults aged 70 and over. Int J Environ Res Public Health. 2014;11(1):643–56.
11. Rhodes RE, Mark RS, Temmel CP. Adult sedentary behavior: a systematic review. Am J Prev Med. 2012;42(3):e3–28.
12. Bellettiere J, Carlson JA, Rosenberg D, Singhania A, Natarajan L, Berardi V, et al. Gender and age differences in hourly and daily patterns of sedentary time in older adults living in retirement communities. PLoS One. 2015;10(8):e0136161.
13. Piirtola M, Kaprio J, Ropponen A. A study of sedentary behaviour in the older Finnish twin cohort: a cross sectional analysis. Biomed Res Int. 2014;2014:209140.
14. Stobert S, Doseman D, Keating N. Aging well: time use patterns of older Canadians 2005. Statistics Canada, Social and Aboriginal Statistic Division; 2006. Contract No.: 89-622-XIE.
15. Krantz-Kent R, Stewart J. How do older Americans spend their time?. Monthly Labor Review, US Department of Labor, Bureau of Labor Statistics. 2007;130(5):8–26.
16. Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. Am J Clin Nutr. 2012;95(2):437–45.
17. Stamatakis E, Hillsdon M, Mishra G, Hamer M, Marmot M. Television viewing and other screen-based entertainment in relation to multiple socioeconomic status indicators and area deprivation: the Scottish Health Survey 2003. J Epidemiol Community Health. 2009;63(9):734–40.
18. Dunstan DW, Barr EL, Healy GN, Salmon J, Shaw JE, Balkau B, et al. Television viewing time and mortality: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Circulation. 2010;121(3):384–91.
19. Aadahl M, Andreasen AH, Hammer-Helmich L, Buhelt L, Jorgensen T, Glumer C. Recent temporal trends in sleep duration, domain-specific sedentary behaviour and physical activity. A survey among 25–79-year-old Danish adults. Scand J Public Health. 2013;41(7):706–11.
20. Arnardottir NY, Koster A, Van Domelen DR, Brychta RJ, Caserotti P, Eiriksdottir G, et al. Objective measurements of daily physical activity patterns and sedentary behaviour in older

adults: Age, Gene/Environment Susceptibility-Reykjavik Study. Age Ageing. 2013;42(2): 222–9.

21. Lohne-Seiler H, Hansen BH, Kolle E, Anderssen SA. Accelerometer-determined physical activity and self-reported health in a population of older adults (65–85 years): a cross-sectional study. BMC Public Health. 2014;14:284.
22. Resnick B, Galik E, Wells CL, Boltz M, Holtzman L. Optimizing physical activity among older adults post trauma: overcoming system and patient challenges. Int J Orthop Trauma Nurs. 2015;19(4):194–206.
23. Barber SE, Forster A, Birch KM. Levels and patterns of daily physical activity and sedentary behavior measured objectively in older care home residents in the United Kingdom. J Aging Phys Act. 2015;23(1):133–43.
24. Reid N, Eakin E, Henwood T, Keogh JW, Senior HE, Gardiner PA, et al. Objectively measured activity patterns among adults in residential aged care. Int J Environ Res Public Health. 2013;10(12):6783–98.
25. Benjamin K, Edwards N, Ploeg J, Legault F. Barriers to physical activity and restorative care for residents in long-term care: a review of the literature. J Aging Phys Act. 2014;22(1): 154–65.
26. Brown CJ, Redden DT, Flood KL, Allman RM. The underrecognized epidemic of low mobility during hospitalization of older adults. J Am Geriatr Soc. 2009;57(9):1660–5.
27. Grant PM, Dall PM, Kerr A. Daily and hourly frequency of the sit to stand movement in older adults: a comparison of day hospital, rehabilitation ward and community living groups. Aging Clin Exp Res. 2011;23(5–6):437–44.
28. Baldwin C, van Kessel G, Phillips A, Johnston K. Accelerometry shows inpatients with acute medical or surgical conditions spend little time upright and are highly sedentary: systematic review. Phys Ther. 2017;97(11):1044–65.
29. Shepperd S, Iliffe S, Doll HA, Clarke MJ, Kalra L, Wilson AD, Gonçalves-Bradley DC. Admission avoidance hospital at home. Cochrane Database Syst Rev. 2016 Sep 1;9(9): CD007491. https://doi.org/10.1002/14651858.CD007491.pub2.
30. Goncalves-Bradley DC, Iliffe S, Doll HA, Broad J, Gladman J, Langhorne P, et al. Early discharge hospital at home. Cochrane Database Syst Rev. 2017;6(6):CD000356.
31. Scott J, Abaraogu UO, Ellis G, Gine-Garriga M, Skelton DA. A systematic review of the physical activity levels of acutely ill older adults in Hospital At Home settings: an under-researched field. Eur Geriatr Med. 2021;12(2):227–38.
32. Harvey J. What happened to my legs when I broke my arm? Case Report Infographic AIMS Med Sci. 2018;5(3):252–258.
33. Conroy DE, Maher JP, Elavsky S, Hyde AL, Doerksen SE. Sedentary behavior as a daily process regulated by habits and intentions. Health Psychol. 2013;32(11):1149–57.
34. Owen N. Sedentary behavior: understanding and influencing adults' prolonged sitting time. Prev Med. 2012;55(6):535–9.
35. Chastin SF, Fitzpatrick N, Andrews M, DiCroce N. Determinants of sedentary behavior, motivation, barriers and strategies to reduce sitting time in older women: a qualitative investigation. Int J Environ Res Public Health. 2014;11(1):773–91.
36. Harvey JA, Chastin SFM, Skelton DA. Acceptability of novel lifelogging technology to determine context of sedentary behaviour in older adults. AIMS Public Health. 2016;3(1): 158–71.
37. Leask CF, Harvey JA, Skelton DA, Chastin SF. Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). Eur Rev Aging Phys Act. 2015;12: 4.
38. Palmer VJ, Gray CM, Fitzsimons CF, Mutrie N, Wyke S, Deary IJ, et al. What do older people do when sitting and why? Implications for decreasing sedentary behavior. Gerontologist. 2019;59(4):686–97.
39. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996–2011. Am J Prev Med. 2011;41(2):207–15.

40. Dontje ML, Leask CF, Harvey J, Skelton DA, Chastin SFM. Why older adults spend time sedentary and break their sedentary behavior: a mixed-methods approach using life-logging equipment. J Aging Phys Act. 2018;26(2):259–66.
41. Leask CF, Sandlund M, Skelton DA, Tulle E, Chastin SFM. Modifying older adults' daily sedentary behaviour using an asset-based solution: views from older adults. AIMS Public Health. 2016;3(3):542–54.
42. Palmer VJ, Gray CM, Fitzsimons C, Mutrie N, Wyke S, Der G, et al. Sitting as a moral practice: Older adults' accounts from qualitative interviews on sedentary behaviours. Sociol Health Illn. 2021;43(9):2102–20.
43. Proper KI, Singh AS, van Mechelen W, Chinapaw MJ. Sedentary behaviors and health outcomes among adults: a systematic review of prospective studies. Am J Prev Med. 2011;40(2):174–82.
44. Rojer AGM, Ramsey KA, Trappenburg MC, van Rijssen NM, Otten RHJ, Heymans MW, et al. Instrumented measures of sedentary behaviour and physical activity are associated with mortality in community-dwelling older adults: a systematic review, meta-analysis and meta-regression analysis. Ageing Res Rev. 2020;61:101061.
45. Cooper R, Kuh D, Hardy R, Mortality Review G, Falcon, Teams HAS. Objectively measured physical capability levels and mortality: systematic review and meta-analysis. BMJ. 2010;341:c4467.
46. Katzmarzyk PT, Lee IM. Sedentary behaviour and life expectancy in the USA: a cause-deleted life table analysis. BMJ Open. 2012;2(4):e000828.
47. de Rezende LF, Rey-Lopez JP, Matsudo VK, do Carmo Luiz O. Sedentary behavior and health outcomes among older adults: a systematic review. BMC Public Health. 2014;14:333.
48. Judice PB, Silva AM, Sardinha LB. Sedentary bout durations are associated with abdominal obesity in older adults. J Nutr Health Aging. 2015;19(8):798–804.
49. George SM, Irwin ML, Matthews CE, Mayne ST, Gail MH, Moore SC, et al. Beyond recreational physical activity: examining occupational and household activity, transportation activity, and sedentary behavior in relation to postmenopausal breast cancer risk. Am J Public Health. 2010;100(11):2288–95.
50. George SM, Moore SC, Chow WH, Schatzkin A, Hollenbeck AR, Matthews CE. A prospective analysis of prolonged sitting time and risk of renal cell carcinoma among 300,000 older adults. Ann Epidemiol. 2011;21(10):787–90.
51. Silveira EA, Mendonca CR, Delpino FM, Elias Souza GV, de Souza P, Rosa L, de Oliveira C, et al. Sedentary behavior, physical inactivity, abdominal obesity and obesity in adults and older adults: a systematic review and meta-analysis. Clin Nutr ESPEN. 2022;50:63–73.
52. Sjogren P, Fisher R, Kallings L, Svenson U, Roos G, Hellenius ML. Stand up for health – avoiding sedentary behaviour might lengthen your telomeres: secondary outcomes from a physical activity RCT in older people. Br J Sports Med. 2014;48(19):1407–9.
53. Shiraishi N, Suzuki Y, Kuromatsu I, Komiya H, Kuzuya M. Sedentary behavior is associated with arteriosclerosis in frail older adults. Nagoya J Med Sci. 2022;84(1):91–100.
54. Copeland JL, Ashe MC, Biddle SJ, Brown WJ, Buman MP, Chastin S, et al. Sedentary time in older adults: a critical review of measurement, associations with health, and interventions. Br J Sports Med. 2017;51(21):1539.
55. Balboa-Castillo T, Leon-Munoz LM, Graciani A, Rodriguez-Artalejo F, Guallar-Castillon P. Longitudinal association of physical activity and sedentary behavior during leisure time with health-related quality of life in community-dwelling older adults. Health Qual Life Outcomes. 2011;9:47.
56. Salinas-Rodriguez A, Manrique-Espinoza B, Palazuelos-Gonzalez R, Rivera-Almaraz A, Jauregui A. Physical activity and sedentary behavior trajectories and their associations with quality of life, disability, and all-cause mortality. Eur Rev Aging Phys Act. 2022;19(1):13.
57. Taani MH, Strath SJ, Cho CC, Ellis J, Oh H. Objective physical activity levels, sedentary time, and muscle mass, strength, and function: impact on physical and mental health-related quality of life in older adults. Res Gerontol Nurs. 2022;15(3):131–9.

58. Sansano-Nadal O, Gine-Garriga M, Rodriguez-Roca B, Guerra-Balic M, Ferri K, Wilson JJ, et al. Association of self-reported and device-measured sedentary behaviour and physical activity with health-related quality of life among european older adults. Int J Environ Res Public Health. 2021;18(24).
59. Amaral Gomes ES, Ramsey KA, Rojer AGM, Reijnierse EM, Maier AB. The association of objectively measured physical activity and sedentary behavior with (instrumental) activities of daily living in community-dwelling older adults: a systematic review. Clin Interv Aging. 2021;16:1877–915.
60. Zhou W, Webster KE, Veliz PT, Larson JL. Profiles of sedentary behaviors in the oldest old: findings from the National Health and Aging Trends Study. Aging Clin Exp Res. 2022;34(9): 2071–9.
61. Jerez-Roig J, Booth J, Skelton DA, Gine-Garriga M, Chastin SFM, Hagen S. Is urinary incontinence associated with sedentary behaviour in older women? Analysis of data from the National Health and Nutrition Examination Survey. PLoS One. 2020;15(2):e0227195.
62. Falvey JR, Mangione KK, Stevens-Lapsley JE. Rethinking hospital-associated deconditioning: proposed paradigm shift. Phys Ther. 2015;95(9):1307–15.
63. Loyd C, Markland AD, Zhang Y, Fowler M, Harper S, Wright NC, et al. Prevalence of hospital-associated disability in older adults: a meta-analysis. J Am Med Dir Assoc. 2020;21 (4):455–61 e5.
64. Kortebein P, Ferrando A, Lombeida J, Wolfe R, Evans WJ. Effect of 10 days of bed rest on skeletal muscle in healthy older adults. JAMA. 2007;297(16):1772–4.
65. Kortebein P, Symons TB, Ferrando A, Paddon-Jones D, Ronsen O, Protas E, et al. Functional impact of 10 days of bed rest in healthy older adults. J Gerontol A Biol Sci Med Sci. 2008;63 (10):1076–81.
66. Escriba-Salvans A, Jerez-Roig J, Molas-Tuneu M, Farres-Godayol P, Moreno-Martin P, Goutan-Roura E, et al. Sarcopenia and associated factors according to the EWGSOP2 criteria in older people living in nursing homes: a cross-sectional study. BMC Geriatr. 2022;22(1): 350.
67. Welch C, Hassan-Smith ZK, Greig CA, Lord JM, Jackson TA. Acute sarcopenia secondary to hospitalisation – an emerging condition affecting older adults. Aging Dis. 2018;9(1):151–64.
68. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. Age Ageing. 2010;39(4):412–23.
69. Ramsey KA, Rojer AGM, D'Andrea L, Otten RHJ, Heymans MW, Trappenburg MC, et al. The association of objectively measured physical activity and sedentary behavior with skeletal muscle strength and muscle power in older adults: a systematic review and meta-analysis. Ageing Res Rev. 2021;67:101266.
70. Gianoudis J, Bailey CA, Daly RM. Associations between sedentary behaviour and body composition, muscle function and sarcopenia in community-dwelling older adults. Osteoporos Int. 2015;26(2):571–9.
71. Seguin R, Lamonte M, Tinker L, Liu J, Woods N, Michael YL, et al. Sedentary behavior and physical function decline in older women: findings from the women’s health initiative. J Aging Res. 2012;2012:271589.
72. Gennuso KP, Gangnon RE, Matthews CE, Thraen-Borowski KM, Colbert LH. Sedentary behavior, physical activity, and markers of health in older adults. Med Sci Sports Exerc. 2013;45(8):1493–500.
73. Rosenberg DE, Bellettiere J, Gardiner PA, Villarreal VN, Crist K, Kerr J. Independent associations between sedentary behaviors and mental, cognitive, physical, and functional health among older adults in retirement communities. J Gerontol A Biol Sci Med Sci. 2016;71(1):78–83.
74. Cooper AJ, Simmons RK, Kuh D, Brage S, Cooper R, Scientific N, et al. Physical activity, sedentary time and physical capability in early old age: British birth cohort study. PLoS One. 2015;10(5):e0126465.

75. Hamer M, Stamatakis E, Mishra GD. Television- and screen-based activity and mental well-being in adults. Am J Prev Med. 2010;38(4):375–80.
76. Gilchrist SC, Bennett A, Judd SE, Akinyemiju T, Howard VJ, Hooker SP, et al. Sedentary bahavior and physical functioning in middle-aged and older adults living in the U.S.: The REGARDS Study. Med Sci Sports Exerc. 2022 Jul 7. https://doi.org/10.1249/MSS.0000000000002983. Online ahead of print.
77. Del Pozo-Cruz J, Irazusta J, Rodriguez-Larrad A, Alfonso-Rosa RM, Alvarez-Barbosa F, Raimundo A, et al. Replacing sedentary behavior with physical activity of different intensities: implications for physical function, muscle function, and disability in octogenarians living in long-term care facilities. J Phys Act Health. 2022;19(5):329–38.
78. Sardinha LB, Santos DA, Silva AM, Baptista F, Owen N. Breaking-up sedentary time is associated with physical function in older adults. J Gerontol A Biol Sci Med Sci. 2015;70(1):119–24.
79. Harvey JA, Chastin SFM, Skelton DA. Breaking sedentary behaviour has the potential to increase/maintain function in frail older adults. J Frailty Sarcopenia Falls. 2018;3(1):26–31.
80. Song J, Lindquist LA, Chang RW, Semanik PA, Ehrlich-Jones LS, Lee J, et al. Sedentary behavior as a risk factor for physical frailty independent of moderate activity: results from the osteoarthritis initiative. Am J Public Health. 2015;105(7):1439–45.
81. Blodgett J, Theou O, Kirkland S, Andreou P, Rockwood K. The association between sedentary behaviour, moderate-vigorous physical activity and frailty in NHANES cohorts. Maturitas. 2015;80(2):187–91.
82. da Silva CR, de Queiroz BM, Oliveira DS, das Merces MC, Oliveira Carneiro JA, Pereira R, et al. Cross-sectional relationships between sedentary behavior and frailty in older adults. J Sports Med Phys Fitness. 2017;57(6):825–30.
83. Tolley APL, Ramsey KA, Rojer AGM, Reijnierse EM, Maier AB. Objectively measured physical activity is associated with frailty in community-dwelling older adults: a systematic review. J Clin Epidemiol. 2021;137:218–30.
84. Li N, Huang F, Li H, Lin S, Yuan Y, Zhu P. Examining the independent and interactive association of physical activity and sedentary behaviour with frailty in Chinese community-dwelling older adults. BMC Public Health. 2022;22(1):1414.
85. Ramsey KA, Zhou W, Rojer AGM, Reijnierse EM, Maier AB. Associations of objectively measured physical activity and sedentary behaviour with fall-related outcomes in older adults: a systematic review. Ann Phys Rehabil Med. 2022;65(2):101571.
86. Jefferis BJ, Iliffe S, Kendrick D, Kerse N, Trost S, Lennon LT, et al. How are falls and fear of falling associated with objectively measured physical activity in a cohort of community-dwelling older men? BMC Geriatr. 2014;14:114.
87. McMichan L, Dick M, Skelton DA, Chastin SFM, Owen N, Dunstan DW, et al. Sedentary behaviour and bone health in older adults: a systematic review. Osteoporos Int. 2021;32(8):1487–97.
88. Moradell A, Rodriguez-Gomez I, Fernandez-Garcia AI, Navarrete-Villanueva D, Marin-Puyalto J, Perez-Gomez J, et al. Associations between daily movement distribution, bone structure, falls, and fractures in older adults: A Compositional Data Analysis Study. Int J Environ Res Public Health. 2021;18(7).
89. LaMonte MJ, Wactawski-Wende J, Larson JC, Mai X, Robbins JA, LeBoff MS, et al. Association of physical activity and fracture risk among postmenopausal women. JAMA Netw Open. 2019;2(10):e1914084.
90. Kesse-Guyot E, Charreire H, Andreeva VA, Touvier M, Hercberg S, Galan P, et al. Cross-sectional and longitudinal associations of different sedentary behaviors with cognitive performance in older adults. PLoS One. 2012;7(10):e47831.
91. Steinberg SI, Sammel MD, Harel BT, Schembri A, Policastro C, Bogner HR, et al. Exercise, sedentary pastimes, and cognitive performance in healthy older adults. Am J Alzheimers Dis Other Dement. 2015;30(3):290–8.

92. Dogra S, Stathokostas L. Correlates of extended sitting time in older adults: an exploratory cross-sectional analysis of the Canadian Community Health Survey Healthy Aging Cycle. Int J Public Health. 2014;59(6):983–91.
93. Hamer M, Poole L, Messerli-Burgy N. Television viewing, C-reactive protein, and depressive symptoms in older adults. Brain Behav Immun. 2013;33:29–32.
94. Tsutsumimoto K, Makizako H, Doi T, Hotta R, Nakakubo S, Shimada H, et al. Prospective associations between sedentary behaviour and incident depressive symptoms in older people: a 15-month longitudinal cohort study. Int J Geriatr Psychiatry. 2017;32(2):193–200.
95. Luo Y, Li Y, Xie J, Duan Y, Gan G, Zhou Y, et al. Symptoms of depression are related to sedentary behavior and sleep duration in elderly individuals: a cross-sectional study of 49,317 older Chinese adults. J Affect Disord. 2022;308:407–12.
96. Netz Y, Goldsmith R, Shimony T, Arnon M, Zeev A. Loneliness is associated with an increased risk of sedentary life in older Israelis. Aging Ment Health. 2013;17(1):40–7.
97. Cukic I, Gale CR, Chastin SFM, Dall PM, Dontje ML, Skelton DA, et al. Cross-sectional associations between personality traits and device-based measures of step count and sedentary behaviour in older age: the Lothian Birth Cohort 1936. BMC Geriatr. 2019;19(1):302.
98. Okely JA, Cukic I, Shaw RJ, Chastin SF, Dall PM, Deary IJ, et al. Positive and negative well-being and objectively measured sedentary behaviour in older adults: evidence from three cohorts. BMC Geriatr. 2019;19(1):28.
99. Gale CR, Cukic I, Chastin SF, Dall PM, Dontje ML, Skelton DA, et al. Attitudes to ageing and objectively-measured sedentary and walking behaviour in older people: The Lothian Birth Cohort 1936. PLoS One. 2018;13(5):e0197357.
100. Cukic I, Shaw R, Der G, Chastin SFM, Dontje ML, Gill JMR, et al. Cognitive ability does not predict objectively measured sedentary behavior: evidence from three older cohorts. Psychol Aging. 2018;33(2):288–96.
101. O'Neil C, Dogra S. Different types of sedentary activities and their association with perceived health and wellness among middle-aged and older adults: a cross-sectional analysis. Am J Health Promot. 2016;30(5):314–22.
102. Shaw RJ, Cukic I, Deary IJ, Gale CR, Chastin SFM, Dall PM, et al. The influence of neighbourhoods and the social environment on sedentary behaviour in older adults in three prospective cohorts. Int J Environ Res Public Health. 2017;14(6).
103. Rojer AGM, Ramsey KA, Amaral Gomes ES, D'Andrea L, Chen C, Szoeke C, et al. Objectively assessed physical activity and sedentary behavior and global cognitive function in older adults: a systematic review. Mech Ageing Dev. 2021;198:111524.
104. Sorman DE, Sundstrom A, Ronnlund M, Adolfsson R, Nilsson LG. Leisure activity in old age and risk of dementia: a 15-year prospective study. J Gerontol B Psychol Sci Soc Sci. 2014;69 (4):493–501.
105. Zlatar ZZ, Wierenga CE, Bangen KJ, Liu TT, Jak AJ. Increased hippocampal blood flow in sedentary older adults at genetic risk for Alzheimer's disease. J Alzheimers Dis. 2014;41(3): 809–17.
106. Hirvensalo M, Rantanen T, Heikkinen E. Mobility difficulties and physical activity as predictors of mortality and loss of independence in the community-living older population. J Am Geriatr Soc. 2000;48(5):493–8.
107. Lindemann U, Oksa J, Skelton DA, Beyer N, Klenk J, Zscheile J, et al. Effect of cold indoor environment on physical performance of older women living in the community. Age Ageing. 2014;43(4):571–5.
108. Stotz A, Rapp K, Oksa J, Skelton DA, Beyer N, Klenk J, et al. Effect of a brief heat exposure on blood pressure and physical performance of older women living in the community-a pilot-study. Int J Environ Res Public Health. 2014;11(12):12623–31.
109. Gale CR, Marioni RE, Cukic I, Chastin SF, Dall PM, Dontje ML, et al. The epigenetic clock and objectively measured sedentary and walking behavior in older adults: the Lothian Birth Cohort 1936. Clin Epigenetics. 2018;10:4.

110. Van Uffelen JG, Heesch KC, Van Gellecum YR, Burton NW, Brown WJ. Which older women could benefit from interventions to decrease sitting time and increase physical activity? J Am Geriatr Soc. 2012;60(2):393–6.
111. Shaw RJ, Cukic I, Deary IJ, Gale CR, Chastin SF, Dall PM, et al. Relationships between socioeconomic position and objectively measured sedentary behaviour in older adults in three prospective cohorts. BMJ Open. 2017;7(6):e016436.
112. Gardner B, Iliffe S, Fox KR, Jefferis BJ, Hamer M. Sociodemographic, behavioural and health factors associated with changes in older adults' TV viewing over 2 years. Int J Behav Nutr Phys Act. 2014;11:102.
113. Hamer M, Stamatakis E. Prospective study of sedentary behavior, risk of depression, and cognitive impairment. Med Sci Sports Exerc. 2014;46(4):718–23.
114. Nicholson L. Development of key themes for physical activity promotion for adults and older adults. NHS Health Scotland Report 2012.
115. Greenwood-Hickman MA, Renz A, Rosenberg DE. Motivators and barriers to reducing sedentary behavior among overweight and obese older adults. Gerontologist. 2016;56(4): 660–8.
116. Heseltine R, Skelton DA, Kendrick D, Morris RW, Griffin M, Haworth D, et al. "Keeping Moving": factors associated with sedentary behaviour among older people recruited to an exercise promotion trial in general practice. BMC Fam Pract. 2015;16:67.
117. Gardiner PA, Eakin EG, Healy GN, Owen N. Feasibility of reducing older adults' sedentary time. Am J Prev Med. 2011;41(2):174–7.
118. Otten JJ, Jones KE, Littenberg B, Harvey-Berino J. Effects of television viewing reduction on energy intake and expenditure in overweight and obese adults: a randomized controlled trial. Arch Intern Med. 2009;169(22):2109–15.
119. Judice PB, Hamilton MT, Sardinha LB, Zderic TW, Silva AM. What is the metabolic and energy cost of sitting, standing and sit/stand transitions? Eur J Appl Physiol. 2016;116(2): 263–73.
120. Leask CF, Skelton DA, Sandlund M, Chastin SFM. Co-creating a tailored intervention to reduce sedentary behaviour in older adults. J Aging Phys Act. 2016;24(Suppl):S92.
121. Douma JG, Volkers KM, Engels G, Sonneveld MH, Goossens RHM, Scherder EJA. Setting-related influences on physical inactivity of older adults in residential care settings: a review. BMC Geriatr. 2017;17(1):97.
122. Ericson-Lidman E, Renstrom AS, Ahlin J, Strandberg G. Relatives' perceptions of residents' life in a municipal care facility for older people with a focus on quality of life and care environment. Int J Older People Nursing. 2015;10(3):160–9.
123. McCarter-Bayer A, Bayer F, Hall K. Preventing falls in acute care: an innovative approach. J Gerontol Nurs. 2005;31(3):25–33.
124. Friedman SM, Munoz B, West SK, Rubin GS, Fried LP. Falls and fear of falling: which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. J Am Geriatr Soc. 2002;50(8):1329–35.
125. Edmonds C, Smith H. Observational pilot study of physica activity on an acute older person's unit. Age Ageing. 2014;43(suppl 1):i33.
126. Koenders N, van Oorsouw R, Seeger JPH, Nijhuis-van der Sanden MWG, van de Glind I, Hoogeboom TJ. "I'm not going to walk, just for the sake of walking...": a qualitative, phenomenological study on physical activity during hospital stay. Disabil Rehabil. 2020;42 (1):78–85.
127. Harvey JA, McBain JR, Cameron H. A survey of therapists views on reducing sedentary behaviour in an acute clinical setting. AIMS Med Sci. 2018;5(4):370–7. https://doi.org/10.3934/medsci.2018.4.370.
128. Hills D, Ekegren C, Plummer V, Freene N, Kunstler B, Robinson T, et al. Nursing perspectives on reducing sedentary behaviour in sub-acute hospital settings: a mixed methods study. J Clin Nurs. 2022;31(9–10):1348–61.
129. Matei R, Thune-Boyle I, Hamer M, Iliffe S, Fox KR, Jefferis BJ, et al. Acceptability of a theory-based sedentary behaviour reduction intervention for older adults ('On Your Feet to Earn Your Seat'). BMC Public Health. 2015;15:606.

130. King AC, Hekler EB, Grieco LA, Winter SJ, Sheats JL, Buman MP, et al. Harnessing different motivational frames via mobile phones to promote daily physical activity and reduce sedentary behavior in aging adults. PLoS One. 2013;8(4):e62613.
131. Fitzsimons CF, Kirk A, Baker G, Michie F, Kane C, Mutrie N. Using an individualised consultation and activPAL feedback to reduce sedentary time in older Scottish adults: results of a feasibility and pilot study. Prev Med. 2013;57(5):718–20.
132. Chang AK, Fritschi C, Kim MJ. Sedentary behavior, physical activity, and psychological health of Korean older adults with hypertension: effect of an empowerment intervention. Res Gerontol Nurs. 2013;6(2):81–8.
133. Rosenberg DE, Gell NM, Jones SM, Renz A, Kerr J, Gardiner PA, et al. The feasibility of reducing sitting time in overweight and obese older adults. Health Educ Behav. 2015;42(5): 669–76.
134. Chastin S, Gardiner PA, Harvey JA, Leask CF, Jerez-Roig J, Rosenberg D, et al. Interventions for reducing sedentary behaviour in community-dwelling older adults. Cochrane Database Syst Rev. 2021;6(6):CD012784.
135. Dogra S, Ashe MC, Biddle SJH, Brown WJ, Buman MP, Chastin S, et al. Sedentary time in older men and women: an international consensus statement and research priorities. Br J Sports Med. 2017;51(21):1526–32.
136. Shrestha N, Grgic J, Wiesner G, Parker A, Podnar H, Bennie JA, et al. Effectiveness of interventions for reducing non-occupational sedentary behaviour in adults and older adults: a systematic review and meta-analysis. Br J Sports Med. 2019;53(19):1206–13.
137. Petrusevski C, Choo S, Wilson M, MacDermid J, Richardson J. Interventions to address sedentary behaviour for older adults: a scoping review. Disabil Rehabil. 2021;43(21): 3090–101.
138. Chase JD, Otmanowski J, Rowland S, Cooper PS. A systematic review and meta-analysis of interventions to reduce sedentary behavior among older adults. Transl Behav Med. 2020;10 (5):1078–85.
139. Schepens Niemiec SL, Carino B, Chatfield AJ, Quan K. mHealth-supported interventions with potential to address sedentary behavior in older adults: a scoping review. J Aging Phys Act. 2022;30(6):1085–100.
140. Rooijackers TH, Metzelthin SF, van Rossum E, Kempen G, Evers S, Gabrio A, et al. Economic evaluation of a reablement training program for homecare staff targeting sedentary behavior in community-dwelling older adults compared to usual care: a cluster randomized controlled trial. Clin Interv Aging. 2021;16:2095–109.
141. Gine-Garriga M, Dall PM, Sandlund M, Jerez-Roig J, Chastin SFM, Skelton DA. A pilot randomised clinical trial of a novel approach to reduce sedentary behaviour in care home residents: feasibility and preliminary effects of the GET READY Study. Int J Environ Res Public Health. 2020;17(8).
142. Chastin SFM, Harvey JA, Dall PM, McInally L, Mavroeidi A, Skelton DA. Beyond "#endpjparalysis", tackling sedentary behaviour in health care. AIMS Med Sci. 2019;6(1): 67–75.
143. John Hopkins Medicine. Activity and Mobility Promotion. Available from: https://www.hopkinsmedicine.org/physical_medicine_rehabilitation/education_training/amp/index.html (viewed 23/07/22).
144. Baldwin CE, Phillips AC, Edney SM, Lewis LK. Recommendations for older adults' physical activity and sedentary behaviour during hospitalisation for an acute medical illness: an international Delphi study. Int J Behav Nutr Phys Act. 2020;17(1):69.
145. Mavroeidi A, McInally L, Tomasella F, Dall PM, Skelton DA. An explorative study of current strategies to reduce sedentary behaviour in hospital wards. AIMS Med Sci. 2019;6(4):285–95.
146. Smith TO, Sreekanta A, Walkeden S, Penhale B, Hanson S. Interventions for reducing hospital-associated deconditioning: a systematic review and meta-analysis. Arch Gerontol Geriatr. 2020;90:104176.

Chapter 14
Sedentary Behaviour and Mortality

Ashleigh R. Homer and David W. Dunstan

Abstract Throughout the past century, non-communicable diseases have formed the leading cause of death worldwide, accounting for 71% of all deaths globally in 2019 (World Health Organisation. Fact Sheet: Noncommunicable Diseases, 2021). In recent decades, the increase in non-communicable disease has coincided with a decrease in daily energy expenditure due to the advent of time- and labour-saving technologies (particularly in the occupational and domestic setting) that have fostered an environment conducive to extended periods of sitting. Indeed, prolonged sitting is now ubiquitous in modern society, and an expanding body of literature shows a consistent association between time spent in sedentary behaviours and an increased mortality risk. The evidence base linking prolonged sitting with premature mortality is convincing and has led to the inclusion of government public health guidelines around reducing prolonged sitting in several countries and globally. In late 2020, the first global combined physical activity and sedentary behaviour guidelines were released by World Health Organization (WHO) (Bull et al. Br J Sports Med 54(24):1451–62, 2020). These include broad recommendations to "sit less and move more", and "every move counts", emphasising that sedentary time should be replaced with physical activity and that some activity is better than none. These guidelines have been informed by an extensive body of work which indicates the importance of reducing both sedentary time and increasing activity levels. However, understanding of the interplay between physical activity and sedentary time is a relatively new consideration, and more research is required to identify whether there is a threshold at which this balance is altered.

A. R. Homer
Sports Performance, Recovery, Injury & New Technologies (SPRINT) Research Centre, Australian Catholic University, Melbourne, Australia
e-mail: Ashleigh.homer@acu.edu.au

D. W. Dunstan (✉)
Baker Heart and Diabetes Institute, Melbourne, Australia
e-mail: david.dunstan@baker.edu.au

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_14

What Is New?

- The first global combined physical activity and sedentary behaviour guidelines were released by the World Health Organization in 2020, which include broad recommendations to "sit less and move more", and "every move counts".
- The COVID-19 pandemic and the resulting lockdowns have seen global reductions in physical activity and increased sedentary time.
- The impact of reduced physical activity and increased sedentary time as a result of the pandemic on mortality will need to be considered in future research.
- The focus of future research should remain around the implementation of a framework in which the deleterious health consequences of too much sitting are seen being an addition to, and not an alternative to, the well-recognised benefits of participation in health enhancing moderate-vigorous physical activity.

14.1 Evolution of Life Expectancy and Causes of Mortality

In modern societies, mortality across the lifespan forms a J-shaped curve, with high early age mortality rates declining throughout early adulthood, followed at mid-life by an exponential acceleration in association with an increase in disease and dysfunction [1]. The history of disease and mortality across the centuries offers an interesting insight into the shifting trends associated with cause-of-death and life expectancy. Scientific and technological advances in the early twentieth century saw a decline in mortality rates from infectious disease, dramatically increasing life expectancy. Consequently, the rise of non-communicable diseases has proven a major scientific and public health challenge. This is exacerbated by the ever-increasing longevity of the global population, and influential lifestyle factors which are becoming endemic in modern society.

14.1.1 The Era of Infectious Disease

Prior to 1900, the main causes of death were infections, arising from unhygienic living conditions and limited access to effective medical care [2]. During this period, life expectancy at birth was estimated to have been approximately 35 years, largely due to the risks posed by disease (e.g., pneumonia, diarrhoea, cholera, tuberculosis, smallpox, typhoid, and plague), injuries, and accidents [3]. Though infectious disease was thought to be the major cause of death, non-communicable disease was still present in these periods. The oldest known case of arterial disease is from 5300 years ago, where computed tomography scans show calcification of the arteries

[4]. Intriguingly, Egyptian mummies have also been found to have atherosclerotic calcification [4].

14.1.2 Epidemiologic Transition to Non-communicable Disease

Deaths from infectious disease declined considerably during the twentieth century, in large part due to improvements in health care, sanitation, immunisation, access to clean running water, and better nutrition. As a consequence, the decrease in infant and child mortality led to a dramatic increase in life expectancy from birth [5]. The result has been a transition towards a rise in mortality resulting from non-communicable diseases. The term "non-communicable disease" refers to a medical condition or disease that is non-infectious or non-transmissible. This type of disease is usually chronic (lasting for a long period of time) and generally progresses slowly. The four main types of non-communicable disease are cardiovascular (CVD), cancer, chronic respiratory diseases (e.g., asthma and chronic obstructive pulmonary disease), and diabetes [6].

Throughout the past century, non-communicable diseases have formed the leading cause of death worldwide. Heart disease became the leading cause of death in the 1920s and has remained at the top for almost 100 years [4, 6]. Over the past decade, ischemic heart disease, stroke, lower respiratory tract infections, cancers, and chronic obstructive lung disease have continued to be the major global killers [6]. Additionally, diabetes has entered the top 10 causes of death worldwide following a 70% increase in mortality rate from 2000 to 2019 [7].

Globally, life expectancy is continuing to rise. In 2019, life expectancy at birth for both sexes was estimated at 73 years. However, there is wide socioeconomic disparity, with life expectancy only 62 years in low-income countries, versus 79 years in high-income countries [8]. In 2019, non-communicable diseases were responsible for 74% of all deaths globally, with 3 in every 10 deaths related to cardiovascular disease (including ischemic heart disease and stroke) [7]. As a proportion, mortality from non-communicable diseases makes up the majority of all deaths in high-income (87%) and upper-middle income (81%) countries, with lower proportions for middle-income (57%) and lower-middle income (37%) countries [7]. However, the burden of these diseases is rising disproportionately among low- and middle-income countries, with nearly three quarters of non-communicable disease deaths occurring in these areas [6]. Consequently, from a global perspective, people are living longer, but increasingly with chronic disease.

14.1.3 The Re-infectious Era?

Infectious diseases are still major killers, with lower respiratory tract infections and diarrhoeal diseases the fourth and eighth leading causes of death in 2019, respectively [7]. In 2019, COVID-19 emerged as the first global pandemic in the twenty-first century. As of November 2021, 260 million confirmed cases of COVID-19 and 5.2 million related deaths had been reported to the World Health Organization (WHO) [9]. The pandemic surfaced long-standing inequalities across income groups, overwhelmed global essential health services and workforces, and revealed crucial gaps in health information systems worldwide. In addition to the influence on global mortality, the COVID-19 pandemic required drastic changes to day-to-day life and social interaction. Global lockdowns calling for physical distancing and minimising human movement resulted in a shift to working remotely, limited outdoor time, and reduced opportunities for physical activities with the closure of recreational sporting facilities. These changes have seen a global reduction in physical activity and increase in sedentary time [10–12].

14.1.4 The Link Between Sedentary Lifestyles and Mortality

Over the most recent decades, the increase in non-communicable disease has coincided with a decrease in daily energy expenditure, which has occurred within an environment conducive to extended periods of sitting [13, 14]. The extent of the problem was highlighted in a study by Ng and Popkin [14] that examined time-use data to describe the rate of change in leisure time sedentary behaviour and four domains of physical activity (active leisure, travel, domestic, and occupational) for the USA, UK, Brazil, China, and India, with forecasts given through to 2030. Sharp declines, particularly in occupational and domestic physical activity, coinciding with the proliferation of time- and labour-saving devices, have led to increasing time spent in sedentary behaviours globally (Fig. 14.1). In 2009, the average American adult spent nearly 38 h/wk. being sedentary. Based on current trends, by 2030 this will increase to nearly 42 h/wk. (Fig. 14.1) [14]. Time spent in sedentary behaviours was even higher in the UK, estimated at around 42 h/wk. in 2005, and projected to increase to 51.5 h/wk. by 2030 [14]. For more information on the prevalence of sedentary behaviour, please refer to Chap. 2.

A body of epidemiological studies support an adverse association between excessive sitting with poor health outcomes (including cardiometabolic risk biomarkers and type 2 diabetes) and premature mortality [15]. Time spent in sedentary behaviours (typically sitting), as distinct from lack of moderate-to-vigorous physical activity (MVPA), is therefore a new focus of research in the physical activity and health field [15]. Recent years have seen a shift from self-reported to device-measured sitting time, which provides new and informative insights into the relationships between sedentary behaviours and health. Here, we review the current

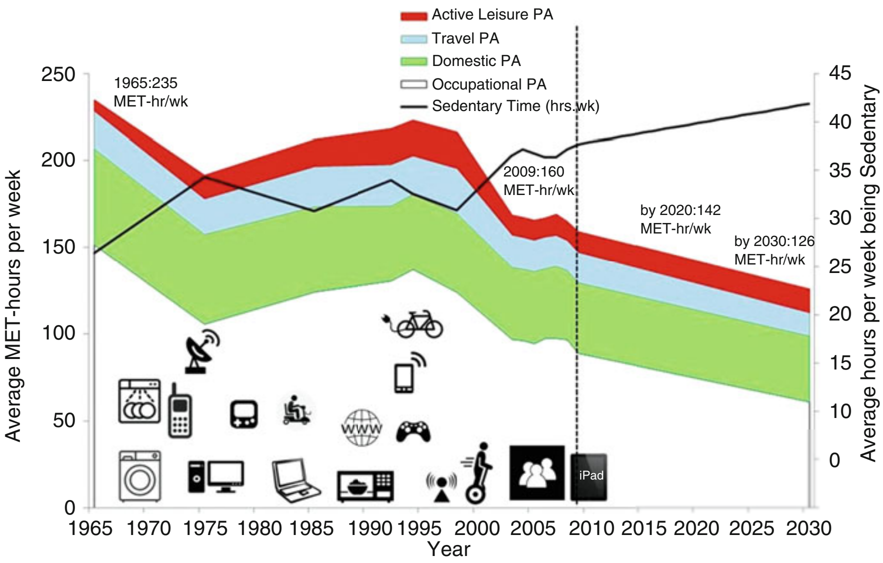

Fig. 14.1 US Adults MET-hours per week (based on time-use surveys) of all physical activity, and hours/week of time in sedentary behaviour: measured for 1965–2009, forecasted for 2010–2030. Icons indicate time and labour-saving devices or popular products that promote sedentary behaviour; either their approximate year of introduction to the market or when their use became commonplace in households. 1970s—clothes dryers and dishwashers became commonplace in households; first mobile phone; satellite TV; personal computers; handheld gaming consoles. 1980s—laptops; mobility scooters. 1990s—worldwide web; microwaves became commonplace in households; PlayStation; smartphones; electric bicycles; Wi-Fi. 2000s—segways; social media (e.g. Facebook, Twitter, YouTube). 2010—first iPad released. Figure adapted with permission from Ng & Popkin, 2012 [14]

literature investigating the association between sedentary behaviour and risk of premature mortality.

14.2 Sedentary Behaviour and Risk of Premature Mortality

The inverse relationship between physical activity and health and mortality outcomes is well established. The weight of this evidence culminated in the release of the first Surgeon General's Report on Physical Activity in 1996 [16], which summarised four decades of epidemiological research on various health and disease outcomes and has led to a raft of public health messages recommending regular participation in MVPA. These recommendations have been widely promulgated with the aim of reducing the burden of non-communicable diseases [17, 18] and have been consistently supported by research showing beneficial associations of physical activity with reduced risk of type 2 diabetes [19, 20], cardiovascular disease (CVD) [21], and premature mortality [22–24].

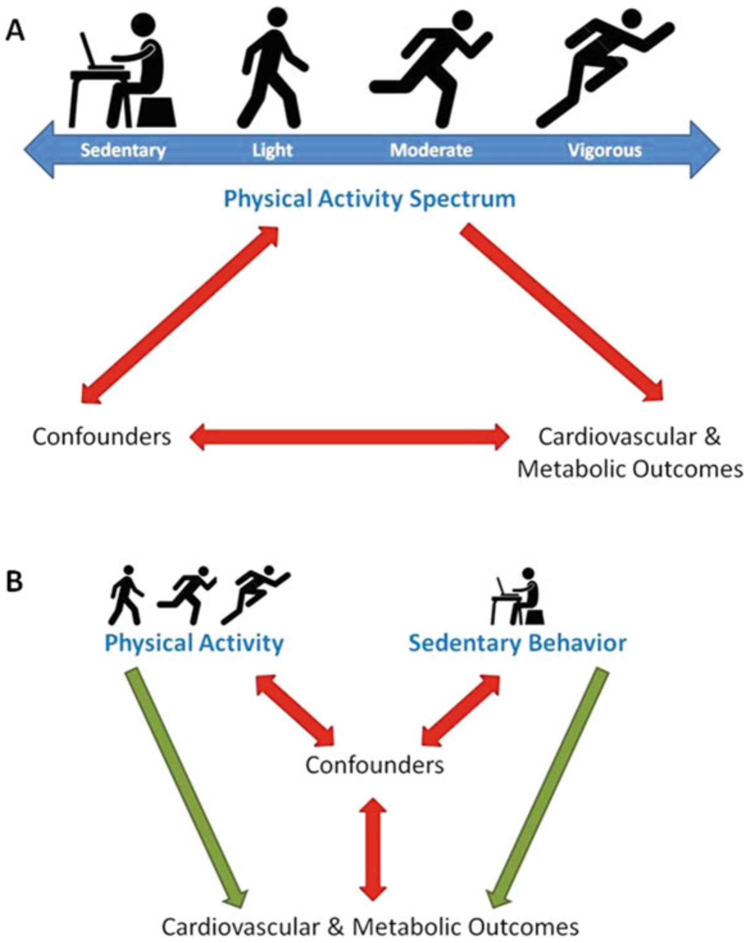

Fig. 14.2 Traditional (**a**) and emerging (**b**) conceptualizations of the relationships between sedentary behaviour and physical activity, and their impact on cardiovascular and metabolic outcomes. (**a**) Time spent in sedentary behaviours was traditionally regarded as part of one end of a physical activity spectrum, which had impacts on cardiovascular and metabolic outcomes opposite to that of physical activity. (**b**) An emerging theory views sedentary behaviours as distinct from physical activity, in recognition of the evidence that high levels of sedentary behaviour can co-exist with high levels of total physical activity and that they may have independent effects on health outcomes. Adapted from Ford & Caspersen, 2012 [25]

The majority of epidemiological studies investigating the beneficial effects of MVPA have regarded time spent in sedentary behaviours as simply the opposite end of a physical activity spectrum (Fig. 14.2). However, a contemporary paradigm views sedentary behaviour as distinct from physical activity. Indeed, high levels of sedentary behaviour can co-exist with high levels of physical activity [26]. In an analysis of the NIH-AARP Diet and Health study, it was found that participants who reported engaging in more than 7 h/wk. of MVPA, but who also watched more than 7 h/d of television had a 50% greater risk of death from all causes, and twice the risk of death from CVD, compared to those who undertook the same level of activity, but watched less than 1 h/d of television [26]. Additionally, recent meta-analyses indicate that large volumes of MVPA may be required to offset adverse health effects for those who spend large amounts of time in sedentary behaviours [27]. This has prompted increasing concern in the public health arena around a decline in "baseline activity" (the light-intensity activities of daily living), which often result in bouts of prolonged sitting. Prolonged sitting is now ubiquitous in modern society, induced by environments that encourage sedentary behaviours such as changes in personal transportation, communication, workplace technologies, and domestic entertainment technologies which have displaced a number of light domestic and occupational duties (Fig. 14.2) [15]. The emergence of this new "physical activity paradigm" has highlighted the potential role that all aspects of human movement may play in impacting health [18, 28].

An expanding body of scientific literature has reported on the relationship between both overall self-reported sitting time and context-specific sedentary behaviours on premature mortality. Below, we review the prospective studies that have investigated the association between context-specific (Sect. 14.2.1) or overall sitting (Sect. 14.2.2) and mortality risk. A review of the current meta-analyses focusing on sedentary behaviours and mortality risk is presented in Sect. 14.2.3. The main findings of these prospective and meta-analysis studies are summarised in Table 14.1.

14.2.1 Specific Sedentary Behaviours

Data from the United States National Human Activity Pattern Survey in 1992–1994 showed that the most common sedentary behaviours, when ranked by percentage of waking hours, were driving a car (10.9%), office work (9.2%), watching television or a movie (8.6%), performing various activities while sitting quietly (5.8%), eating (5.3%), and talking to someone in person or over the phone (3.8%) [29]. Many epidemiological studies have attempted to capture overall sedentary behaviour through the examination of common context-specific sedentary behaviours, as this is easier for an individual to accurately recall compared to total sitting throughout the day, which is generally under-estimated by the population [30]. Emerging evidence suggests some sitting behaviours may be more metabolically harmful than others [31]. Below, we summarise the epidemiologic literature investigating domain-specific sedentary behaviours and mortality risk.

Table 14.1 Summary of the main findings of prospective studies and meta-analyses investigating associations between sedentary behaviour and mortality

Reference	Sedentary Domain	Cause of Death	Reference Category	Comparison Category	Summary Estimate (95% CI)
Prospective Studies					
Inoue et al. (2008)	*Men*				
Japan Public Health Centre	Overall Sitting	All-Cause	<3 h/d	≥8 h/d	HR 1.18 (1.04–1.35)
(JPHC) Study	*Women*				
	Overall Sitting	All-Cause	<3 h/d	≥8 h/d	HR1.10 (0.82–1.25)
Katzmarzyk et al. (2009)	*Combined*				
Canada Fitness Survey	Overall Sitting	All-Cause	"Almost none of the time"	"Almost all of the time"	HR 1.54 (1.25–1.91)
		CVD	"Almost none of the time"	"Almost all of the time"	HR 1.54 (1.09–2.17)
		Cancer	"Almost none of the time"	"Almost all of the time"	HR 1.07 (0.72–1.61)
		Other Causes	"Almost none of the time"	"Almost all of the time"	HR 2.15 (1.47–3.14)
	Men				
	Overall Sitting	All-Cause	"Almost none of the time"	"Almost all of the time"	HR 1.32 (0.99–1.76)
		CVD	"Almost none of the time"	"Almost all of the time"	HR 1.35 (0.85–2.13)
		Cancer	"Almost none of the time"	"Almost all of the time"	HR 1.00 (0.58–1.71)
		Other Causes	"Almost none of the time"	"Almost all of the time"	HR 1.73 (1.04–2.89)

	Women				
	Overall Sitting	All-Cause	"Almost none of the time"	"Almost all of the time"	HR 1.85 (1.35–2.55)
		CVD	"Almost none of the time"	"Almost all of the time"	HR 1.81 (1.07–3.07)
		Cancer	"Almost none of the time"	"Almost all of the time"	HR 1.14 (0.62–2.10)
		Other Causes	"Almost none of the time"	"Almost all of the time"	HR 2.77 (1.56–4.90)
Dunstan et al. (2010)	Television Viewing	All-Cause	<2 h/d	≥4 h/d	HR 1.46 (1.04–2.05)
Australian Diabetes, Obesity and		CVD	<2 h/d	≥4 h/d	HR 1.80 (1.00–3.25)
Lifestyle Study (AusDiab)		Cancer	<2 h/d	≥4 h/d	HR 1.48 (0.88–2.49)
		Other Causes	<2 h/d	≥4 h/d	HR 1.03 (0.49–2.15)
Warren et al. (2010)	Television Viewing	CVD	<4 h/wk	>12 h/wk	HR 0.96 (0.68–1.36)
Aerobics Centre Longitudinal	Travel	CVD	<4 h/wk	>10 h/wk	HR 1.50 (1.08–2.09)
Study (ACLS)	Combined television and Travel	CVD	<11 h/wk	>23 h/wk	HR 1.37 (1.01–1.87)
Patel et al. (2010)	*Men*				
Cancer Prevention Study II	Leisure Time Sitting	All-Cause	<3 h/d	≥6 h/d	RR 1.17 (1.11–1.24)
		CVD	<3 h/d	≥6 h/d	RR 1.18 (1.08–1.30)
		Cancer	<3 h/d	≥6 h/d	RR 1.04 (0.94–1.15)

(continued)

Table 14.1 (continued)

Reference	Sedentary Domain	Cause of Death	Reference Category	Comparison Category	Summary Estimate (95% CI)
		Other Causes	<3 h/d	≥6 h/d	RR 1.33 (1.20–1.47)
	Leisure Time Sitting (h/d) and Total	All-Cause	<3 h/d + ≥ 52.5 MET-h/wk	≥6 h/d + <24.5 MET-h/wk	RR 1.48 (1.33–1.65)
	Physical Activity (MET-h/wk)		<3 h/d + ≥ 52.5 MET-h/wk	≥6 h/d + ≥ 52.5 MET-h/wk	RR 1.07 (0.97–1.18)
	Women				
	Leisure Time Sitting	All-Cause	<3 h/d	≥6 h/d	RR 1.34 (1.25–1.44)
		CVD	<3 h/d	≥6 h/d	RR 1.33 (1.17–1.52)
		Cancer	<3 h/d	≥6 h/d	RR 1.30 (1.16–1.46)
		Other Causes	<3 h/d	≥6 h/d	RR 1.41 (1.25–1.60)
	Leisure Time Sitting (h/d) and Total	All-Cause	<3 h/d + ≥ 52.5 MET-h/wk	≥6 h/d + <24.5 MET-h/wk	RR 1.94 (1.70–2.20)
	Physical Activity (MET-h/wk)		<3 h/d + ≥ 52.5 MET-h/wk	≥6 h/d + ≥ 52.5 MET-h/wk	RR 1.25 (1.07–1.45)
Stamatakis et al. (2011)	Recreational Screen Time	All-Cause	<2 h/d	≥4 h/d	HR 1.54 (1.06–2.24)
Scottish Health Survey		CVD	<2 h/d	≥4 h/d	HR 2.10 (1.14–3.88)
Wijndaele et al. (2011)	Television Viewing	All-Cause	Every 1 h/d increase		HR 1.05 (1.01–1.09)
		CVD	Every 1 h/d increase		

European Prospective Investigation					HR 1.08 (1.01–1.16)
of Cancer (EPIC)-Norfolk Study		Cancer	Every 1 h/d increase		HR 1.04 (0.98–1.10)
Matthews et al. (2012)	Television Viewing	All-Cause	<1 h/d	≥7 h/d	HR 1.61 (1.47–1.76)
		CVD	<1 h/d	≥7 h/d	HR 1.85 (1.56–2.20)
		Cancer	<1 h/d	≥7 h/d	HR 1.22 (1.06–1.40)
		Other Causes	<1 h/d	≥7 h/d	HR 2.11 (1.77–2.50)
	Overall Sitting	All-Cause	<3 h/d	≥9 h/d	HR 1.19 (1.12–1.27)
		CVD	<3 h/d	≥9 h/d	HR 1.16 (1.02–1.30)
		Cancer	<3 h/d	≥9 h/d	HR 1.12 (1.77–2.50)
		Other Causes	<3 h/d	≥9 h/d	HR 1.34 (1.20–1.51)
Ford et al. (2012)	Recreational Screen Time	All-Cause	<1 h/d	≥5 h/d	HR 1.34 (0.81–2.21)
US National Health and Nutrition		Circulatory System Diseases	<1 h/d	≥5 h/d	HR 1.12 (0.47–2.65)
Examination Survey (NHANES)					
van der Ploeg et al. (2012)	*Combined*				
45 and Up Study	Overall Sitting	All-Cause	<4 h/d	≥11 h/d	HR 1.40 (1.27–1.55)
			<4 h/d + 0 min/wk	≥11 h/d + 0 min/wk	

(continued)

Table 14.1 (continued)

Reference	Sedentary Domain	Cause of Death	Reference Category	Comparison Category	Summary Estimate (95% CI)
	Overall Sitting (h/d) and Physical				HR 1.56 (1.26–1.92)
	Activity (min/wk)				
	Overall Sitting (h/d) and Physical		<4 h/d + ≥300 min/wk	≥11 h/d + ≥300 min/wk	HR 1.57 (1.28–1.93)
	Activity (min/wk)				
	Men				
	Overall Sitting	All-Cause	<4 h/d	≥11 h/d	HR 1.32 (1.16–1.50)
	Women				
	Overall Sitting	All-Cause	<4 h/d	≥11 h/d	HR 1.62 (1.37–1.92)
Koster et al. (2012)	Overall Sitting	All-Cause	Lowest quartile	Highest quartile	HR 3.26 (1.59–6.69)
US National Health and Nutrition					
Examination Survey (NHANES)					
Leon-Munoz et al. (2013)	Changes in Overall Sitting Time	All-Cause	Consistently sedentary	Consistently non-sedentary	HR 0.75 (0.62–0.90)
			Consistently sedentary	Formerly sedentary	HR 0.86 (0.70–1.05)
			Consistently sedentary	Newly sedentary	HR 0.91 (0.76–1.10)
Chau et al. (2013)	Occupational Sitting	All-Cause	“Mostly sitting”	“Heavy labour”	HR 0.95 (0.64–1.40)

Nord-Trondelag Health Study 3			"Mostly sitting"	"Much walk and lift"	HR 0.65 (0.44–0.97)
(HUNT3)		Cardiometabolic Disease	"Mostly sitting"	"Heavy labour"	HR 1.55 (0.83–2.90)
	Television Viewing	All-Cause	<1 h/d	≥4 h/d	HR 1.11 (0.83–1.48)
		Cardiometabolic Disease	<1 h/d	≥4 h/d	HR 1.08 (0.68–1.72)
	Overall Sitting	All-Cause	<4 h/d	≥10 h/d	HR 1.65 (1.24–2.21)
		Cardiometabolic Disease	<4 h/d	≥10 h/d	HR 2.15 (1.34–3.44)
Kim et al. (2013)	*Men*				
Multiethnic Cohort Study	Overall Sitting	All-Cause	<5 h/d	≥10 h/d	HR 1.04 (0.98–1.11)
		CVD	<5 h/d	≥10 h/d	HR 1.06 (0.96–1.18)
		Cancer	<5 h/d	≥10 h/d	HR 0.97 (0.87–1.07)
		Other Causes	<5 h/d	≥10 h/d	HR 1.11 (1.00–1.23)
	Television Viewing	All-Cause	<1 h/d	≥5 h/d	HR 1.19 (1.10–1.29)
		CVD	<1 h/d	≥5 h/d	HR 1.20 (1.05–1.37)
		Cancer	<1 h/d	≥5 h/d	HR 1.16 (1.00–1.33)
		Other Causes	<1 h/d	≥5 h/d	HR 1.21 (1.05–1.40)
		All-Cause	<1 h/d	≥3 h/d	

(continued)

Table 14.1 (continued)

Reference	Sedentary Domain	Cause of Death	Reference Category	Comparison Category	Summary Estimate (95% CI)
	Leisure Time Sitting (excl. Television)				HR 1.06 (1.00–1.12)
		CVD	<1 h/d	≥3 h/d	HR 1.09 (0.99–1.20)
		Cancer	<1 h/d	≥3 h/d	HR 1.04 (0.94–1.14)
		Other Causes	<1 h/d	≥3 h/d	HR 1.05 (0.95–1.17)
	Travel	All-Cause	<1 h/d	≥3 h/d	HR 1.00 (0.94–1.08)
		CVD	<1 h/d	≥3 h/d	HR 1.08 (0.96–1.21)
		Cancer	<1 h/d	≥3 h/d	HR 1.03 (0.91–1.16)
		Other Causes	<1 h/d	≥3 h/d	HR 0.90 (0.79–1.02)
	Occupational Sitting	All-Cause	<1 h/d	≥5 h/d	HR 0.94 (0.88–1.02)
		CVD	<1 h/d	≥5 h/d	HR 0.93 (0.82–1.05)
		Cancer	<1 h/d	≥5 h/d	HR 0.92 (0.81–1.05)
		Other Causes	<1 h/d	≥5 h/d	HR 1.00 (0.87–1.15)
	Women				
	Total Sitting	All-Cause	<5 h/d	≥10 h/d	

					HR 1.11 (1.04–1.19)
		CVD	<5 h/d	≥10 h/d	HR 1.19 (1.06–1.34)
		Cancer	<5 h/d	≥10 h/d	HR 0.97 (0.87–1.09)
		Other Causes	<5 h/d	≥10 h/d	HR 1.20 (1.07–1.35)
	Television Viewing	All-Cause	<1 h/d	≥5 h/d	HR 1.32 (1.21–1.44)
		CVD	<1 h/d	≥5 h/d	HR 1.33 (1.14–1.55)
		Cancer	<1 h/d	≥5 h/d	HR 1.07 (0.92–1.25)
		Other Causes	<1 h/d	≥5 h/d	HR 1.62 (1.39–1.89)
	Other Leisure Activities	All-Cause	<1 h/d	≥3 h/d	HR 1.07 (1.01–1.14)
		CVD	<1 h/d	≥3 h/d	HR 1.10 (0.99–1.22)
		Cancer	<1 h/d	≥3 h/d	HR 1.05 (0.95–1.17)
		Other Causes	<1 h/d	≥3 h/d	HR 1.07 (0.96–1.19)
	Travel	All-Cause	<1 h/d	≥3 h/d	HR 1.04 (0.95–1.13)
		CVD	<1 h/d	≥3 h/d	HR 1.16 (1.01–1.34)
		Cancer	<1 h/d	≥3 h/d	HR 1.03 (0.88–1.19)

(continued)

Table 14.1 (continued)

Reference	Sedentary Domain	Cause of Death	Reference Category	Comparison Category	Summary Estimate (95% CI)
		Other Causes	<1 h/d	≥3 h/d	HR 0.92 (0.78–1.09)
	Occupational Sitting	All-Cause	<1 h/d	≥5 h/d	HR 0.98 (0.90–1.08)
		CVD	<1 h/d	≥5 h/d	HR 1.12 (0.95–1.31)
		Cancer	<1 h/d	≥5 h/d	HR 0.87 (0.76–1.00)
		Other Causes	<1 h/d	≥5 h/d	HR 1.01 (0.85–1.21)
Campbell et al. (2013)	Pre-diagnosis Overall Sitting	All-Cause	<3 h/d	≥6 h/d	RR 1.36 (1.10–1.68)
Cancer Prevention Study II		Colorectal Cancer	<3 h/d	≥6 h/d	RR 1.33 (0.96–1.84
		CVD	<3 h/d	≥6 h/d	RR 1.22 (0.73–2.03)
		Other Causes	<3 h/d	≥6 h/d	RR 1.48 (1.05–2.08)
	Post-diagnosis Overall Sitting	All-Cause	<3 h/d	≥6 h/d	RR 1.27 (0.99–1.64)
		Colorectal Cancer	<3 h/d	≥6 h/d	RR 1.62 (1.07–2.44)
		CVD	<3 h/d	≥6 h/d	RR 1.27 (0.73–2.21)
		Other Causes	<3 h/d	≥6 h/d	RR 1.02 (0.68–1.54)

Seguin et al. (2014)	Overall Sitting	All-Cause	≤4 h/d	≥11 h/d	HR 1.12 (1.05–1.21)
Women's Health Initiative		CVD	≤4 h/d	≥11 h/d	HR 1.13 (0.99–1.29)
Observational Study		CHD	≤4 h/d	≥11 h/d	HR 1.27 (1.04–1.55)
		Cancer	≤4 h/d	≥11 h/d	HR 1.21 (1.07–1.37)
Pavey et al. (2015)	Overall Sitting	All-Cause	<4 h/d	8- < 11 h/d	HR 1.21 (1.01–1.44)
Australian Longitudinal Study on			<4 h/d	≥11 h/d	HR 1.24 (0.98–1.56)
Women's Health	Overall Sitting (h/d) and Physical	All-Cause	<4 h/d + not meeting PAG	≥11 h/d + not meeting PAG	HR 1.52 (1.17–1.98)
	Activity Guidelines (PAG)	All-Cause	<4 h/d + meeting PAG	≥11 h/d + meeting PAG	HR 0.48 (0.24–0.96)
Keadle et al. (2015)	Television Viewing	All-Cause	<1 h/d	>7 h/d	HR 1.33 (1.25–1.41)
NIH-AARP Diet and Health Study		Cancer	<1 h/d	>7 h/d	HR 1.12 (1.02–1.24)
		CHD	<1 h/d	>7 h/d	HR 1.64 (1.42–1.90)
		Stroke	<1 h/d	>7 h/d	HR 0.97 (0.72–1.30)
		COPD	<1 h/d	>7 h/d	HR 1.54 (1.10–2.16)
		Accidents	<1 h/d	>7 h/d	HR 1.01 (0.62–1.64)
		Alzheimer Disease	<1 h/d	>7 h/d	HR 1.46 (0.91–2.34)

(continued)

Table 14.1 (continued)

Reference	Sedentary Domain	Cause of Death	Reference Category	Comparison Category	Summary Estimate (95% CI)
		Diabetes	<1 h/d	>7 h/d	HR 1.93 (1.24–2.98)
		Influenza/ Pneumonia	<1 h/d	>7 h/d	HR 2.18 (1.29–3.69)
		Parkinson Disease	<1 h/d	>7 h/d	HR 1.77 (1.04–3.02)
		Kidney Disease	<1 h/d	>7 h/d	HR 1.22 (0.70–2.11)
		Sepsis	<1 h/d	>7 h/d	HR 1.85 (0.95–3.59)
		Liver Disease	<1 h/d	>7 h/d	HR 1.65 (0.91–2.99)
		Suicide	<1 h/d	>7 h/d	HR 1.55 (0.72–3.36)
		Hypertension	<1 h/d	>7 h/d	HR 1.22 (0.56–2.65)
Celis-Morales et al. (2018)	Discretionary screen time (overall)	All-cause mortality	Increments 1 h/day		HR 1.04 (1.02, 1.07)
	Television viewing	All-cause mortality	Increments 1 h/day		HR 1.06 (1.03, 1.08)
	Computer screen time	All-cause mortality	Increments 1 h/day		HR 1.03 (1.00, 1.06)
Jefferis et al. (2019)	Total sedentary time	All-cause mortality	≤560 min/day	≥673 min/day	HR 3.08 (1.93, 4.92)
Lemes et al. (2019)	Television viewing time	All-cause mortality	Frequency: never/seldom/ sometimes	Frequency: often/very often	HR 1.65 (1.02, 2.68)

Tarp et al. (2020)	Total sedentary time	All-cause mortality	6.1 h/day	10.4 h/day	1.31 (0.80, 2.17)
Gilchrist et al. (2020)	Total sedentary time	Cancer mortality	<709.7 min/day	≥782.6 min/16 h day	HR 2.03 (1.41, 2.92)
Li et al. (2021)	Television viewing time	Colorectal cancer mortality	<1.5 h/day	≥4.5 h/day	HR 1.33 (1.02–1.73)
The JACC study					
Meta-analyses					
Grontved and Hu (2011)	Television viewing	All-Cause	Risk per 2 h/d increase		RR 1.13 (1.07–1.18)
Ford and Caspersen (2012)	Screen time	Fatal and non-fatal CVD	Risk per 2 h/d increase		HR 1.17 (1.13–1.20)
	Overall sitting	Fatal and non-fatal CVD	Risk per 2 h/d increase		HR 1.05 (1.01–1.09)
Wilmot et al. (2012)	Various (television viewing, screen	All-Cause	Low sitting	High sitting	HR 1.49 (1.14–2.03)
	time, overall sitting)	CVD	Low sitting	High sitting	HR 1.90 (1.36–2.66)
Chau et al. (2013)	Total daily sitting	All-Cause	Risk per 1/d increase		HR 1.02 (1.01–1.03)
Biswas et al. (2015)	Various (television viewing, screen	All-Cause	Low sitting	High sitting	HR 1.22 (1.08–1.38)
	time, overall sitting)	CVD	Low sitting	High sitting	HR 1.15 (1.07–1.24)
		Cancer	Low sitting	High sitting	HR 1.13 (1.06–1.21)
Patterson et al. (2018)	Total sitting	All-cause	Risk per 1 h/day increase		RR 1.02 (1.01–1.03)
		CVD-mortality	Risk per 1 h/day increase		RR 1.02 (1.01–1.03)

(continued)

Table 14.1 (continued)

Reference	Sedentary Domain	Cause of Death	Reference Category	Comparison Category	Summary Estimate (95% CI)
		Cancer mortality	Risk per 1 h/day increase		RR 1.01 (1.00–1.02)
	Television viewing	All-cause	Risk per 1 h/day increase		RR 1.05 (1.04–1.05)
		CVD-mortality	Risk per 1 h/day increase		RR 1.04 (1.01–1.08)
		Cancer mortality	Risk per 1 h/day increase		RR 1.02 (1.01–1.03)
Ekelund et al. (2019a)	Sitting time	CVD-Mortality	<4 h/day	>8 h/day	HR 1.32 (1.22–1.44)*
HRs reported for Low Physical Activity levels		Cancer mortality	<4 h/day	>8 h/day	HR 1.21 (1.14–1.28)
*Confidence interval estimated from figure	Television time	CVD-Mortality	<1 h/day	>5 h/day	HR 1.59 (1.40–1.80)*
		Cancer mortality	<1 h/day	>5 h/day	HR 1.09 (0.95–1.25)
Ekelund et al. (2019b)	Sedentary time	All-cause mortality	Min/day 448 (371–519)	Min/day 650 (624–705)	HR 2.63 (1.94–3.56)
Ekelund et al. (2020)	Total physical activity and sedentary time	All-cause mortality	High PA (396 CPM) low sedentary (8.5 h/day)	Low PA (138 CPM) high sedentary (10.7 h/day)	HR 2.40 (1.85–3.13)
Zhao et al. (2020)	Sitting time	All-cause	Risk per 1 h/day increase		HR 1.03 (1.02–1.03)
		CVD-related	Risk per 1 h/day increase		HR 1.04 (1.02–1.07)
		Cancer mortality	Risk per 1 h/day increase		HR 1.01 (1.00–1.02)

	Television viewing	All-cause mortality	Risk per 1 h/day increase		HR 1.07 (1.06–1.09)
		CVD-related	Risk per 1 h/day increase		HR 1.04 (1.01–1.06)

Occupational Sitting

The modern field of physical activity epidemiology arguably dates back to the early 1950s with the seminal studies of Morris and colleagues [32], involving employees of the London Transport Executive (bus drivers compared to conductors) and Post Office (civil servants compared to postal workers). Those who were employed in physically active occupations (bus conductors and postmen) had lower mortality rates from heart disease than those engaged in less active occupations (bus drivers and telephone switchboard operators). These early studies provided the initial evidence that insufficient physical activity contributed to premature mortality risk. However, it has recently been proposed that some of the associations observed in these studies may also be attributed to differences in time spent sitting, rather than simply the lack of occupational physical activity *per se* [28]. Unfortunately, the independent contributions to mortality risk of sitting versus lack of physical activity cannot be determined from these studies [18].

In a 3.3-year follow-up of the Nord-Trøndelag Health Study 3 (HUNT3), the overall trend of occupational sitting (from "mostly sitting" to "heavy labour") was not associated with all-cause or cardiometabolic related mortality [33, 34]. In contrast, participants with jobs requiring "much walking and lifting" had a 35% lower risk of all-cause mortality than those with jobs requiring "mostly sitting" [33, 34]. A major limitation of this study was the short follow-up period. However, a comprehensive assessment of the Multiethnic Cohort Study also showed no correlation between work-related sitting time and mortality with a median of 13.7 years follow-up [35]. Therefore, the relationship between occupational sitting and premature mortality is currently unclear and needs to be addressed in further studies.

Television Viewing

Television viewing is the most prevalent and possibly the most pervasive leisure-time sedentary behaviour in industrialised countries [36]. Apart from sleeping and working, television viewing is the most commonly reported daily leisure-time activity in many populations around the world, corresponding to approximately 3.5 h/d of television viewing in European countries, 4 h/d in Australia, and 5 h/d in the USA based on self-reported measures [36–39]. Consequently, television time has been used as an indicator of overall leisure-time sedentary behaviour. Importantly, because this is likely to be the type of sedentary behaviour most amenable to voluntary change, reducing television viewing time has been identified as a potential target for behaviour modification [40].

In the Australian Diabetes, Obesity and Lifestyle Study (AusDiab), with a median follow-up of 6.6 years, there was a significant positive association between television viewing and mortality from all causes and CVD, but not from cancer [41]. For each 1 h/d increase in television viewing time, the risk of all-cause mortality increased by 11%; and risk of CVD mortality increased by 18%. After adjustment for exercise time, those who watched television for ≥4 h/d were at 46% increased risk of all-cause mortality, 80% increased risk of CVD mortality, and showed a trend towards an increased risk of cancer mortality, compared to those who watched <2 h/d [41].

Similarly, an analysis of the European Prospective Investigation of Cancer (EPIC)-Norfolk Study over 9.5 years follow-up showed 5% increased risk of all-cause mortality, and 8% increased risk of CVD mortality for each 1 h/d increase in television viewing time. Again, there was a non-significant trend for association between television viewing time and cancer mortality [40].

In the NIH-AARP Diet and Health Study, television viewing time (>7 h/d compared with <1 h/d) was associated with greater risk of all-cause, CVD, and cancer mortality [26]. Participation in high levels of MVPA (>7 h/wk) did not fully mitigate this effect in participants with high television viewing time [26].

For both men and women, television viewing in the Multiethnic Cohort Study was deleteriously associated with all-cause, CVD, and other cause mortality, but not cancer mortality [35]. Compared to <1 h/d, ≥5 h/d of television viewing was associated with a 19% and 32% increased risk of all-cause mortality; 20% and 33% increased risk of CVD mortality; and 21% and 62% increased risk of other (non-CVD, non-cancer) causes of mortality for men and women, respectively. There was also a tendency for an association of high television viewing with cancer mortality risk for men, but not for women [35].

However, not all studies have shown significant associations between television viewing and mortality. A 21-year follow-up of the Aerobics Centre Longitudinal Study (ACLS) showed a non-significant trend for increased CVD mortality risk across incremental quartiles of television viewing [42]. There was also no significant difference in CVD mortality risk observed between the highest (>12 h/wk) and lowest (<4 h/wk) quartiles of television viewing time. Conversely, there was a significant positive relationship when combining television viewing and time spent riding in a car. Those in the highest quartile (>23 h/wk) of combined sedentary behaviour showed 37% higher risk of CVD mortality compared to those in the lowest quartile (<11 h/wk) [42].

Similar to the findings observed for occupational sitting, television viewing in the HUNT3 study [33, 34] was not significantly associated with all-cause or cardiometabolic disease-related mortality. There were also no significant differences between those in the highest television viewing category (≥4 h/d) compared to the lowest category (<1 h/d). In addition to the short follow-up period, the authors acknowledged suboptimal measurement of television viewing time as a limitation of this study, which resulted in 70% of respondents reporting television viewing in the moderate 1–3 h/d category. Moreover, the study population was from a semirural region of Norway, where participants may have different patterns of sedentary behaviour and physical activity compared to those from more urban areas [33, 34].

A recent study expanded on the known causes of mortality that have been associated with prolonged television viewing time [43]. After 14.1 years of follow-up from the NIH-AARP Diet and Health Study, each 2 h/d increment in television viewing time was significantly associated with mortality risk from cancer, heart disease, chronic obstructive pulmonary, diabetes, influenza/pneumonia, Parkinson disease, liver disease, and suicide. Additionally, the Japan Collaborative Cohort (JACC) Study for Evaluation of Cancer Risks reported strong associations for television viewing and colorectal cancer mortality [44]. The study found that compared to <1.5 h/day, watching 4.5 h/day of television viewing significantly increased risk of dying from colorectal cancer [44]. These studies have substantially increased the breadth of mortality outcomes that have been associated with high levels of television viewing and suggest that sedentary behaviour, particularly television viewing, may be a more important target for public health intervention than previously thought [43].

Recreational Screen Time

In the Scottish Health Survey, recreational screen time (including television viewing and computer use, but not workplace screen time) was positively associated with all-cause and CVD mortality risk. For every 1 min/d increase in screen time, the risk of all-cause mortality and CVD events (both fatal and non-fatal) increased by 0.1% [39].

Conversely, Ford [45] did not show a deleterious association between recreational screen time (time spent watching television, videos or using a computer outside of work) and mortality from all causes or diseases of the circulatory system in the US National Health and Nutrition Examination Survey (NHANES).

A recent study of the UK Biobank data investigated the associations of discretionary screen time (time spent on a computer or television for leisure) [46]. The results showed that for every 1 h/day increase in overall discretionary screen time, hazard ratio (HR) for all-cause mortality was 1.04 (95% confidence interval (CI) 1.02, 1.07). However, when this was stratified into television viewing and computer viewing, the associations for television viewing were stronger (HR 1.06, 95% CI 1.03, 1.08) compared to computer viewing (HR 1.03, 95%CI 1.00, 1.06).

Leisure Time Sitting

In a 14-year follow-up of the Cancer Prevention Study II, men and women who reported sitting ≥6 h/d had 17% and 34% increased risk of all-cause mortality, respectively, compared to those who reported sitting ≤3 h/d [47]. In a stratified analysis, men and women who had high levels of sitting (≥6 h/d) and low levels of physical activity (<24.5 MET-h/wk) were at higher risk of all-cause mortality than those who reported both sitting the least (<3 h/d) and being the most physically active (≥52.5 MET-h/wk). Moreover, women with high levels of physical activity and high levels of sitting were still at greater risk of mortality compared to those with high activity and low sitting. Time spent sitting was most strongly associated with increased risk of CVD for both men and women, whereas it was associated with increased cancer mortality risk only among women [47].

A study specifically investigating a cohort of participants diagnosed with colorectal cancer, found that spending ≥6 h/d of leisure time sitting (including sitting during transport, watching television, and reading), assessed pre-diagnosis, was positively associated with increased risk of all-cause mortality compared to those who reported <3 h/d of leisure time sitting. Whereas, leisure time spent sitting post-diagnosis was significantly correlated with mortality specifically related to colorectal cancer [48].

Analysis of the Multiethnic Cohort Study revealed that ≥3 h/d compared to <1 h/d of leisure time sitting (not including television or meals) was associated with a 6% and 7% increased risk of all-cause mortality for men and women, respectively [35]. No significant effects were observed for other causes of death. The smaller effect sizes in this study could be due to the exclusion of television viewing in the leisure time category.

Transport

In contrast to the absence of an association for television viewing in the ACLS study, there was a significant positive gradient for CVD mortality risk across quartiles of time spent riding in a car [42]. Men in the highest quartile (>10 h/wk) were at 50% greater risk of CVD mortality compared to those in the lowest quartile (<4 h/wk) [42].

No association between any cause of mortality and sitting in a car or bus was observed for men in the Multiethnic Cohort Study [35]. However, women in the highest transport sitting category (≥3 h/d) showed a 16% higher risk of CVD mortality compared to those in the lowest category (<1 h/d).

Mentally Active vs Passive Sedentary Behaviour

Increasing research into context-specific sedentary behaviours has prompted investigations into differential associations of mentally active vs passive sedentary behaviours. A mentally active sedentary behaviour refers to a task which is completed whilst sedentary, that requires a higher level of thinking [49]. For example, working at a computer, playing a strategic video game, or studying may be considered more mentally active than watching television. This research has primarily addressed the associations with mental health outcomes such as depression [50]. At present, these observations have not been extended to mortality risk.

14.2.2 Overall Sedentary Behaviour/Sitting

An analysis of the Japan Public Health Centre (JPHC) Study reported that Japanese men who spent ≥8 h/d in sedentary behaviours had a significantly elevated risk of all-cause mortality compared with men who spent <3 h/d sedentary [51]. However, there was no corresponding association observed in Japanese women [51]. With respect to the interpretation of sedentary outcomes, this study is limited by its primary focus on the effects of physical activity, and lack of description around what constituted sedentary behaviour.

The Canada Fitness Survey 12-year follow-up study showed a detrimental dose-response relationship of daily sitting time (almost none, ¼, ½, ¾, or almost all of the time) with all-cause and CVD mortality in both men and women. Similar results were obtained after stratification by smoking status, BMI, and leisure time physical activity level (greater or less than 7.5 MET/h/wk) [52]. The relationship between sitting and cancer mortality was not significant [52]. Unfortunately, due to the minimal control of baseline physical health, the potential for reverse causation cannot be ruled out in this study.

In the NIH-AARP Diet and Health study, similar patterns were observed for overall sitting as for television viewing (described previously), but the associations for overall sitting were weaker. Independent of MVPA, overall sitting was found to be positively associated with all-cause but not CVD or cancer mortality [26]. Compared to those who sat for <3 h/d, individuals sitting ≥9 h/d showed a 19%, 16%, and 12% increased risk of all-cause, CVD, and cancer mortality, respectively [26].

Despite a relatively short follow-up period (2.8 years), analysis of the 45 and Up study of Australian Adults also showed a positive association between total sitting time and all-cause mortality, independent of leisure-time physical activity. An 11% increase in risk of all-cause mortality was observed for each increase in sitting category (<4 h/d, 4–8 h/d, 8–11 h/d, ≥11 h/d) [53]. In agreement with other analyses, inactive participants with high levels of sitting showed the highest mortality rate, but an association between high sitting and mortality was also observed among participants with high levels of physical activity relative to those with low amounts of sitting [53].

Similarly, Chau and colleagues [33, 34] observed a significant positive association between total sitting and all-cause and cardiometabolic related mortality in the HUNT3 Study after 3.3 years follow-up. This is in contrast to their results for separate domains of sitting (occupational and television viewing time, discussed previously), which did not show significant associations. In the highest category of total sitting time (≥10 h/d), there was a 65% and 115% greater risk of all-cause and cardiometabolic related mortality, respectively, compared to those in the lowest total sitting category (<4 h/d) [33, 34].

In the Multiethnic Cohort Study, total daily sitting was not significantly associated with all-cause, CVD, or cancer-related mortality in men [35]. However, there was a significant association with other causes of mortality. In contrast, significant associations were observed in women. Compared to women who reported sitting for <5 h/d, those who sat ≥10 h/d had 11% greater risk of all-cause; 19% greater risk of CVD, and 20% greater risk of other causes of mortality [35].

A 12-year follow-up of the Women's Health Initiative Observational Study investigated the risks of sedentary behaviour in older women with a focus on minority representation [54]. Significant deleterious linear trends between sedentary behaviour and risk of all-cause, CVD, coronary heart disease and cancer mortality were observed. Compared with women who reported the least time in sedentary behaviours (≤4 h/d), women reporting the highest time in sedentary behaviours (>11 h/d) had 12% increased risk of all cause, 27% increased risk of coronary heart disease mortality, and 21% increased risk of cancer mortality, but no significant effect on risk of CVD mortality. Interaction tests indicated that the association between sedentary behaviour and all-cause mortality was stronger in black women and women in the “other” race group (including Asians, Native Americans, Pacific Islanders, and multi-racial women) compared to those in the White and Hispanic categories [54].

Similarly, an analysis of the Australian Longitudinal Study on Women’s Health [55] assessed older women for a median follow-up of 6 years. Self-reported total sitting time was non-linearly positively associated with all-cause mortality, with a threshold around 7–9 hours of sitting per day. This is consistent with the thresholds suggested by previous studies. Women sitting for 8 ≤ 11 h/d and ≥ 11 h/d were reported to be at greater risk of all-cause mortality. However, this effect was attenuated and the associations with mortality for those sitting ≥11 h/d were no longer significant with adjustment for chronic conditions, self-reported health, and assistance with daily tasks. A significant interaction between sitting time and physical activity was observed, with only those not meeting the physical activity guidelines and sitting for prolonged periods at higher risk of mortality [55].

In one of the earliest mortality-focused study to date to use objective accelerometer data, Koster and colleagues reported a positive association between overall sedentary time and all-cause mortality after a mean 2.8-year follow-up of the NHANES study [56]. Participants in the two highest quartiles of sedentary time (h/d) were at 1.74-fold and 2.26-fold greater risk of all-cause mortality than those in the lowest quartile, independent of MVPA. Importantly, this study is in agreement with the majority of epidemiological studies using subjective measurements of sedentary time. However, the estimated risk is much higher than previously reported, and more studies using device-based assessment, over longer follow-up periods, are needed to corroborate these results.

In an interesting analysis of self-reported sitting time in a prospective cohort of older Spanish adults (≥60 years), the risk of continued sedentariness or changes in sedentary behaviour on mortality were assessed [57]. Self-reported sitting time was recorded on two occasions, 2 years apart, and long-term all-cause mortality determined at 10-year follow-up. Approximately 40% of respondents changed their sedentary behaviour over this 2-year period. The authors found that, compared with those who were consistently sedentary (sitting time > median for both time points), those who were consistently non-sedentary were at significantly less risk of all-cause mortality. Moreover, those who were newly sedentary or formerly sedentary showed non-significant trends towards lower risk of mortality than those who were consistently sedentary. This finding provides an interesting insight, as it suggests that the relevant exposure is cumulative sitting time, and thus those who reduce their sitting time may benefit from a less sedentary lifestyle [57].

The increased focus on device-measured sitting time has minimised inherent limitations in self-reported data and provides new insights into the interrelationship between sedentary behaviour and physical activity. Tarp and colleagues [58] explored this relationship in their recent analysis of the NHANES cohort. The study examined associations of total and intensity-specific physical activity and sedentary time with all-cause mortality. Interestingly, in this cohort, there were no significant associations of sedentary time and risk of all-cause mortality [58]. However, a similar study using data from a population-based sample of older men in the UK found strong associations between increased sedentary time and all-cause mortality [59]. Given device-based measurement is relatively new with respect to sedentary behaviour, there is a clear need for further prospective cohort studies to clarify these associations and the strength of such in different populations.

Summary and Limitations

Prospective studies generally indicate that time spent in overall or specific sedentary behaviours is associated with increased risk for all-cause and CVD-related mortality in both men and women; however, an association with cancer is less clear. However, some studies report no significant effects of sedentary behaviour on mortality risk. The apparent discrepancies may be explained by a number of limitations and methodological differences between studies, for example, the heterogeneity in data collection, including the different manner in which sitting behaviours have been determined, the questions that were asked, and the population from which the information was collected. This could have contributed to measurement bias and under-reporting of sitting behaviour. In recent years, there has been an increase in studies using device-based measures of sitting time. Although there are limitations with this type of data collection, more studies using objective data are needed to clarify the strength of the association between sedentary behaviour and mortality. Limitations also extend to the period of follow-up, which was very short for some studies; and the confounders that were or were not adjusted for in the models, including some that did not appropriately adjust for physical activity or BMI. Moreover, all but one study used baseline sitting time as the measure of sedentary behaviour, which does not take into account changes in behaviour over time. This could increase the chance of random error and may under-estimate the reported associations. Finally, reverse causality is difficult to determine and may have contributed to the associations reported.

14.2.3 Meta-analyses of Sedentary Behaviour and Mortality Risk

A growing number of systematic reviews have examined sedentary behaviour, health outcomes, and mortality. Below is a summary of the current meta-analyses that have focused on sedentary behaviour and premature mortality. The main findings of these studies are presented in Table 14.1.

All-Cause Mortality

Grontved and Hu [36] analysed three studies which reported specifically on television viewing time as a measure of sedentary behaviour and all-cause mortality. The authors found that each 2 h/d increment in television viewing time was associated with a 13% increase in risk of all-cause mortality. Piecewise regression analysis revealed that the relationship with all-cause mortality was non-linear, with an inflection point at 3 h/d of television viewing, above which there was a 30% increased risk of mortality. Television viewing is often associated with increased food intake, and consumption of unhealthy diets; therefore, it has been suggested that some of the association of television viewing with health and mortality outcomes could be explained by diet, particularly snacking behaviours [60]. However, pooling of the estimates with additional adjustment for dietary variables did not attenuate the effect estimate for all-cause mortality in this study [36].

Wilmot and colleagues [61] analysed eight studies reporting on sedentary behaviour and all-cause mortality. The studies used reported data on multiple sedentary behaviours, including either television time/screen-based entertainment, self-reported sitting time, or both. Because the studies did not employ standardised measures of sedentary behaviour, it did not allow a summary measure to be calculated in the meta-analysis. The authors found that adults with the highest time spent in sedentary behaviours have a 49% increase in the risk of all-cause mortality compared to those with the lowest time spent in sedentary behaviours [61].

In a meta-analysis of six prospective studies that specifically investigated total daily sitting as the quantitative exposure variable and all-cause mortality as the outcome, Chau and colleagues [34] reported a 34% higher risk among adults sitting for 10 h/d compared with 1 h/d. Overall, the dose-response relationship between daily sitting and all-cause mortality showed a 2% increase in risk per hour of daily sitting. In agreement with the findings of Grontved and Hu [36], the association between sitting time and all-cause mortality was non-linear, with a significant relation above 7 h/d.

Biswas and colleagues [62] analysed 13 studies reporting on sedentary behaviour and all-cause mortality. Sedentary behaviour in all but one study was quantified using self-report. After adjustment for physical activity, greater time spent sedentary was independently associated with 22% higher risk of all-cause mortality. Pooled associations revealed that those with high levels of physical activity and high sitting were at 30% lower relative risk of all-cause mortality than those with low levels of physical activity and high sitting. The ability to draw definitive conclusions from this finding are limited by the lack of definition of high vs low sedentary time and also for physical activity. However, this suggests that high levels of physical activity may modify the deleterious effects of prolonged sedentary time and highlights the need to better understand the relationship between sedentary behaviour, physical activity, and the risks/benefits to health.

Patterson and colleagues [63] examined the dose–response association between multiple types of sedentary behaviour and all-cause, CVD, and cancer mortality. They also aimed to map the attenuating effect of physical activity on mortality risk across the continuous sedentary behaviour dose-spectrum. Thirty-four studies which included self-reported sedentary behaviours were included. Overall, total sitting and television viewing time are associated with greater risk of premature mortality, independent of physical activity levels [63]. The study also identified important threshold for mortality risk. Sitting for longer than 6–8 h/day total and 3–4 h/day of television viewing was identified to significantly increase risk of all-cause and CVD mortality [63].

The increased use of device-based measures of sedentary behaviour and physical activity has seen a concurrent increase in studies reporting these objective outcomes. A recent meta-analysis examined dose-response associations of sedentary behaviours and all-cause, cardiovascular, and cancer mortality [27]. Ekelund and colleagues included eight studies which examined sedentary behaviour and physical activity with waist-worn accelerometry. The study reported that greater time spent being active at any intensity and less time spent sedentary were associated with substantially reduced risk for premature mortality, with evidence of a non-linear dose-response pattern in middle-aged and older adults [27].

Cardiovascular Disease Mortality

In an analysis of six studies that have reported on screen time, and two studies on sitting time, Ford and colleagues [25] found 17% and 5% increase in fatal and non-fatal CVD risk, respectively, for each additional 2 h/d increase in sitting.

In a meta-analysis of eight studies reporting data on multiple sedentary behaviours, including either television time/screen-based entertainment, self-reported sitting time, or both, Wilmot and colleagues [61] found a 90% increase in risk of CVD mortality for adults with the highest amount of time spent in sedentary behaviours, compared to those with the lowest time spent in sedentary behaviours.

Biswas and colleagues [62] analysed seven studies reporting on sedentary behaviour and CVD mortality. After adjustment for physical activity, greater time spent sedentary was independently associated with 15% higher risk of CVD mortality.

Ekelund and colleagues [64] conducted a harmonised meta-analysis with data from 850,060 participants to examine whether associations of daily sitting and television viewing- and CVD- and cancer-mortality differed by self-reported physical activity levels. The findings showed substantial increased risk of CVD mortality for those that sat >8 h/day and did little physical activity (HR 1.32). The risk was even greater in those who watched television for >5 h/day (HR 1.59) [64]. This association was still evident in those who completed some physical activity, but the risk was no longer significant in those completing 60–75 min/day of MVPA [64]. Section 8.2 provides more information on the association between sedentary behaviour and CVD mortality.

Cancer Mortality

In contrast to all-cause and CVD mortality outcomes, results from studies investigating an association between sedentary behaviour and cancer-related mortality are less clear. Nonetheless, in a meta-analysis of eight studies that included cancer (breast, colon, colorectal, endometrial, and epithelial ovarian) mortality as an outcome measure, Biswas and colleagues [62] found that greater time spent sedentary was independently associated with 13% higher risk of cancer mortality, after adjustment for physical activity. For more information on sedentary behaviour and cancer mortality, please refer to Sect. 9.4.

Summary and Limitations

Meta-analyses investigating the detrimental association of sedentary behaviour with mortality provide strong evidence that excessive sitting is associated with elevated mortality risk. However, these analyses are subject to a number of limitations. Some meta-analyses have included a very small number of studies, and the follow-up period of some of the studies is relatively short. One of the major limitations is the heterogeneity in the studies analysed, both in terms of the units (e.g., overall sitting, television time, occupational sitting) and categories (quantification of high versus low sitting time) in which sedentary time was measured; and the confounders that were adjusted for in various models (including some that did not appropriately adjust for physical activity). Publication bias due to selective reporting may also be an issue [65].

14.2.4 The Importance of Addressing the Interplay Between Sedentary Behaviour and Physical Activity in Relation to Mortality Risk

The most comprehensive overview of the relationships between sedentary behaviour and mortality was initially published as part of the 2018 Physical Activity Guidelines Advisory Committee (PAGC) [66] and subsequently updated within the 2020 World Health Organization (WHO) physical activity and sedentary behaviour guidelines

[67]. Notably both acknowledged the strong evidence that exists for the dose-response associations between sedentary behaviour and all-cause mortality and cardiovascular mortality (with an increasing slope at higher amounts of sedentary behaviour). Key take-aways from these reviews are:

1. The hazards of sedentary behaviour are most pronounced in those who are also physically inactive (i.e., not meeting physical activity guidelines).
2. Those who are highly sedentary require higher amounts of physical activity to achieve the same level of absolute mortality risk as those who are less sedentary.

These observations have led to an increased emphasis on achieving a healthier "balance" between time spent in sedentary behaviour and physical activity for mitigating mortality risk. Consequently, the WHO 2020 Guidelines on Physical Activity and Sedentary Behaviour provide a new focus on sedentary behaviour and its interrelationships with physical activity [68]. Specifically, the integration of the sedentary behaviour guidelines within the physical activity guidelines highlights that multiple approaches or strategies could be employed to reduce risk [67]. This includes lowering time spent in sedentary behaviour, increasing time spent in physical activity or preferably, the combination of both strategies. It is anticipated that the new sedentary behaviour guidelines will be the catalyst for more targeted research on the health benefits of attending to both physical activity and sedentary behaviour for optimising the "balance" of these behaviours.

New Insights From Objective Monitoring Supporting the Promotion of Physical Activity of Any Intensity

The enhanced measurement capacity provided by objective activity monitors has also highlighted the strong relationship that sedentary behaviour has with light-intensity physical activity, where a large proportion of the variation in sedentary time can be attributed to displacement of light physical activities, whereas the correlations between sedentary activity and MVPA, or light activity and MVPA are generally weak [69]. That is, the more time participants spend in light-intensity activity, the less time they spend sedentary. In recent years, these findings have been extended with multiple studies investigating the associations of device-measured sedentary behaviour and physical activity on mortality. Displacement of sedentary behaviour with both light intensity and MVPA reduces mortality risk [70, 71]. These findings, particularly that of LaMonte and colleagues [70] are encouraging given the perceived barriers to regular participation in MVPA that are frequently reported by adults [72]. Reducing sedentary time and increasing light-intensity physical activity is likely to be a feasible and achievable goal for most individuals that does not require the extra perceived effort to achieve good health outcomes [73].

Some Types of Sedentary Behaviours May Be More Detrimental For Mortality Risk

There is a growing body of epidemiological evidence indicating that certain sedentary behaviours may be more detrimental for health than others [31, 65, 74]. For example, television viewing has consistently been shown to be associated with mortality risk, as discussed previously. Further, the risk attenuation observed for sitting time at higher levels of physical activity is not evident for television viewing (or something along these lines). Adoption of emerging technologies such as geolocation data, acceleration signals in mobile phones, and inclinometers will help to obtain more accurate measurements and extend understanding contextual influence of sedentary behaviour [65]. Further, recent trends in using compositional data analysis (applying a 24-hour framework to device-measured activity data) to assess health risks of sedentary behaviour has the potential to provide a novel and sophisticated analysis technique to better understand the differential health risks of context-specific sedentary time.

14.2.5 Remaining Questions

Does Reducing Prolonged Sitting Extend Quality of Life/Reduce Years of Disability?

Accelerometer data from the NHANES study show that the most sedentary age group is adults aged ≥60 years [26, 75]. This could be due to chronic conditions that reduce the ability to participate in physical activity and conversely more sedentary behaviour. However, diminished physical function is not necessarily due to chronic disease, nor does chronic disease necessarily affect function. An interesting question in this context is whether reducing sedentary behaviour can improve quality of life and extend active (or reduce disabled) life expectancy. A study in Australian adults observed that television viewing time is deleteriously associated with physical well-being, mental well-being and vitality, independently of leisure-time physical activity and waist circumference [76]. However, the causal relationships in this context remain unclear, and other domains of sedentary behaviour need to be further investigated.

What Other Variables Related to Physical Activity and Sedentary Behaviour May Be Important For Mortality Risk?

Increased caloric intake and reduced energy expenditure, leading to energy surplus, are the most commonly proposed mechanisms for explaining the relationship between television viewing time and health outcomes [41]. This stems from evidence showing that increased snacking is associated with high levels of television viewing time and increased adiposity [60, 77]. However, the association between sedentary behaviour and mortality has been shown to be independent of diet quality and energy intake [40, 41]. Moreover, though sedentary behaviour tends to increase in those who are overweight or obese (indicating energy surplus), the association between sedentary behaviour and mortality is still evident even after adjustment for BMI [41, 47, 53–56, 78].

In a recent review, Bouchard and colleagues [79] summarise the importance of sedentary behaviour, physical activity level, and cardiorespiratory fitness on health and premature mortality. They conclude that there are interdependent associations between all of these variables, but also evidence supporting their independent effects on health outcomes. The interdependence of these variables makes it very difficult to tease out their independent relations, and additional research is needed to help clarify how each of these variables contributes to health and mortality risk. Figure 14.3 illustrates the various health outcomes which are associated with increased sedentary time and low physical activity, and the potential biological mechanisms which may underlie these associations.

14.3 Summary

More than 60 years of scientific enquiry demonstrating evidence for a causal link between physical activity, health, and premature mortality have culminated in the current public health recommendations for MVPA. By comparison, the evidence for an independent effect of sedentary behaviour on health and premature mortality is just emerging. Current evidence linking prolonged sitting time with significant compromises to cardiometabolic health indicates that, even in physically active adults, concurrent reductions in the amount of time spent sitting is likely to confer health benefits and reduce the risk of premature mortality. The evidence base linking prolonged sitting with a number of adverse health outcomes, including premature mortality, is convincing, and consistent among several countries [80]. The result of this expanding evidence base has been the first global joint sedentary behaviour and physical activity guidelines, released by the WHO in 2020 [81]. These guidelines are broad and non-prescriptive, with a focus on sitting less and moving more, whatever that may mean for the individual. These scoping guidelines are inclusive and break down traditional barriers to MVPA, particularly for clinical populations. While there are still prescriptive guidelines for physical activity, the recommendations emphasise the importance of limiting sedentary time and moving more. This represents a significant milestone for sedentary behaviour researchers. However, further research is required to inform advice that can be given to patients and the general population. This type of information would particularly aid physicians in advising patients to reduce their daily sitting time and avoid prolonged unbroken sitting periods. While the field is making good steps in the direction of more active living in many patients, the focus needs to remain on in a paradigm where the deleterious health

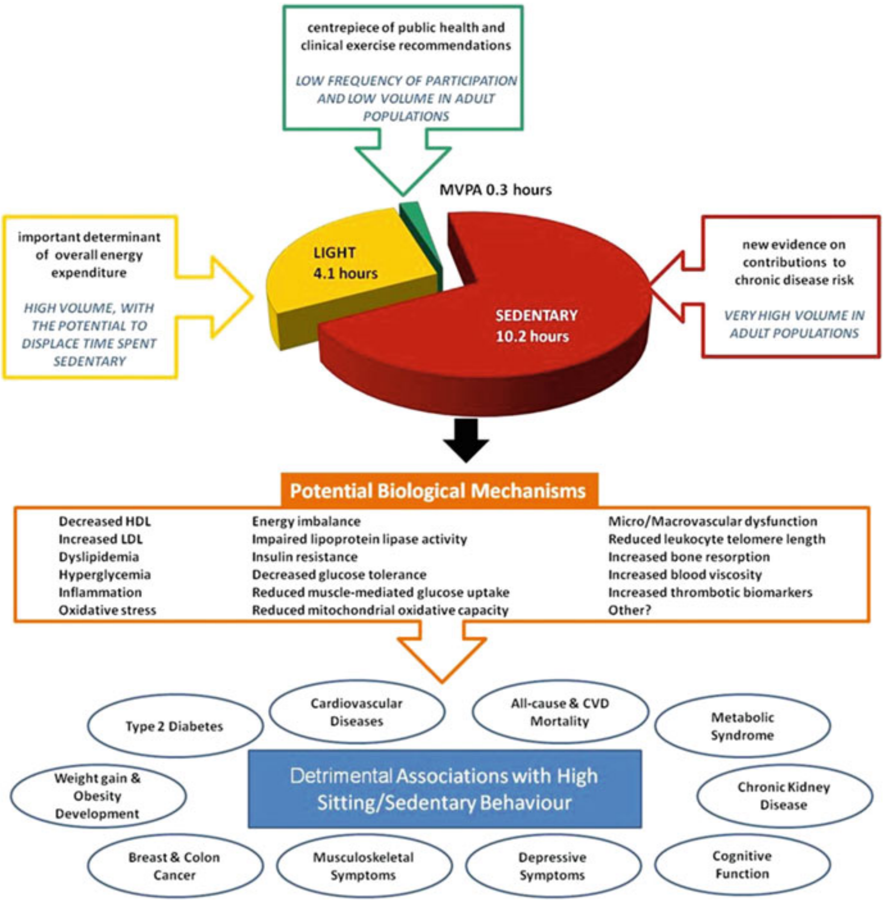

Fig. 14.3 Illustration of how the most sedentary individuals in the population allocate their waking hours, and potential biological mechanisms linking sedentary behaviour to health outcomes. Data from the pie chart was populated using objective activity monitoring from accelerometer measurements in a large population-based sample (NHANES). Data represent US adults who are in the top quartile of sedentary time (<100 counts per minute cut-point); associated levels of light-intensity activity (100 to 1951 cut-point); and moderate-to-vigorous intensity activity (>1952 cut-point). Adapted with permission from Owen et al., 2012 [13]

consequences of too much sitting should be seen as an addition to and not an alternative to the well-recognised benefits of participation in health enhancing MVPA.

References

1. Finch CE. Evolution in health and medicine Sackler colloquium: evolution of the human lifespan and diseases of aging: roles of infection, inflammation, and nutrition. Proc Natl Acad Sci USA. 2010;107(Suppl 1):1718–24.
2. Jones DS, Podolsky SH, Greene JA. The burden of disease and the changing task of medicine. N Engl J Med. 2012;366(25):2333–8.
3. CDC. Achievements in Public Health, 1900–1999: Control of Infectious Diseases. MMWR Weekly. 1999;48(29):621–9.
4. Ausubel JH, Meyer PS, Wernick IK. Death and the human environment: the United States in the 20th century. Technol Soc. 2001;23:131–46.
5. Olshansky SJ. Has the rate of human aging already been modified? Cold Spring Harbor perspectives in medicine 2015;5(12).
6. World Health Organisation. Fact Sheet: Noncommunicable Diseases 2021. Available from: https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases.
7. World Health Organisation. Fact sheet: The top 10 causes of death: World Health Organisation. Available from: https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death.
8. World Health Organisation. Global Health Observatory data: life expectancy: World Health Organisation. Available from: https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates.
9. World Health Organisation. WHO Coronavirus (COVID-19) Dashboard 2021. Available from: https://covid19.who.int/.
10. Barwais FA. Assessing physical activity and sedentary time during the COVID-19 pandemic using self-reported measurement. Natl J Physiol Pharm Pharmacol. 2020;10(11):1019–24.
11. Kunstler B, Slattery P, Grundy E, Goodwin D, Saeri AK. Physical activity and sedentary behaviour during the COVID-19 pandemic: an Australian population study. 2020.
12. Meyer J, Mcdowell C, Lansing J, Brower C, Smith L, Tully M, et al. Changes in physical activity and sedentary behaviour due to the COVID-19 outbreak and associations with mental health in 3,052 US adults. 2020.
13. Owen N, Healy GN, Howard B, Dunstan DW. Too much sitting: health risks of sedentary behaviour and opportunities for change. President's Council on Fitness, Sport & Nutrition: Research Digest. 2012;13(3).
14. Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. Obes Rev. 2012;13(8):659–80.
15. Dunstan DW, Howard B, Healy GN, Owen N. Too much sitting—a health hazard. Diabetes Res Clin Pract. 2012;97(3):368–76.
16. Manley AF. Physical activity and health: a report of the Surgeon General. Atlanta, GA: Diane Publishing Co.; 1996.
17. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Circulation. 2007;116(9):1081–93.
18. Katzmarzyk PT. Physical activity, sedentary behavior, and health: paradigm paralysis or paradigm shift? Diabetes. 2010;59(11):2717–25.
19. Gill JM, Cooper AR. Physical activity and prevention of type 2 diabetes mellitus. Sports Med. 2008;38(10):807–24.
20. Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med. 2002;346(6):393–403.
21. Thompson PD. Exercise and physical activity in the prevention and treatment of atherosclerotic cardiovascular disease. Arterioscler Thromb Vasc Biol. 2003;23(8):1319–21.
22. Lollgen H, Bockenhoff A, Knapp G. Physical activity and all-cause mortality: an updated meta-analysis with different intensity categories. Int J Sports Med. 2009;30(3):213–24.

23. Paffenbarger RS Jr, Hyde RT, Wing AL, Hsieh CC. Physical activity, all-cause mortality, and longevity of college alumni. N Engl J Med. 1986;314(10):605–13.
24. Blair SN, Kohl HW 3rd, Paffenbarger RS Jr, Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality. A prospective study of healthy men and women. JAMA. 1989;262(17):2395–401.
25. Ford ES, Caspersen CJ. Sedentary behaviour and cardiovascular disease: a review of prospective studies. Int J Epidemiol. 2012;41(5):1338–53.
26. Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. Am J Clin Nutr. 2012;95(2): 437–45.
27. Ekelund U, Tarp J, Steene-Johannessen J, Hansen BH, Jefferis B, Fagerland MW, et al. Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. BMJ. 2019:l4570.
28. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet (London, England). 2016;388(10051):1302.
29. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes. 2007;56(11): 2655–67.
30. Dong L, Block G, Mandel S. Activities contributing to total energy expenditure in the United States: results from the NHAPS study. Int J Behav Nutr Phys Act. 2004;1(1):4.
31. Dempsey PC, Hadgraft NT, Winkler EAH, Clark BK, Buman MP, Gardiner PA, et al. Associations of context-specific sitting time with markers of cardiometabolic risk in Australian adults. Int J Behav Nutr Phys Act. 2018;15(1):114.
32. Morris JN, Heady JA, Raffle PA, Roberts CG, Parks JW. Coronary heart-disease and physical activity of work. Lancet (London, England). 1953;265:6796.
33. Chau JY, Grunseit A, Midthjell K, Holmen J, Holmen TL, Bauman AE, et al. Sedentary behaviour and risk of mortality from all-causes and cardiometabolic diseases in adults: evidence from the HUNT3 population cohort. Br J Sports Med. 2015;49(11):737–42.
34. Chau JY, Grunseit AC, Chey T, Stamatakis E, Brown WJ, Matthews CE, et al. Daily sitting time and all-cause mortality: a meta-analysis. PLoS One. 2013;8(11):e80000.
35. Kim Y, Wilkens LR, Park SY, Goodman MT, Monroe KR, Kolonel LN. Association between various sedentary behaviours and all-cause, cardiovascular disease and cancer mortality: the Multiethnic Cohort Study. Int J Epidemiol. 2013;42(4):1040–56.
36. Grontved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. JAMA. 2011;305(23):2448–55.
37. Baigorri A. Time use at different stages of life: results from 13 European countries. Luxembourg: Eurostat; 2003.
38. Australian Bureau of Statistics How Australians Use Their Time, 2006: Australian Bureau of Statistics; 2008. Available from: http://www.abs.gov.au/ausstats/ABS@.nsf/Latestproducts/4153.0Main%20Features22006.
39. Nielsen. State of the Media: TV usage trends Q3 and Q4 2010: Nielsen Co. Available from: http://www.nielsen.com/us/en/insights/reports/2011/state-of-the-media-tv-usage-trends-q3-and-q4-2010.html.
40. Wijndaele K, Brage S, Besson H, Khaw KT, Sharp SJ, Luben R, et al. Television viewing and incident cardiovascular disease: prospective associations and mediation analysis in the EPIC Norfolk Study. PLoS One. 2011;6(5):e20058.
41. Dunstan DW, Barr EL, Healy GN, Salmon J, Shaw JE, Balkau B, et al. Television viewing time and mortality: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Circulation. 2010;121(3):384–91.
42. Warren TY, Barry V, Hooker SP, Sui X, Church TS, Blair SN. Sedentary behaviors increase risk of cardiovascular disease mortality in men. Med Sci Sports Exerc. 2010;42(5):879–85.

43. Keadle SK, Moore SC, Sampson JN, Xiao Q, Albanes D, Matthews CE. Causes of death associated with prolonged TV viewing: NIH-AARP Diet and Health Study. Am J Prev Med. 2015;49(6):811–21.
44. Li Y, Eshak ES, Cui R, Shirai K, Liu K, Iso H, et al. Television viewing time and the risk of colorectal cancer mortality among Japanese population: The JACC Study. Cancer Res Treat. 2021;53(2):497–505.
45. Ford ES. Combined television viewing and computer use and mortality from all-causes and diseases of the circulatory system among adults in the United States. BMC Public Health. 2012;12:70.
46. Celis-Morales CA, Lyall DM, Steell L, Gray SR, Iliodromiti S, Anderson J, et al. Associations of discretionary screen time with mortality, cardiovascular disease and cancer are attenuated by strength, fitness and physical activity: findings from the UK Biobank study. BMC Med. 2018;16(1).
47. Patel AV, Bernstein L, Deka A, Feigelson HS, Campbell PT, Gapstur SM, et al. Leisure time spent sitting in relation to total mortality in a prospective cohort of US adults. Am J Epidemiol. 2010;172(4):419–29.
48. Campbell PT, Patel AV, Newton CC, Jacobs EJ, Gapstur SM. Associations of recreational physical activity and leisure time spent sitting with colorectal cancer survival. J Clin Oncol. 2013;31(7):876–85.
49. Hallgren M, Dunstan DW, Owen N. Passive versus mentally active sedentary behaviors and depression. Exerc Sport Sci Rev. 2020;48(1):20–7.
50. Hallgren M, Nguyen T-T-D, Owen N, Stubbs B, Vancampfort D, Lundin A, et al. Cross-sectional and prospective relationships of passive and mentally active sedentary behaviours and physical activity with depression. Br J Psychiatry. 2020;217(2):413–9.
51. Inoue M, Iso H, Yamamoto S, Kurahashi N, Iwasaki M, Sasazuki S, et al. Daily total physical activity level and premature death in men and women: results from a large-scale population-based cohort study in Japan (JPHC study). Ann Epidemiol. 2008;18(7):522–30.
52. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009;41(5):998–1005.
53. van der Ploeg HP, Chey T, Korda RJ, Banks E, Bauman A. Sitting time and all-cause mortality risk in 222 497 Australian adults. Arch Intern Med. 2012;172(6):494–500.
54. Seguin R, Buchner DM, Liu J, Allison M, Manini T, Wang CY, et al. Sedentary behavior and mortality in older women: the Women's Health Initiative. Am J Prev Med. 2014;46(2):122–35.
55. Pavey TG, Peeters GG, Brown WJ. Sitting-time and 9-year all-cause mortality in older women. Br J Sports Med. 2015;49(2):95–9.
56. Koster A, Caserotti P, Patel KV, Matthews CE, Berrigan D, Van Domelen DR, et al. Association of sedentary time with mortality independent of moderate to vigorous physical activity. PLoS One. 2012;7(6):e37696.
57. Leon-Munoz LM, Martinez-Gomez D, Balboa-Castillo T, Lopez-Garcia E, Guallar-Castillon P, Rodriguez-Artalejo F. Continued sedentariness, change in sitting time, and mortality in older adults. Med Sci Sports Exerc. 2013;45(8):1501–7.
58. Tarp J, Hansen BH, Fagerland MW, Steene-Johannessen J, Anderssen SA, Ekelund U. Accelerometer-measured physical activity and sedentary time in a cohort of US adults followed for up to 13 years: the influence of removing early follow-up on associations with mortality. Int J Behav Nutr Phys Act. 2020;17(1).
59. Jefferis BJ, Parsons TJ, Sartini C, Ash S, Lennon LT, Papacosta O, et al. Objectively measured physical activity, sedentary behaviour and all-cause mortality in older men: does volume of activity matter more than pattern of accumulation? Br J Sports Med. 2019;53(16):1013–20.
60. Thorp AA, McNaughton SA, Owen N, Dunstan DW. Independent and joint associations of TV viewing time and snack food consumption with the metabolic syndrome and its components; a cross-sectional study in Australian adults. Int J Behav Nutr Public Health. 2013;10(96).

61. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012;55(11):2895–905.
62. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32.
63. Patterson R, McNamara E, Tainio M, de Sa TH, Smith AD, Sharp SJ, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. Eur J Epidemiol. 2018.
64. Ekelund U, Brown WJ, Steene-Johannessen J, Fagerland MW, Owen N, Powell KE, et al. Do the associations of sedentary behaviour with cardiovascular disease mortality and cancer mortality differ by physical activity level? A systematic review and harmonised meta-analysis of data from 850 060 participants. Br J Sports Med. 2019;53(14):886–94.
65. de Rezende LF, Rodrigues Lopes M, Rey-Lopez JP, Matsudo VK, Luiz OC. Sedentary behavior and health outcomes: an overview of systematic reviews. PLoS One. 2014;9(8): e105620.
66. Katzmarzyk PT, Powell KE, Jakicic JM, Troiano RP, Piercy K, Tennant B. Sedentary behavior and health: update from the 2018 physical activity guidelines advisory committee. Med Sci Sports Exerc. 2019;51(6):1227–41.
67. Dempsey PC, Biddle SJH, Buman MP, Chastin S, Ekelund U, Friedenreich CM, et al. New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. Int J Behav Nutr Phys Act. 2020;17(1).
68. Dempsey PC, Matthews CE, Dashti SG, Doherty AR, Bergouignan A, van Roekel EH, et al. Sedentary behavior and chronic disease: mechanisms and future directions. J Phys Act Health. 2020;17(1):52–61.
69. Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ, et al. Objectively measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Diabetes Care. 2008;31(2):369–71.
70. Lamonte MJ, Buchner DM, Rillamas-Sun E, Di C, Evenson KR, Bellettiere J, et al. Accelerometer-measured physical activity and mortality in women aged 63 to 99. J Am Geriatr Soc. 2018;66(5):886–94.
71. Ekelund U, Tarp J, Fagerland MW, Johannessen JS, Hansen BH, Jefferis BJ, et al. Joint associations of accelerometer-measured physical activity and sedentary time with all-cause mortality: a harmonised meta-analysis in more than 44 000 middle-aged and older individuals. Br J Sports Med. 2020;54(24):1499–506.
72. Korkiakangas EE, Alahuhta MA, Laitinen JH. Barriers to regular exercise among adults at high risk or diagnosed with type 2 diabetes: a systematic review. Health Promot Int. 2009;24(4): 416–27.
73. Matson TE, Anderson ML, Renz AD, Greenwood-Hickman MA, McClure JB, Rosenberg DE. Changes in self-reported health and psychosocial outcomes in older adults enrolled in sedentary behavior intervention study. Am J Health Promot. 2019;33(7):1053–7.
74. Bakker EA, Hopman MTE, Lee D-C, Verbeek ALM, Thijssen DHJ, Eijsvogels TMH. Correlates of Total and domain-specific Sedentary behavior: a cross-sectional study in Dutch adults. BMC Public Health. 2020;20(1).
75. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. Am J Epidemiol. 2008;167 (7):875–81.
76. Dempsey PC, Howard BJ, Lynch BM, Owen N, Dunstan DW. Associations of television viewing time with adults' well-being and vitality. Prev Med. 2014;69:69–74.
77. Pearson N, Biddle SJ. Sedentary behavior and dietary intake in children, adolescents, and adults. A systematic review. Am J Prev Med. 2011;41(2):178–88.

78. Stamatakis E, Hamer M, Dunstan DW. Screen-based entertainment time, all-cause mortality, and cardiovascular events: population-based study with ongoing mortality and hospital events follow-up. J Am Coll Cardiol. 2011;57(3):292–9.
79. Bouchard C, Blair SN, Katzmarzyk PT. Less sitting, more physical activity, or higher fitness? Mayo Clin Proc. 2015;90(11):1533–40.
80. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc. 2011;43(7):1334–59.
81. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54(24):1451–62.

Part III
Understanding Sedentary Behaviour and Promoting Reductions in Time Spent Sedentary

Chapter 15
An Ecological Model for Understanding and Influencing Sedentary Behaviour

Nyssa Hadgraft, David Dunstan, and Neville Owen

Abstract With the evidence that time spent sitting can have adverse health consequences, a research priority is to build the requisite knowledge base for effective interventions—that is, what needs to be changed in order to change sitting time? To do so requires an understanding of the environmental and contextual determinants of sedentary behaviours, particularly to guide broad-reach public health approaches. Conceptual models that focus explicitly on environmental and contextual factors can assist in developing this key element of the overall sedentary behaviour epidemiology research agenda. Sedentary behaviours can usefully be understood as inherently context-specific—taking place in domestic environments, during transportation, and in educational and workplace environments. Within this perspective, an ecological model that emphasises the role of 'behaviour settings'—context-specific environmental influences—has relevance. This chapter presents an approach informed by a behavioural epidemiology framework, drawing on evidence about sedentary behaviour and health, and about the contexts of time spent sitting. The aim is to provide an understanding of the environment- and policy-relevant determinants of sedentary behaviour (considered distinctly, but not separate from personal and social factors). To demonstrate how this approach can be helpful, we apply the five principles of an ecological model to sitting in the workplace. We outline how this model can provide an environmentally focused perspective and help to direct attention to multiple levels of influence on sedentary behaviour, and present an example of a workplace sitting-

N. Hadgraft
Centre for Urban Transitions, Swinburne University of Technology, Melbourne, VIC, Australia
e-mail: nhadgraft@swin.edu.au

D. Dunstan
Physical Activity Laboratory, Baker Heart and Diabetes Institute, Institute for Physical Activity and Nutrition, Deakin University, Melbourne, VIC, Australia
e-mail: david.dunstan@baker.edu.au

N. Owen (✉)
Centre for Urban Transitions, Swinburne University of Technology, Physical Activity Laboratory, Baker Heart and Diabetes Institute, Melbourne, VIC, Australia
e-mail: neville.owen@baker.edu.au

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_15

reduction intervention. We discuss some of the strengths and limitations of an ecological/environmental approach and suggest opportunities for future research.

What Is New?

- Evidence of differential associations of sedentary time in different environmental settings with health risk biomarkers and mental health indices.
- Identification of modest but statistically significant links of sedentary behaviour with neighbourhood environment attributes.
- Recent intervention trials in the workplace setting have employed environmental and ecological approaches, and have targeted multiple levels of influence.

15.1 Introduction

As noted in other chapters, research into all aspects of sedentary behaviour has increased considerably in recent years. There is now a substantial body of sedentary behaviour epidemiology evidence linking high levels of sitting with increased risk of a number of chronic diseases, risk factors and premature mortality. Furthermore, evidence from experimental studies in laboratory settings has begun to confirm and elaborate upon the implications of this observational-study evidence (see Chap. 5 for further detail). These findings point to the need for intervention trials to identify the feasibility and benefits of changing sedentary behaviours [1–5].

As with research involving other health behaviours, conceptual frameworks—models and theories—can assist in explaining and predicting sedentary behaviour, and can provide strong guidance for developing interventions. With the rapidly strengthening evidence base on the adverse health outcomes associated with sedentary behaviours, greater attention now needs to be focused on understanding the factors that influence too much sitting—*the determinants of sedentary behaviours*. Specific knowledge of the antecedents of sedentary behaviours in the *contexts in which they take place* is crucial to the design and implementation of effective evidence-based interventions. The application of theories and models to the study of sedentary behaviour is central to developing this stage of the research agenda.

To place the focus of this chapter in the perspective of sedentary behaviour epidemiology, Fig. 15.1 outlines the *behavioural epidemiology framework* [6–8]. This framework proposes six main phases of research on sedentary behaviour and their interrelationships. For example, understanding the important influences on particular sedentary behaviours (Phase IV) associated with adverse health outcomes (as identified within Phase I) will assist judgements about how difficult or how easy it may be to change them. Or conducting real-world assessments of the impact of manipulating such influences through intervention trials (Phase V) can provide strong clues for possible research directions on the determinants of behaviour.

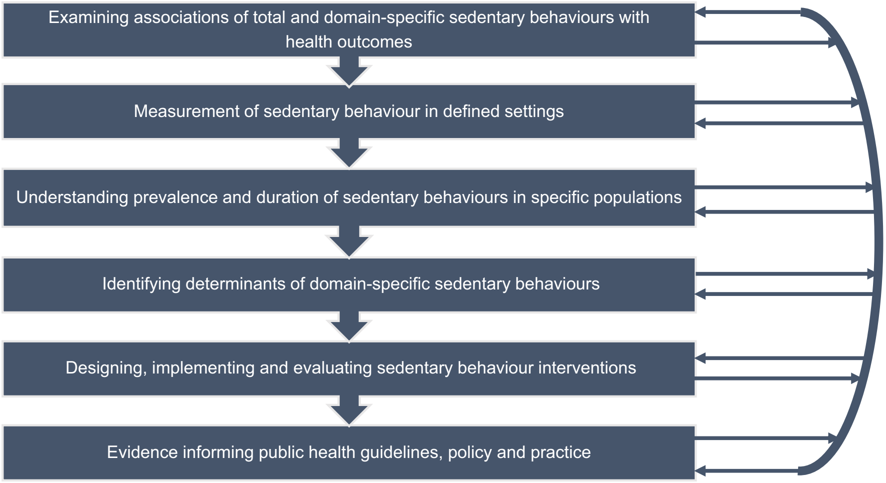

Fig. 15.1 Behavioural epidemiology perspective on understanding and influencing sedentary behaviours [6–8]

A key underpinning of the framework shown in Fig. 15.1 is that all of these phases of research can inform and influence each other. In this chapter, we will focus on the relevance of ecological models for informing research in Phases IV and V of the behavioural epidemiology framework, where the evidence base is more limited.

Research in Phases I through to VI, as illustrated in Fig. 15.1, may be thought of as a logical sequence of evidence building. However, considering the set of arrows on the right-hand side of the figure, this perspective on sedentary behaviour epidemiology research should not be taken to imply that each respective phase will require evidence from the preceding phases as essential building blocks. As evidence emerges on sedentary behaviour determinants and interventions (Phases IV and V) for example, this may point to fruitful new research directions identifying health outcomes and relevant mechanisms (Phase I), or as the policy context around sedentary behaviours is elaborated (Phase VI), research on determinants of sedentary behaviour (Phase IV) may require a different focus and novel opportunities for intervention trials (Phase V) may arise.

This chapter outlines a strategic perspective for research employing theories and models in the sedentary behaviour field. Specifically, we use particular illustrations of how conceptual frameworks can assist in progressing our understanding of the factors that can influence sitting, and can strengthen, in practical ways, the knowledge base underlying interventions. *This requires a conceptual perspective to capture the complexity of the determinants of sedentary behaviours across the key settings in which they occur.* We propose an ecological model of sedentary behaviour [9] as a framework for guiding future research studies. We employ this model throughout this chapter and demonstrate how it can be used to progress knowledge in the field.

Research in this relatively new and emerging field of sedentary behaviour epidemiology has been informed by theories and models used in physical activity research [10, 11]. However, as we will discuss, there are unique characteristics of sedentary behaviour that suggest the need for a distinct, strategic approach to guide future research.

15.2 Strategies for Understanding Sedentary Behaviour

Research into the determinants of sedentary behaviour can be seen as both related to and distinct from research on physical activity and exercise. For the purposes of this chapter, when we refer to 'physical activity' we are generally referring to activity performed at a moderate-to-vigorous intensity—activity that increases heart rate and is often performed as planned bouts, which would be inclusive of 'exercise'. While we make a clear and explicit distinction between physical inactivity (too little exercise) and sedentary behaviour (too much sitting), we understand that these are two distinct attributes that nevertheless may mutually influence each other, with synergistic behavioural, physical and mental health impacts that can be influenced by the environmental context and the attributes of the sedentary behaviours involved [12–15].

15.2.1 Physical Activity and Sedentary Behaviour: Some Key Differences

Interventions designed to increase physical activity or reduce sedentary behaviour have a common goal: to reduce the population-wide chronic disease burden associated with inactivity. Both approaches generally aim to encourage people to introduce more activity into their day, although the intensity of that activity is likely to differ. Sedentary behaviour interventions are designed primarily to support people to shift some of their sitting time to light-intensity activities, such as standing or walking; physical activity interventions have a greater focus on encouraging participants to accumulate more moderate-to-vigorous physical activity.

While there are close links between physical activity and sedentary behaviour, there are key qualitative differences between the two behaviours that underpin the need for novel strategies to guide research on sedentary behaviour interventions. In this context, Biddle and Gorely [16, 17] provide an informative elaboration of some of the distinctions between the nature of the relevant behaviours and the factors likely to determine these behaviours, for moderate-to-vigorous physical activity and for two specific examples of sedentary behaviour:

- *Moderate-to-vigorous physical activity*: Low frequency and short duration, often taking place as a bout on one occasion (or fewer) each day. It requires both conscious planning and moderate-to-high effort to carry out and is likely to be influenced by factors at multiple levels including individual-level goals and motivation, social support and a supportive physical environment.

- *Domestic sedentary behaviour (television viewing and other screen time)*: Occurs in regular prolonged bouts, typically in the evening and on weekends for working adults. It can be of long duration, in bouts of 2–3 h with infrequent breaks. It requires a low level of effort and little conscious planning. It is highly habitual and influenced by individual preferences, by social norms and typically by the physical environment—including furniture arrangements—of domestic settings.
- *Occupational sedentary behaviour (workplace sitting)*: Takes place in regular prolonged bouts for office workers, typically occurring on weekdays. It is often of very long duration—6–7 h accumulated across a day with infrequent breaks. It requires minimal effort or conscious planning and is highly habitual. Key drivers include habit, social norms, job requirements (such as computer-based work), and the workplace physical environment (including office furniture and spatial design features).

As noted above, there are some key differences in the relationships of environmental contexts with moderate-to-vigorous physical activities compared to sedentary behaviours—particularly related to the contextual factors that are likely to influence the frequency and duration of the two behaviours. Sitting is highly frequent and can occur in long bouts that may only be interrupted briefly for a short duration. In contrast, physical activities (specifically those of a moderate-to-vigorous nature) tend to occur at lower frequencies in relatively short, distinct bouts (e.g. 30 min to 1 h). An active person may go to the gym for an hour, four times a week, but may do little physical activity outside of these sessions. Importantly, the influencing factors or drivers of these behaviours are likely to differ, including the relative importance of habit and individual motivation.

Even the two examples of sedentary behaviour provided—TV viewing/screen time and workplace sitting—are likely to be influenced by different factors. Biddle and Gorely [16] suggest that this key difference in the level of conscious processing is likely to have implications for the application of particular theories of behaviour in relation to sedentary behaviour. While approaches for physical activity have typically focused on the role of conscious decision-making, individual-level theories for sedentary behaviour may need to have a greater focus on the importance of habit, or unconscious decision-making.

As outlined above, physical activity and sedentary behaviour should not be treated simply as two sides of the same coin [18, 19]; inactivity (low/insufficient levels of moderate-to-vigorous physical activity) is not the same as being sedentary (high levels of sitting). It is possible, for example, to be both highly sedentary and highly active (consider an office worker who cycles to work and then sits at a computer for long, unbroken blocks of time). Recognising the distinct determinants of physical activity and sedentary behaviour is particularly important for understanding these behaviours and appropriately intervening [8, 9, 16]. Influencing sedentary behaviour requires specific, targeted approaches based on the rapidly progressing research in this field, rather than just applying the approaches that have previously been found to be effective for understanding physical activity.

15.2.2 *Identifying Determinants of Sedentary Behaviour: A Population-Health Perspective*

The current sedentary behaviour epidemiology knowledge base provides indications of possible correlates (cross-sectional associations or predictors) of sedentary behaviour. Considerably less evidence exists on 'determinants' of sedentary behaviour [20]—a term implying a cause-and-effect relationship of one or more attributes with the probability or the extent of engagement, in a particular sedentary behaviour [21].

Of the correlates that have been identified, the most consistent evidence relates to individual-level factors, such as socio-demographics and health behaviour-related attributes [22]. Please refer to Chap. 2 for further details on the correlates of sedentary behaviour. Evidence for environmental correlates of sedentary behaviour is increasing, although this has largely been limited to exploring associations with the neighbourhood-built environment [20]. The relationship between interpersonal or social influences with sedentary behaviour is also less clear from existing quantitative studies. A review by O'Donoghue and her colleagues [20] found that family-related factors, specifically household composition and the presence of children, appeared to be associated with sedentary time but found no evidence to support an association between social norms or social interactions with non-family members (e.g. colleagues and friends) with sedentary behaviour, although the number of studies reviewed was small.

Interestingly, findings from qualitative research provide some additional evidence to suggest that aspects of the sociocultural and physical environmental may be important influences of behaviour. Interviews with office-based workers suggest, for example, that perceived social norms linking productivity with being at one's desk create a barrier to taking more regular breaks from sitting [23], while supportive social environments may facilitate reduced sitting time. In addition, office furniture that feasibly only allows computer-based work to be performed seated is likely to be a key factor influencing sedentary behaviour in office-based workers [24, 25].

Another example of informative qualitative evidence on social attributes is the study by Chastin and his colleagues [26], who reported how social influences may play a significant role in influencing sedentary time for older adults. The older women interviewed for their study identified perceived societal expectations that older adults should sit frequently, combined with insufficient environmental features to accommodate brief pauses from sitting, as key factors influencing the amount of time they spent sitting. A further nuance is that older adults' sitting varies significantly across the day, likely reflecting the interactions of settings, social and physical health influences [27, 28].

While the above provides snapshots of the evidence pertaining to interpersonal determinants of sedentary behaviour (which are addressed in more detail in Chaps. 2, 14, 16 and 28) it highlights the need to broaden thinking beyond individual-level factors and attempt to identify potentially modifiable environmental and social influences on sedentary behaviour. Conceptual models of the social and environmental determinants of sedentary behaviour can assist with this process, but need to

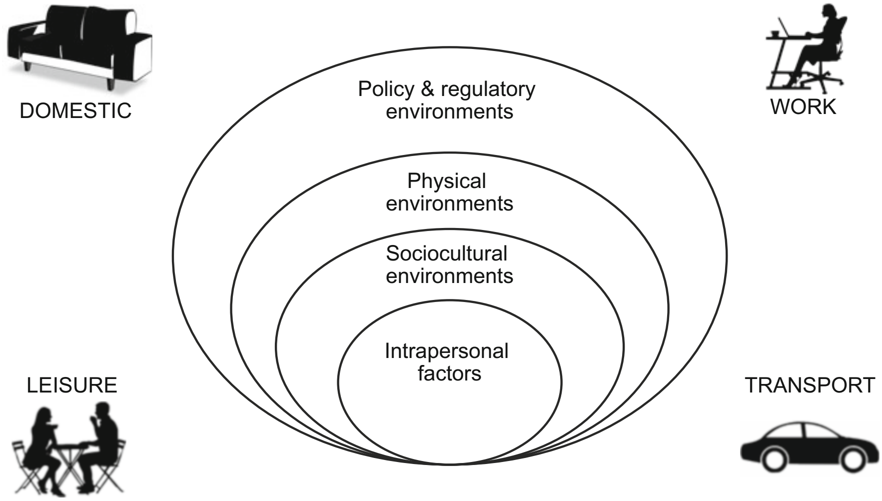

Fig. 15.2 A simplified ecological model of health behaviour (Reproduced with permission from Springer Nature) [32]

incorporate such nuances and complexities, including the differences that may emerge across the wide range of different settings in which these behaviours take place [29, 30] and the interaction between different levels of influence [20, 31].

As we will illustrate in the following section with reference to Fig. 15.2, there are challenges in taking an explicit social and environmental perspective on the determinants of sedentary behaviour. This reflects, in part, some of the roots of research in our relatively new sedentary behaviour field. Within physical activity research, individual-level theoretical models primarily have been employed in the design of interventions [6]. For example, social-cognitive approaches include strategies to try and increase participants' self-efficacy for physical activity, such as using goal setting and feedback on performance to alter participants' belief in their capability to undertake physical activity [33].

However, strategies that only target factors influencing behaviour at the individual level and fail to take account of the broader social and environmental context in which it occurs will not be sufficient to achieve changes that are of public health significance. In order to appropriately target such a prevalent and ubiquitous behaviour in a population health context, it will be necessary to incorporate an understanding of multiple levels of influences across different settings.

As noted earlier, there are still a number of gaps in our understanding of the determinants of sedentary behaviour; the evidence for this phase of the behavioural epidemiology framework is comparatively less developed than the preceding phases [34]. As an example, while a large body of research has focused on understanding attributes associated with TV viewing time or overall sitting time [16, 20, 22], less research has explored likely determinants of occupational sitting (despite the significant contribution of this setting to many adults' overall levels of sitting). Other chapters in this book address the current state of knowledge relating to correlates of sedentary behaviour at the individual level (Chap. 16), the community level (Chap. 23) and related to the social and physical environment (Chap. 24).

We suggest that the use of an ecological model for sedentary behaviour may assist in addressing some of these research gaps and improving our understanding of the underlying determinants. Understanding the determinants of sedentary behaviours across different settings is particularly important as the factors that influence the amount of sedentary time a person engages in and related health consequences may depend on the specific setting in which it takes place [35].

15.3 An Ecological Model of Health Behaviour

Ecologic models have been used to explore and address a number of different health behaviours, including physical activity, healthy eating and tobacco smoking [36]. These ecological approaches largely arose after recognition that methods focused predominately on individual-level factors failed to achieve inroads in promoting healthy behaviours [36, 37].

Ecological models aim to recognise the complexity of health behaviours, acknowledging that there is unlikely to be a single cause-and-effect pathway. In line with approaches used to address some of these other health risk factors, the application of an ecological model to sedentary behaviour may also assist in guiding future research and identifying novel intervention targets across the multiple levels of influence.

A key distinction is that while individual-level models emphasise the role of person-level attributes (e.g. motivation, self-efficacy) that influence individual behavioural choices, ecologic models focus to a greater extent on individuals' interactions with their physical and sociocultural environments [38]. According to this notion, the act of motivating or educating a person to change their behaviour is expected to be limited if social and environmental conditions are not also supportive of this behaviour. However, while supportive environments are considered *necessary* for healthy behaviours, the idea that there are multiple levels of influence on behaviour means that altering the environment on its own may not be *sufficient* for behavioural change [39].

Ecological perspectives of health behaviour have five key principles that can be used to guide research and understand the precursors to behaviour [36, 39]:

1. There are multiple levels of influence on health behaviours
2. Environmental contexts are significant determinants of health behaviours
3. Influences on behaviours interact across levels
4. Ecological models should be behaviour-specific
5. Multi-level interventions should be most effective in changing behaviours

15.3.1 Applying an Ecological Model: Multi-level Approaches for Understanding the Determinants of Sedentary Behaviours

It has been noted previously that the choice of approaches for addressing health behaviour interventions tends to be influenced by disciplinary backgrounds of researchers rather than what may necessarily be the best approach [40]. For example, psychological influences highlight the importance of individually focused solutions to addressing health behaviours, while a practitioner from an urban design background may emphasise the importance of environmental influences on behaviour [41]. A disadvantage of this approach is that it has the tendency to lead to narrow, silo-type approaches to analysing problems and developing solutions [40].

Increasingly, it is being recognised that behavioural health risk factors such as insufficient physical activity and excessive levels of sedentary behaviour are complex problems, requiring multi-faceted solutions. To address these issues, we therefore require theoretical frameworks that can recognise and incorporate this complexity [42]. We suggest that ecological models are better suited to this task when compared with individually focused models and can provide the framework for developing appropriate interventions.

Importantly, ecological models have much in common with best-practice health promotion approaches. The Ottawa Charter for Health Promotion [43] emphasises the importance of multi-faceted approaches, suggesting that the ideal conditions for encouraging healthy behaviours include supportive environments and policies, and ensuring that individuals are educated, but also that they have sufficient resources to make healthy choices. The national preventive health framework in the USA, *Healthy People 2030*, outlines the importance of addressing the social, environmental and economic determinants of health, in addition to individual-level factors [44]. In line with these approaches to preventive health and health promotion more generally, an ecological model may also be beneficial for guiding research and interventions into the new public health challenges posed by excessive sedentary behaviour, with ultimate translational relevance.

15.3.2 Ecological Model Principles and Individual-Level Theories

Ecological models do not discount that individual-level characteristics, such as motivation or individual preferences, may influence sedentary behaviour. Social-cognitive theories formed the basis of many interventions that have aimed to encourage higher levels of physical activity in the population [36]. The direct application of social-cognitive theories to sedentary behaviour is still somewhat limited [34]. However, there is some evidence to suggest that dual-process theories may be helpful for understanding some of the cognitive influences on sedentary behaviour. Dual-process theories propose that we have two processing pathways—one automatic and non-conscious and the other controlled and reflective. As discussed earlier, it is highly probable that automatic, cue-driven processing plays an important role in sedentary behaviour, whereas physical activity, which occurs in less frequent bouts, may involve more controlled processing [16]. Some studies have found evidence to support an association between habits and sedentary behaviour amongst university students [45] and older adults [46] where those with stronger habits reported spending more time sitting. Interestingly, the application of a form of controlled processing—having specific intentions to reduce sedentary behaviour—was associated with lower levels of sitting time in both samples [45, 46], suggesting a possible explanation for some of the variation in sedentary behaviour, and a pathway to explore within interventions.

However, a limitation of individual-level theories, including the dual-process model, is that their specificity does not account for the broader social and contextual attributes that can influence behaviour. While an ecological model does not discount the role of cognitive processes in influencing behaviour, it is considered that individual attributes are only one level of influence of sedentary behaviour and should not be considered in isolation from contextual factors that are also likely to be influential. From an ecological perspective, approaches centred on solely educating individuals about the health consequences of their behaviour and motivating them to change are not expected to be sustainable in the long term, unless combined with strategies targeting the broader environmental, social and policy context in which the behaviour occurs [36].

15.4 An Ecological Model of Sedentary Behaviour

An ecological model of sedentary behaviour identifies four domains—*leisure, household, transport*, and *occupation* [9]. The range of potential influences and their relative importance is considered to differ in each of these domains [9]. This is based on a preceding ecological model of physical activity behaviour. Figure 15.2 depicts a simplified version of the main levels of influence that ecological models identify. This perspective directs research attention to broader potential influences on sedentary behaviours, beyond the more usual focus on individual-level attributes that are addressed by psychological and social-cognitive theoretical models [34].

As previously stated, a key underpinning of ecological models is the emphasis on environmental and social factors as important influences of behaviour. While the empirical evidence for environmental determinants of sedentary behaviour is still emerging [20], the habitual, unconscious nature of many instances of sedentary behaviour leads to the hypothesis that particular cues in our environment act as triggers for sitting. When one takes the time to think about what influences sitting throughout the day, this makes some intuitive sense. For example, are you sitting down right now while reading this chapter? If so, perhaps this is because you are at a desk—at home, in the library, or at your workplace—which is at a fixed height designed for use with a chair. Perhaps you are also sitting down because this is the behaviour demonstrated by others in your environment and social norms encourage you to emulate that behaviour. The social norms around what is 'normal' or 'acceptable' behaviour are likely to be important influences of when and where we sit, as they are with other behaviours. An emerging body of literature has investigated the application of choice architecture techniques, or 'nudging', to the field of sedentary behaviour and physical activity, whereby small changes are made to micro-environments (such as home settings and workplaces) to promote behavioural change [4, 17]. More research (including high-quality, controlled trials) is needed to ascertain whether such strategies could be effective for changing sedentary behaviour.

15.4.1 The 'Behaviour Settings' Construct Within an Ecological Model of Sedentary Behaviour

The potential utility of an ecological model for sedentary behaviour also arises from the importance that it places on 'behaviour settings' [47]—the physical and social context in which sedentary behaviour takes place. The complexity of understanding and influencing sedentary behaviour stems from the reality that sitting occurs in numerous contexts and a blanket approach targeting 'sedentary behaviour' fails to take these nuances into account. Common examples of sedentary behaviours—such as watching television, driving a car and sitting at a desk at the workplace are each likely to have distinct determinants and require different approaches [9]. The relative importance of each of these settings is also likely to differ across population groups. For working adults in sedentary jobs, intervening in the workplace setting may have the biggest impact on total daily sitting time [48]. For retirees, the household setting is often where the largest proportion of sedentary time occurs and thus intervening in this setting may be most effective [49]. For adults living in outer suburban areas, addressing time sitting in motor vehicles may be fruitful [31]. Feasible strategies for reducing sitting are also likely to differ between settings. In the workplace, for example, activity-permissive workstations are often trialled [50], while in the home environment feasible strategies may include encouraging people to take more frequent breaks from sedentary leisure activities (such as standing up and moving during commercial breaks or between episodes [51]). For further details on sedentary behaviour interventions targeting different population subgroups and settings, please refer to this chapter.

Further empirical evidence is needed to test the principles of an ecologic model of sedentary behaviour as outlined above. Using the ecologic model as a guide, there are opportunities for novel research questions about the possible determinants of sedentary behaviour in each of the common domains. This evidence will further our understanding of this highly prevalent health risk factor and provide an important knowledge base to inform settings-based interventions.

15.4.2 Environmental Influences on Sedentary Behaviour

When thinking about environmental influences on behaviour, these can include perceptions and objectively measured aspects of the built environment, the natural environment and the sociocultural environment. There is a body of research linking aspects of the built environment, particularly population density and access to destinations, with walking [52], sedentary time [53] and cycling for transport [54].

A review of the evidence linking neighbourhood environmental attributes with sedentary behaviours by Koohsari and his colleagues [31] found somewhat mixed evidence. Less than 30% of instances examined were significantly associated in the expected direction (i.e. environmental attributes more favourable to physical activity being associated with lower levels of sedentary behaviour). Many of the studies found no evidence for the expected associations. One possible explanation that was suggested was a lack of correspondence between the setting (neighbourhood environment) and the behaviours measured in the studies; the sedentary behaviour outcome was frequently an assessment of total sitting time accumulated across the day. In accordance with the ecological model, it would be expected that neighbourhood environment features would be most relevant to behaviour that occurs in that setting (i.e. the home) and would not necessarily influence behaviour in other settings, such as the workplace. The review recommended the need for improved measures of sedentary behaviour and environmental attributes (objective rather than self-report) and more prospective study designs. In addition, the limited understanding of possible interactions between environmental factors with other levels of influence on sedentary behaviour, such as socio-demographic characteristics, was also noted. The review also highlighted the need for studies to consider a distinct analytic approach for understanding the determinants of sedentary behaviour, rather than viewing it as simply a contrasting behaviour to physical activity.

The review by Koohsari et al. did not include studies assessing environmental features of internal environments such as the workplace or home environment. This is an important research gap as altering the indoor environment—such as through replacing traditional seated desks with height-adjustable desks—has become a key focus of many interventions to reduce sedentary time. An ecological approach may assist in identifying the specific, and potentially distinct (indoor and outdoor), environmental determinants of sedentary behaviour in key settings and thus provide a stronger underlying evidence base for this growing field.

15.4.3 Application of an Ecological Model in Sedentary Behaviour Research: The Workplace

To illustrate how the ecological model can assist in guiding research and understanding of sedentary behaviour, we will use the workplace as an example. As will be discussed in further detail in Sect. 15.2, of the key domains of sedentary behaviour [18], the workplace is of particular interest, largely due to the volumes of time that adults spend in the workplace and the increasingly sedentary nature of jobs.

The Workplace as a Sedentary Behaviour Setting

For those in office-based jobs, at least two-thirds of working hours can be spent sedentary [55–57]. Thus, workplace sitting on its own contributes a significant proportion of total daily sitting time for many adults. Reducing the amount of time that people spend sitting at work may therefore have broad-ranging effects on population levels of sedentary behaviour. Sedentary behaviour in the workplace may also be amenable to change, relative to sedentary behaviour occurring in other settings, as it occurs within a regulatory context where employers have legal responsibilities for the health and safety of their employees. Indeed, researchers in this field have called for sedentary behaviour to be considered explicitly as an occupational health and safety issue and treated accordingly within this framework [58].

The workplace has been used as a setting for implementing strategies targeting a range of health risk behaviours including physical activity, nutrition and tobacco control [10]. Working adults spend a significant proportion of their waking hours at work and can be viewed as a captive audience for these messages [59]. For employers, implementing health promotion programs in the workplace can make good business sense, with the potential for economic benefits arising from lower workplace injury rates, reduced absenteeism and greater staff retention [60].

In workplace health promotion, ecological models are consistent with best-practice guidelines. For example, the World Health Organization's Healthy Workplaces Model [61] identifies four areas to incorporate into strategies for improving workplace health: the *physical workplace environment*, the *psychosocial work environment*, *personal health resources* and *enterprise community involvement*. These four pillars emphasise the importance of considering the multi-level influences on health behaviour, in line with principles of an ecological model of health behaviour. In Sect. 18.2, examples will be presented of how a sedentary behaviour program can address the keys to a healthy workplace outlined by this model.

The value of using an ecological model for thinking about the possible determinants of behaviour is that, from the outset, we are challenged to consider how multiple different levels of influence may be involved. Rather than just focus on the most conspicuous factors or those in a particular disciplinary area, an ecological model can encourage a broader, multidisciplinary perspective that can take into account factors that may not previously have been considered.

An ecological model also aligns with our understanding of the workplace as a complex social system [62]. Sedentary behaviour, like other behaviours that occur in this setting, is likely to be influenced by a range of factors including individuals' health status and motivations, beliefs, social norms, social climate, environmental features, and organisational policies and procedures [62–64]. To give an example of how an ecological model of sedentary behaviour can be applied, we will now step through the five principles of ecological models as they apply to the workplace. For illustrative purposes, we focus on office-based workplaces.

1. There are multiple levels of influence on health behaviours

   Thinking about how much time we spend sitting at work, we can identify a range of factors that influence this behaviour. Many of us rely on computers to perform our work, and the typical furniture setup to facilitate this work is a desk and chair. Thus, environmental influences are prominent. However, we can also consider individual-level factors. Some might enjoy sitting down and find this a more comfortable posture than standing. We may have health-related issues that are benefited by sitting. Social norms are also likely to be influential. Perceptions of expected behaviour in the workplace (e.g. that workers are not productive unless they are at their desk) or fear of not wanting to stand out by behaving differently (e.g. by getting up more frequently to stretch or move around the office) may also play a role [23, 24].
2. Environmental contexts are significant determinants of health behaviours

   The environmental features of the workplace are likely to be important contributors to the amount of time spent sitting. As mentioned above, fixed height desks often limit workers' ability to stand or move throughout their workday. Furniture in meeting rooms and office kitchens is often designed for sitting. Other aspects of the physical environment, such as the location of communal equipment (e.g. printers, bins, kitchens, bathrooms), can encourage or limit the opportunities that people have to move away from their sedentary desk work. The availability and accessibility of staircases as an alternative to lifts is another environmental factor influencing activity more generally.
3. Influences on behaviours interact across levels

   As outlined, we can identify multiple different influences of sedentary behaviour in the workplace. There is also evidence to suggest that these factors are likely to interact across levels as specified by the ecological model. Studies that have explored barriers and enablers to using height-adjustable desks in the workplace provide some indication of this phenomenon. One study found that workplaces that simply provided staff with height-adjustable desks with minimal other instruction had lower use of these desks compared to a workplace that supplemented the desks with education and encouragement of their use [65]. Similarly, interpersonal or social factors can interact with individual and environmental level factors to influence workplace sitting. Seeing others use their height-adjustable workstation can provide important social support that can encourage workers to stand up [66]—indicating an interaction between environmental and social influences. In contrast, negative interpersonal interactions (such as concerns about noise projection with standing) may also influence takeup or use of workstations that facilitate standing [66].
4. Ecological models should be behaviour-specific

   When thinking about how to address sedentary behaviour, it is important to consider the setting in which it takes place. In contrast to the relative privacy and freedom of the home environment, behaviour in the workplace is influenced by a

Table 15.1 A multi-level intervention designed to reduce and break up workplace sitting in office workers: Stand Up Victoria

Level of influence	Strategies
Individual	• Face-to-face and telephone health coaching, focusing on goal setting and providing support, behaviour change strategies, instruction/demonstration on workstation use
Organisational	• Senior management and staff representative consultation • Participant brainstorming session to identify suitable strategies for that worksite • Leadership support and communication through tailored management emails
Environmental	• Sit-stand workstation

range of social norms, organisational policies and expectations about behavioural conduct. For many, the degree of volition we have with our behaviour differs markedly. For these reasons, the underlying models of behaviour underpinning strategies for addressing sedentary behaviour should differ between these two settings. This follows the underlying premise of ecological models——that they should be behaviour-specific. Even within the workplace setting, there are different contexts in which sedentary behaviour occurs that should be considered when planning interventions. Some examples of sedentary behaviour that occur in a workplace include sitting at a desk in front of a computer, sitting in a meeting and sitting in a kitchen/tearoom during a break. Each can be explained by multiple levels of influence; however, the relative importance of each of these levels may differ according to the behavioural context.

5. Multi-level interventions should be most effective in changing behaviours

   While early research aiming to intervene on sedentary behaviour in the workplace focused attention on the discernible environmental influences by altering the physical workstations used by workers [67], there are some more recent examples of intervention development that have taken a broader approach along the lines of an ecological model. These provide some evidence that multi-level interventions may be more effective than those that just focus on a singular level.

The *Stand Up Victoria* study is an example of a workplace intervention targeting sedentary behaviour that was developed using an ecologic model of sedentary behaviour as the guiding framework [68]. The intervention involved an environmental component, but also targeted organisational and individual factors thought likely to influence sedentary behaviour (see Table 15.1). Within this ecological framework, social-cognitive theory was also used to guide the development of the intervention [68, 69].

The design of the study involved an initial 3-month intervention period (when the full multi-component intervention was applied), followed by a 9-month maintenance period. During the maintenance period, participants in the intervention group retained their workstations; however, the other intervention components ceased at 3 months [69].

In recent years, an increasing number of studies have been conducted assessing the effectiveness of various activity-permissive workstations for reducing sitting. Generally, these have been shown to lead to reductions in sitting time [67, 70, 71]. However, as discussed in other chapters, there is evidence that a multi-component approach targeting influences at the individual, organisational and environmental level may lead to greater reductions in sitting time when compared with the provision of a sit-stand workstation in isolation [50]. This would support the premises of the ecological model, particularly the need to identify and target the multiple levels of influence on behaviour. Further research is needed to assess the relative importance and contribution of each of these different levels of influence in the context of sedentary behaviour interventions.

Stand Up Victoria has provided an example of how an ecological model can be used to guide sedentary behaviour intervention development, in contrast to initial intervention trials in the field which tended to use single-focus and/or individually oriented approaches [72]. It is also important to note that within the ecological framework used to guide the *Stand Up Victoria* approach, strategies designed using a social-cognitive theoretical approach were able to be incorporated successfully within a broader strategy addressing aspects of organisational, social and physical environments at work. The *Stand Up Victoria* project provided early evidence to demonstrate how interventions at multiple levels (Principle 5 above, arguably the strongest test of the utility of the ecological approach) may be carried out in practice.

15.5 Limitations of Models and Theories in Applications to Sedentary Behaviour

Models and theories can assist us to make sense of behaviour and the world around us. For behaviours that pose a risk to health, theories can help to provide a framework for understanding their underlying causes and guide intervention development. Broader models can assist with identifying relationships between different factors and understanding the pathways through which these impact on behaviour. Understanding these interactions can aid in identifying the most appropriate and effective intervention targets within complex causative pathways.

However, there may be inherent limitations with the use of currently available models and theories of behavioural and social sciences in the context of understanding the determinants of sedentary behaviour. Many theories that have been used to describe health behaviours focus on individual-level influences, including education and awareness-raising, motivation and other cognitive processes. When applied with a focus primarily at the individual level, they often do not account for the other levels of influence—social, environmental or policy—which may also encompass relevant determinants of sedentary behaviour. For these reasons, the predominant social-cognitive models may provide a helpful but only partial account of the range of relevant determinants. For practitioners involved in designing an intervention, it can also be difficult to identify which of the multitude of theories available in the literature would be most useful or relevant for the health behaviour of interest.

Additionally, it may be unclear as to how such theories can actually be translated from the research environment into programs that can be scaled up and applied in real-world settings. The overall outcome of interventions aimed at reducing sedentary behaviour should be to ultimately effect change on a population level. As such, it is important to consider the need for theories and models to be accessible so that they can also be up-scaled and usefully translated to broader scale interventions, not just applicable in smaller scale laboratory studies.

15.5.1 Limitations of Ecological Models

We have emphasised the potential utility of an ecological model for understanding and influencing sedentary behaviour. However, although we have outlined the strengths of such a model, there are limitations. A key principle of ecological models is that there are multiple levels of influence, all of which are deemed to be important (albeit varyingly so, depending on the setting, the person and other factors). It has been suggested that when these models have been applied in practice there has at times been an exclusive focus on environmental influences. This parallels criticisms of individual-level models—that they provide a narrow, incomplete account of human behaviour [40]. Multidisciplinary research partnerships that involve team members with broad expertise in interests and backgrounds may foster research that is more true to a fundamental principle of ecological models: addressing multiple levels of influence and their interactions.

Another limitation of the application of models identifying multiple levels of influence is that they can be difficult to design, evaluate and measure, due to their complexity. Public health programs designed with an ecological framework in mind may feature large-scale environmental and policy changes that occur in natural, uncontrolled settings. What is delivered in practice often will be out of the hands of researchers and like many public health interventions will not be amenable to evaluations using controlled experimental methods. This poses challenges for evaluating the effectiveness of intervening on multiple levels and unpicking which components of which levels of the intervention are most effective [4, 5].

Nevertheless, this reflects the real-world complexity of the strategies likely to be necessary in order to make significant progress in addressing large-scale and complex public health issues. From a researcher's perspective, the use of an ecological model presents challenges as multi-level studies are complex and demanding. Teams from a broad range of disciplines are likely to be needed to provide the expertise on the different levels of influence and assist with measurement and analysis of these components. However, this could also be viewed as a positive step. It is increasingly recognised that the public health challenges we face are multi-faceted and will not be successfully addressed by applying a narrow mind-set that focuses all attention on individual choice. By encouraging the framing of these issues through an ecological model, there is the opportunity to encourage researchers and practitioners from different backgrounds to collaborate, share perspectives and break down research silos. New insights and perspectives on approaching a particular challenging problem may arise from the opportunity to share knowledge across disciplinary areas.

A further limitation is that ecological models do not specify the processes through which different variables interact to influence behaviour. Unlike individual-level theories of the determinants of health behaviours, which specify within a formal framework the interrelationships between variables and how these are thought to determine behaviour, an ecological model does not provide this level of specificity. Sallis and Owen [36] propose that this is a key issue to keep in mind when applying ecological models; they should be viewed as guiding frameworks, rather than as explanatory theories. Instead of being a formal theoretical model, a key feature of ecological frameworks is that they can incorporate specific individual-level, more formally articulated theories into a broader framework.

Recognising some of the limitations of ecological models, there has been a broad collaborative project to develop a systems-based approach to understanding the multiple levels of determinants of sedentary behaviour and how they may interact [73]. This approach specifically aims to address the limitation that ecological models do not specify the connections between different levels of influences. Following a consensus process, some recommendations for priority research areas have been suggested.

15.6 Research Advances and Opportunities

There is still more to be done to further our understanding of the most effective ways to influence and reduce sedentary behaviour. There are some notable research advances in understanding key building blocks for an ecological approach to sedentary behaviour. Prominent in the newer body of evidence are examinations of environmental and related factors that can influence sedentary behaviour, and new analytic methods for making sense of the complexities of the relevant findings. These have been the topic of recent review papers [74–76]. Initial research using Bayesian network analysis applied to Eurobarometer data provides some insights into the complex interrelatedness between different levels of influence on sedentary behaviour [77]. This innovative approach suggests avenues for further research to extend the understanding of the various influences on sedentary behaviour, and how these differ across the life course and within specific behaviour settings. Recently reported findings on the outcomes of complex interventions including environmental elements are promising [78–80], with some optimism being expressed in recent reviews of qualitative and quantitative findings [81–83]. An approach showing promise is the application of choice architecture techniques, or ‘nudging’, to the field of sedentary behaviour and physical activity [84]. The potential of such approaches for modifying sedentary behaviours will become more apparent through future research evidence.

From the ecological model and associated principles we have outlined in this chapter, we propose some key questions for research:

1. What are the broader and more generalisable social, environmental and policy level determinants of sedentary behaviour?
2. What specific social, environmental and policy level determinants are influential for the key 'behaviour settings'—the home environment, transportation and the workplace/school?
3. Are there cultural or national level variations in the relative importance of individual, social, environmental and policy influences on sedentary behaviour?
4. How do environmental determinants of sedentary behaviour interact with other more well-studied levels of influence on health behaviours, such as personal characteristics and social influences?
5. Do environmental factors have differential strengths of influence on sedentary behaviours in some population groups compared with others? (For example, across different age groups; amongst those from different socioeconomic status backgrounds).
6. What is the feasibility of multi-level interventions in different settings—from design, implementation and evaluation perspectives?
7. Do interventions that target multiple levels of influence result in more sustainable changes than those that target single, or fewer, levels of influence?
8. What are the key sociocultural determinants of sedentary behaviour and how do these factors influence intervention effectiveness and sustainability?
9. What are the essential (and non-essential) components of multi-level sedentary behaviour interventions in the workplace that can achieve sustainable behavioural change?
10. What are the features of exemplary organisations (workplaces, schools, etc.) that have been successful in reducing sedentary behaviour?
11. How best to assess the quality and comprehensiveness of studies that report using an ecological framework?

15.7 Conclusions

An ecological model of sedentary behaviour can provide strong guidance in understanding how the determinants of sedentary behaviours in particular settings may be better understood and influenced. This evidence, in turn, can influence the development of interventions and strategies to address sedentary behaviour through a focus on improving health outcomes, in line with the six phases of the behavioural epidemiology framework (Fig. 15.1). While individual-level attributes that may be addressed with conceptual and methodological rigour using social-cognitive theories remain important, the field of sedentary behaviour epidemiology will advance in ways more relevant to improving health outcomes if its research strategy proceeds using a broader multidisciplinary, ecologic perspective. Taking forward a rigorous and relevant research agenda within the framework of an ecological model of sedentary behaviour is challenging, and there are many new and potentially fruitful directions for research.

References

1. Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. Appl Physiol Nutr Metab. 2010;35(6):725–40.
2. Hamilton MT, Healy GN, Dunstan DW, Zderic TW, Owen N. Too little exercise and too much sitting: inactivity physiology and the need for new recommendations on sedentary behavior. Curr Cardiovasc Risk Rep. 2008;2(4):292–8.
3. Dunstan DW, Dogra S, Carter SE, Owen N. Sit less and move more for cardiovascular health: emerging insights and opportunities. Nat Rev Cardiol. 2021;18(9):637–48.
4. Owen N, Healy G, Dempsey PC, Salmon J, Timperio A, Clark B, Goode A, Koorts H, Ridgers ND, Hadgraft N, Lambert G, Eakin E, Kingwell BA, Dunstan DW. Sedentary behavior & public health: integrating the evidence and identifying potential solutions. Annu Rev Public Health. 2020;41:265–87.
5. Owen N. Emergence of research on sedentary behaviour and health. In: Zhu W, Owen N, editors. Sedentary behaviour and health: concepts, evidence, assessment and intervention. Urbana-Champaign, IL: Human Kinetics; 2016.
6. Sallis JF, Owen N. Physical activity and behavioral medicine. SAGE Publications; 1998.
7. Sallis JF, Owen N, Fotheringham MJ. Behavioral epidemiology: a systematic framework to classify phases of research on health promotion and disease prevention. Ann Behav Med. 2000;22(4):294–8.
8. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105–13.
9. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. Am J Prev Med. 2011;41(2):189–96.
10. Rosenberg DE, Lee IM, Young DR, Prohaska TR, Owen N, Buchner DM. Novel strategies for sedentary behavior research. Med Sci Sports Exerc. 2015;47(6):1311–5.
11. Hadgraft NT, Owen N, Dempsey PC. Physical activity and public health. In: Detels R, Leyland A, Baum F, Li L, Quarraisha K, editors. Oxford textbook of global public health. 7th ed. London: Oxford University Press; 2021.
12. Dempsey PC, Hadgraft NT, Winkler EAH, Clark BK, Buman MP, Gardiner AP, Owen N, Lynch BM, Dunstan DW. Associations for context-specific sitting time with markers of cardiometabolic risk in Australian adults. Int J Behav Nutr Phys Act. 2018;15:114.
13. Sugiyama T, Hadgraft N, Clark BK, Dunstan DW, Owen N. Sitting at work and waist circumference: a cross-sectional study of Australian workers. Prev Med. 2020;141:106243.
14. Sugiyama T, Chandrabose M, Homer AR, Sugiyama M, Dunstan DW, Owen N. Car use and cardiovascular disease risk: systematic review and research agenda. J Transp Health. 2020;19: 100930.
15. Hallgren M, Dunstan DW, Owen N. Passive versus mentally-active sedentary behaviors and depression. Exerc Sport Sci Rev. 2020;48(1):20–7.
16. Biddle SJH, Gorely T. Sitting psychology: towards a psychology of sedentary behaviour. In: Papaioannou AG, Hackfort D, editors. Routledge companion to sport and exercise psychology: global perspectives and fundamental concepts. East Sussex: Routledge; 2014.
17. Biddle SJH, Mutrie N, Gorely T. Psychology of physical activity: determinants, well-being, and interventions. 4th ed. London: Routledge; 2021.

18. Mielke GI, da Silva ICM, Gomersall SR, Owen N, Hallal PC. Reliability of a multi-domain sedentary behaviour questionnaire and comparability to an overall sitting time estimate. J Sports Sci. 2020;38(3):351–6.
19. Lynch BM, Healy GN, Dunstan DW, Owen N. Sedentary versus inactive: distinctions for disease prevention. Nat Rev Cardiol. 2010;7(11)
20. O'Donoghue G, Perchoux C, Mensah K, Lakerveld J, van der Ploeg H, Bernaards C, et al. A systematic review of correlates of sedentary behaviour in adults aged 18–65 years: a socio-ecological approach. BMC Public Health. 2016;16(1):1.
21. Bauman AE, Sallis JF, Dzewaltowski DA, Owen N. Toward a better understanding of the influences on physical activity: the role of determinants, correlates, causal variables, mediators, moderators, and confounders. Am J Prev Med. 2002;23(Suppl 2):5–14.
22. Rhodes RE, Mark RS, Temmel CP. Adult sedentary behavior: a systematic review. Am J Prev Med. 2012;42(3):e3–28.
23. Gilson ND, Burton NW, van Uffelen JG, Brown WJ. Occupational sitting time: employees' perceptions of health risks and intervention strategies. Health Promot J Austr. 2011;22(1): 38–43.
24. De Cocker K, Veldeman C, De Bacquer D, Braeckman L, Owen N, Cardon G, et al. Acceptability and feasibility of potential intervention strategies for influencing sedentary time at work: focus group interviews in executives and employees. Int J Behav Nutr Phys Act. 2015;12(1)
25. Cole JA, Tully MA, Cupples ME. "They should stay at their desk until the work's done": a qualitative study examining perceptions of sedentary behaviour in a desk-based occupational setting. BMC Res Notes. 2015;8(1):683.
26. Chastin SF, Fitzpatrick N, Andrews M, DiCroce N. Determinants of sedentary behavior, motivation, barriers and strategies to reduce sitting time in older women: a qualitative investigation. Int J Environ Res Public Health. 2014;11(1):773–91.
27. Van Cauwenberg J, Van Holle V, De Bourdeaudhuij I, Owen N, Deforche B. Diurnal patterns and correlates of older adults' sedentary behavior. PloS One. 2015;10(8):e0133175.
28. Kikuchi H, Inoue S, Sugiyama T, Owen N, Oka K, Nakaya T, et al. Distinct associations of different sedentary behaviors with health-related attributes among older adults. Prev Med. 2014;67:335–9.
29. Kozo J, Sallis JF, Conway TL, Kerr J, Cain K, Saelens BE, et al. Sedentary behaviors of adults in relation to neighborhood walkability and income. Health Psychol. 2012;31(6):704–13.
30. Mielke GI, da Silva IC, Owen N, Hallal PC. Brazilian adults' sedentary behaviors by life domain: population-based study. PloS One. 2014;9(3):e91614.
31. Koohsari MJ, Sugiyama T, Sahlqvist S, Mavoa S, Hadgraft N, Owen N. Neighborhood environmental attributes and adults' sedentary behaviors: review and research agenda. Prev Med. 2015;77:141–9.
32. Hadgraft NT, Dunstan DW, Owen N. Models for understanding sedentary behaviour. In: Leitzmann M, Jochem C, Schmid D, editors. Sedentary behaviour epidemiology. Springer series on epidemiology and public health. Cham: Springer; 2018. https://doi.org/10.1007/978-3-319-61552-3_15.
33. Ashford S, Edmunds J, French DP. What is the best way to change self-efficacy to promote lifestyle and recreational physical activity? A systematic review with meta-analysis. Br J Health Psychol. 2010;15(Pt 2):265–88.
34. Memon AR, Stanton R, To Q, Schoeppe S, Urooj A, Alley S, Hayman M, Vandelanotte C. Sedentary behaviour research in adults: A scoping review of systematic reviews and meta-analyses. J Sports Sci. 2021; https://doi.org/10.1080/02640414.2021.1928382.
35. Dempsey PC, Hadgraft NT, Winkler EA, Clark BK, Buman MP, Gardiner PA, Owen N, Lynch BM, Dunstan DW. Associations of context-specific sitting time with markers of cardiometabolic risk in Australian adults. Int J Behav Nutr Phys Act. 2018;15(1):1–1.
36. Sallis JF, Owen N. Ecological models of health behavior. In: Glanz K, Rimer BK, Viswanath K, editors. Health behavior: theory, research, and practice. 5th ed. Wiley; 2015.

37. Trost SG, Owen N, Bauman AE, Sallis JF, Brown W. Correlates of adults' participation in physical activity: review and update. Med Sci Sports Exerc. 2002;34(12):1996–2001.
38. Stokols D, Grzywacz JG, McMahan S, Phillips K. Increasing the health promotive capacity of human environments. Am J Health Promot. 2003;18(1):4–13.
39. Sallis JF, Owen N, Fisher EB. Ecological models of health behavior. Health behavior and health education: theory, research, and practice. Vol. 4. 2008. p. 465–486.
40. King AC. Theory's role in shaping behavioral health research for population health. Int J Behav Nutr Phys Act. 2015;12:146.
41. Adams MA, Frank LD, Schipperijn J, Smith G, Chapman J, Christiansen LB, et al. International variation in neighborhood walkability, transit, and recreation environments using geographic information systems: the IPEN adult study. Int J Health Geogr. 2014;13(1):1.
42. Owen N, Salmon J, Koohsari MJ, Turrell G, Giles-Corti B. Sedentary behaviour and health: mapping environmental and social contexts to underpin chronic disease prevention. Br J Sports Med. 2014;48(3):174–7.
43. World Health Organization. Ottawa charter for health promotion. 1986.
44. U.S. Department of Health and Human Services: Healthy People 2030 Framework. https://www.healthypeople.gov/2020/About-Healthy-People/Development-Healthy-People-2030/Framework
45. Conroy D, Maher J, Elavsky S, Hyde A, Doerksen S. Sedentary behavior as a daily process regulated by habits and intentions. Health Psychol. 2013;32(11):1149–57.
46. Maher JP, Conroy DE. A dual-process model of older adults' sedentary behavior. Health Psychol. 2015;
47. Barker RG. Ecological psychology. Stanford University Press; 1968.
48. Kazi A, Duncan M, Clemes S, Haslam C. A survey of sitting time among UK employees. Occup Med. 2014;64(7):497–502.
49. Leask CF, Harvey JA, Skelton DA, Chastin SF. Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). Eur Rev Aging Phys Act. 2015;12:4.
50. Neuhaus M, Healy GN, Dunstan DW, Owen N, Eakin EG. Workplace sitting and height-adjustable workstations: a randomized controlled trial. Am J Prev Med. 2014;46(1):30–40.
51. Steeves JA, Thompson DL, Bassett DR. Energy cost of stepping in place while watching television commercials. Med Sci Sports Exerc. 2012;44:330–5.
52. Sugiyama T, Neuhaus M, Cole R, Giles-Corti B, Owen N. Destination and route attributes associated with adults' walking: a review. Med Sci Sports Exerc. 2012;44(7):1275–86.
53. Owen N, Sugiyama T, Koohsari MJ, Debourdeauduij I, Hadgraft N, Oyeyemi A, Aguinaga-Ontoso I, Mitáš J, Troelsen J, Davey R, Schofield G, Cain K, Sarmiento O, Reis R, Salvo D, Macfarlane D, Sallis J, Cerin E. Associations of neighborhood environmental attributes with adults' objectively-assessed sedentary time: IPEN adult multi-country study. Prev Med. 2018;115:126–33.
54. Owen N, De Bourdeaudhuij I, Sugiyama T, Leslie E, Cerin E, Van Dyck D, et al. Bicycle use for transport in an Australian and a Belgian city: associations with built-environment attributes. J Urban Health. 2010;87(2):189–98.
55. Thorp AA, Healy GN, Winkler E, Clark BK, Gardiner PA, Owen N, et al. Prolonged sedentary time and physical activity in workplace and non-work contexts: a cross-sectional study of office, customer service and call centre employees. Int J Behav Nutr Phys Act. 2012;9:128.
56. Parry S, Straker L. The contribution of office work to sedentary behaviour associated risk. BMC Public Health. 2013;13(1):296.
57. Healy GN, Eakin EG, Lamontagne AD, Owen N, Winkler EA, Wiesner G, et al. Reducing sitting time in office workers: short-term efficacy of a multicomponent intervention. Prev Med. 2013;57(1):43–8.
58. Straker L, Healy GN, Atherton R, Dunstan DW. Excessive occupational sitting is not a "safe system of work": time for doctors to get chatting with patients. Med J Aust. 2014;201(3):138–40.

59. Bale JM, Gazmararian JA, Elon L. Effect of the work environment on using time at work to exercise. Am J Health Promot. 2014;29(6):345–52.
60. Burton J, World Health Organization. WHO Healthy workplace framework and model: Background and supporting literature and practices. 2010. http://www.who.int/occupational_health/healthy_workplace_framework.pdf. Accessed 16 Feb 2016.
61. World Health Organization. Healthy workplaces: a model for action: for employers, workers, policy-makers and practitioners. 2010. http://www.who.int/occupational_health/publications/healthy_workplaces_model.pdf. Accessed 16 Feb 2016.
62. Pronk NP. Design recommendations for active workplaces. Ergon Des. 2015;23(3):36–40.
63. Hadgraft NT, Lynch BM, Clark BK, Healy GN, Owen N, Dunstan DW. Excessive sitting at work and at home: correlates of occupational sitting and TV viewing time in working adults. BMC Public Health. 2015;15(1):899.
64. De Cocker K, Duncan MJ, Short C, van Uffelen JG, Vandelanotte C. Understanding occupational sitting: prevalence, correlates and moderating effects in Australian employees. Prev Med. 2014;67:288–94.
65. Wilks S, Mortimer M, Nylen P. The introduction of sit-stand worktables; aspects of attitudes, compliance and satisfaction. Appl Ergon. 2006;37(3):359–65.
66. Chau JY, Daley M, Srinivasan A, Dunn S, Bauman AE, van der Ploeg HP. Desk-based workers' perspectives on using sit-stand workstations: a qualitative analysis of the Stand@Work study. BMC Public Health. 2014;14:752.
67. Neuhaus M, Eakin EG, Straker L, Owen N, Dunstan DW, Reid N, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. Obes Rev. 2014;15(10):822–38.
68. Neuhaus M, Healy GN, Fjeldsoe BS, Lawler S, Owen N, Dunstan DW, et al. Iterative development of stand up Australia: a multi-component intervention to reduce workplace sitting. Int J Behav Nutr Phys Act. 2014;11:21.
69. Dunstan DW, Wiesner G, Eakin EG, Neuhaus M, Owen N, LaMontagne AD, et al. Reducing office workers' sitting time: rationale and study design for the stand up Victoria cluster randomized trial. BMC Public Health. 2013;13:1057.
70. Shrestha N, Ijaz S, Kukkonen-Harjula KT, Kumar S, Nwankwo CP. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2015;1:Cd010912.
71. Tew GA, Posso MC, Arundel CE, McDaid CM. Systematic review: height-adjustable workstations to reduce sedentary behaviour in office-based workers. Occup Med (Lond). 2015;
72. Chau JY, van der Ploeg HP, van Uffelen JG, Wong J, Riphagen I, Healy GN, et al. Are workplace interventions to reduce sitting effective? A systematic review. Prev Med. 2010;51(5):352–6.
73. Chastin SF, Schwarz U, Skelton DA. Development of a consensus taxonomy of sedentary behaviors (SIT): report of Delphi Round 1. PloS One. 2013;8(12):e82313.
74. Sugiyama T, Hadgraft N, Clark BK, Dunstan DW, Chevez A, Healy GN, Cerin E, LaMontagne AD, Shibata A, Oka K, Owen N. Office spatial design attributes, sitting, and face-to-face interactions: systematic review and research agenda. Build Environ. 2020;2:107426.
75. Müller AM, Chen B, Wang NX, Whitton C, Direito A, Petrunoff N, Müller-Riemenschneider F. Correlates of sedentary behaviour in Asian adults: a systematic review. Obes Rev. 2020;21(4):e12976.
76. Lin CY, Koohsari MJ, Liao Y, Ishii K, Shibata A, Nakaya T, McCormack GR. Hadgraft the physically-active and sedentary behaviour: a systematic review of observational studies. Int J Behav Nutr Phys Act. 2020;17(1):1–24.
77. Buck C, Loyen A, Foraita R, Van Cauwenberg J, De Craemer M, Mac Donncha C, Oppert JM, Brug J, Lien N, Cardon G, Pigeot I. Factors influencing sedentary behaviour: a system based analysis using Bayesian networks within DEDIPAC. PloS One. 2019;14(1):e0211546.
78. Healy GN, Eakin EG, Owen N, Lamontagne AD, Moodie M, Winkler EA, Fjeldsoe BS, Wiesner G, Willenberg L, Dunstan DW. A cluster randomized controlled trial to reduce office workers' sitting time: impact on activity outcomes. Med Sci Sports Exerc. 2016;48(9):1787–97.

79. Pereira MA, Mullane SL, Toledo MJ, Larouche ML, Rydell SA, Vuong B, Feltes LH, Mitchell NR, de Brito JN, Hasanaj K, Carlson NG. Efficacy of the 'Stand and Move at Work' multicomponent workplace intervention to reduce sedentary time and improve cardiometabolic risk: a group randomized clinical trial. Int J Behav Nutr Phys Act. 2020;17 (1):1.
80. Edwardson CL, Biddle SJ, Clarke-Cornwell A, Clemes S, Davies MJ, Dunstan DW, Eborall H, Granat MH, Gray LJ, Healy GN, Richardson G. A three arm cluster randomised controlled trial to test the effectiveness and cost-effectiveness of the SMART Work & Life intervention for reducing daily sitting time in office workers: study protocol. BMC Public Health. 2018;18(1): 1–3.
81. Blackburn NE, Wilson JJ, McMullan II, et al. The effectiveness and complexity of interventions targeting sedentary behaviour across the lifespan: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2020;17:53. https://doi.org/10.1186/s12966-020-00957-0.
82. Hadgraft NT, Brakenridge CL, Dunstan DW, Owen N, Healy GN, Lawler SP. Perceptions of the acceptability and feasibility of reducing occupational sitting: review and thematic synthesis. Int J Behav Nutr Phys Act. 2018;15(1):1–8.
83. Rawlings GH, Williams RK, Clarke DJ, English C, Fitzsimons C, Holloway I, Lawton R, Mead G, Patel A, Forster A. Exploring adults' experiences of sedentary behaviour and participation in non-workplace interventions designed to reduce sedentary behaviour: a thematic synthesis of qualitative studies. BMC Public Health. 2019;19(1):1099. https://doi.org/10.1186/s12889-019-7365-1.
84. Landais LL, Damman OC, Schoonmade LJ, Timmermans DR, Verhagen EA, Jelsma JG. Choice architecture interventions to change physical activity and sedentary behavior: a systematic review of effects on intention, behavior and health outcomes during and after intervention. Int J Behav Nutr Phys Act. 2020;17(1):1–37.

Chapter 16
Sedentary Behaviour at the Individual Level: Correlates, Theories, and Interventions

Stuart J. H. Biddle

Abstract Sedentary behaviour is highly frequent in individuals, and this chapter concerns sedentary behaviour with a focus on the individual level of analysis. Using the behavioural epidemiology framework, the chapter summarises issues concerning individual-level knowledge and approaches. It focuses mainly on correlates, theoretical frameworks, and behaviour change. Correlates discussed include whether sedentary behaviour and physical activity are associated, and the co-existence of other health behaviours. Barriers to sedentary behaviour change are considered. A number of psychological theories and frameworks are covered that have been popular in wider physical activity and health behaviour research alongside alternative perspectives, including notions of behavioural economics, habit, and nudging. Theories are conceptualised through reflective, automatic, and dual-process approaches. Coverage is given to sedentary behaviour interventions, including recent systematic reviews for young people, adults, and in the workplace. Behaviour change techniques are considered, especially those that seem to be most useful for successful sedentary behaviour change.

What Is New?

- There is an increasing recognition given to the complexity of sedentary behaviours in contemporary society, including the diversity of screen-based devices.
- However, 'newer' devices, such as smartphones, remain under-studied in the context of sedentary behaviour.

(continued)

S. J. H. Biddle (✉)
Centre for Health Research, University of Southern Queensland, Springfield, QLD, Australia
e-mail: stuart.biddle@usq.edu.au

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_16

- The interdependence between sedentary and active behaviours is increasingly being recognised, and this has implications for the study of health effects and interventions.
- Dual-process approaches, including the use of automatic processing frameworks, are emerging as important theoretical developments in the study of sedentary behaviour.
- The COVID-19 pandemic has increased sedentary behaviour, creating even greater urgency in finding effective behaviour change interventions.
- Sedentary behaviour research has made good inroads into the workplace, especially with a greater recognition and acceptance of sit-to-stand desks for ambulatory office staff.

16.1 Introduction

Sedentary behaviour is ultimately undertaken by individuals. However, any analysis of an individual behaviour cannot be done properly without due recognition of wider social and environmental contexts and influences. The ecological model puts the individual at one of many levels, including social, environmental, and societal levels of behavioural influence [1]. For the purposes of this chapter, the focus will be on the individual. This will include individual-level:

- Correlates of sedentary behaviour
- Barriers to being less sedentary
- Theories and frameworks
- Interventions to reduce sedentary behaviour that have included individual-level factors

It is recognised that it is not always easy to separate individual from social and environmental approaches. They can operate along a continuum of distal and proximal influences. One framework, however, that is helpful in understanding the landscape of the individual in the context of sedentary behaviour is the behavioural epidemiology framework [2]. This has five phases:

1. Measuring sedentary behaviour
2. Establishing the association between sedentary behaviour and health outcomes
3. Understanding the correlates of sedentary behaviour
4. Interventions to change sedentary behaviour (usually to decrease)
5. Translating findings into policy and practice.

For the current chapter, the main focus will be on phases III (correlates) and IV (interventions), with an emphasis on the individual.

An important issue to recognise is that individuals undertake a variety of sedentary behaviours across many different settings. This, along with other issues, shows the complexity of sedentary behaviour (see Fig. 16.1). Indeed, it could be claimed

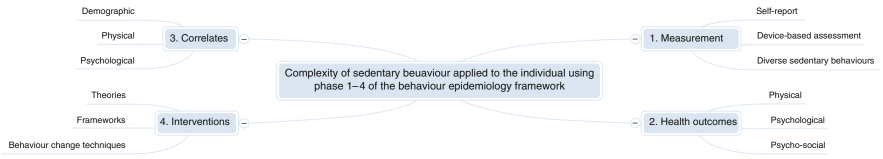

Fig. 16.1 An illustration of the complexity of sedentary behaviour at the individual level, using the behavioural epidemiology framework

that this complexity has increased in recent years as we adopt more diverse methods of measuring behaviour and recognise that sedentary behaviours can take many different forms in diverse social and environmental contexts. We also acknowledge that nearly all of the research literature has been with ambulatory individuals without disabilities. For others, such as those who use wheelchairs, the constant reference to the need to reduce sitting is inappropriate and 'ablelist' [3, 4]. In this chapter, therefore, we draw on research addressing ambulatory adults and young people unless otherwise indicated. More research is needed on sedentary behaviour and physical activity for those living with disabilities [5, 6].

16.2 Individual Correlates of Sedentary Behaviour

Correlates refer to factors that are associated (correlated) with the behaviour of interest. Determinants should be referred to when there is a causal, or near causal, association. Most of the time, we are studying and referring to correlates. Several systematic reviews of the correlates of sedentary behaviour have been published from the mid-2000s, including those investigating young people, adults, and older adults [7]. The findings for children and adolescents highlight significant gaps in our knowledge concerning the correlates of sedentary behaviour [8]. Review authors for this age group note that although many potential correlates have been studied, few of these have been investigated frequently enough to be able to draw firm conclusions. It is also evident within the reviews that the correlates of sedentary behaviours other than screen-viewing behaviours (usually referred to as 'screen time' although 'screen use' may be a better term; [9]) have received little attention, and many studies reviewed are cross-sectional. In addition, the findings suggest that the majority of correlates identified are unmodifiable correlates (moderators). These include body weight, body mass index (BMI), ethnicity, age, and sex. More work with better designs is required to identify the modifiable correlates (mediators) of sedentary behaviour.

In a review of likely 'determinants' of sedentary behaviour in young people, Stierlin et al. [10] excluded cross-sectional studies from their synthesis. They found good evidence for age being a determinant, with increasing age being associated with greater sedentary behaviour, including screen use. Evidence concerning sex was inconsistent. Weight status tends to be associated with screen time but not overall sedentary behaviour, possibly reflecting dietary effects ([11] see later).

Data on correlates of sedentary behaviour in adults are quite limited and rely largely on self-reported estimates of only a few sedentary behaviours, such as television (TV) viewing. O'Donoghue et al.'s review revealed 74 studies of which 62 focused on individual-level correlates, categorised as behavioural, physical (biological and genetic), psychological, and socio-economic [12]. Moreover, they identified correlates of sedentary behaviour across the domains of screen use, transport, and leisure, as well as total sedentary time from self-reported or device-assessed measures. Many correlates were studied too infrequently to draw conclusions. However, trends were evident for higher levels of sedentary behaviour to be associated with lower physical activity, greater consumption of high energy snacks (see later), greater adiposity, and worse mental health. Demographic indicators included older age as a correlate. However, for other individual correlates, such as sex and socio-economic status, associations were dependent on the nature of the sedentary behaviour in question. For example, leisure screen use was negatively associated with educational attainment, while the reverse was true for total sedentary time (with work time included). These findings reflect the complexity of sedentary behaviours and that not all types will be driven by the same influences. This recognition has been an important advance in recent years.

From a review of 22 studies reporting correlates of sedentary behaviour in older adults, Chastin et al. [13] reviewed evidence on the individual-level correlates of age, sex, marital status, employment and retirement status, educational attainment, and health. They found significant effects for age, but these varied such that total sedentary time seemed to increase with age, but TV viewing and car travel decreased after around 65 years. Evidence was inconsistent for the two correlates of sex and marital status. TV viewing was less for those in employment, including those volunteering. Chastin et al. also found that lower levels of educational attainment were associated with more sedentary behaviour. Unsurprisingly, those reporting poorer health also had higher sedentary behaviour levels.

One criticism of the study of correlates of sedentary behaviour is that they focus too much on TV viewing and computer use, to the neglect of more recent technological devices, such as mobile phones [14]. In a review of young people's uses of devices, Thomas et al. [14] found that only 5% of large epidemiological studies reported data on mobile phone use. Moreover, Leask and colleagues [15], when reporting data obtained from older adults using wearable cameras, found that 84% of screen time was in front of a TV. That said, 62% of sedentary behaviour identified via camera images did not involve screens at all. For these older adults, only 6% of their screen use involved the use of small devices such as phones.

In summary, many correlates identified across the lifespan, at the individual level, tend to show somewhat inconsistent trends—probably due to the complexity of this field, as stated—and reflect correlates that are not modifiable. However, they could be used as moderators in analyses. Additional consideration needs to be given to whether physical activity is a correlate of sedentary behaviour, and how time in one behaviour affects time in another [16–18]. Moreover, further research is needed concerning other health behaviours coexisting with sedentary behaviours (see later).

16.3 How Do Sedentary and Physically Active Behaviours Coexist?

Until the early 2000s, most researchers referred to 'sedentary behaviour' as being equivalent to low levels of physical activity. But in the context of the contemporary sedentary behaviour literature, it has become accepted that sedentary behaviour refers to periods of sitting/reclining/lying with low energy expenditure, during waking hours. It excludes nighttime sleep [19]. This means that it is best seen as part of a continuum of 'movement' behaviours across a 24-h period—that is, if a person is doing one (e.g. sedentary behaviour), then they cannot be doing another (e.g. light physical activity). However, some behaviours on the continuum will be more highly correlated than others over, say, a 24-h period. It is far more likely that time spent being sedentary, such as passive sitting, will detract from light physical activity than moderate-to-vigorous physical activity (MVPA). The reason for this is that elements of light physical activity, such as standing or light ambulation, are more or less the opposite of sitting. The act of standing negates the act of sitting. It is more complicated, however, when analysing moderate-to-vigorous physical activity. To what extent do high levels of sitting detract from taking part in, say, 1 h of moderate-to-vigorous physical activity daily? Given that there are 24 h in the day, it is logical to assume that any combination of sedentary and moderate-to-vigorous physical activity could be possible, that is, high MVPA with high sitting, high MVPA with low sitting, low MVPA with high sitting, and low MVPA with low sitting [20]. The latter might be reflected in someone who is on their feet most of the day but does little or no moderate-to-vigorous physical activity, or 'exercise'.

There have been two approaches in studying the association between sedentary behaviour and physical activity. First, researchers investigated whether the two behaviours were associated, such that high sedentary behaviour might be a correlate of low physical activity, or whether high levels of physical activity were associated with less sedentary behaviour. Given that most studies are cross-sectional, the direction of influence cannot be ascertained.

Pearson et al. [21] conducted a comprehensive meta-analysis of 254 independent samples from 163 papers. With the exception of reading, all sedentary behaviours were inversely associated with physical activity, but most associations were small. Where a composite measure of sedentary behaviour was used, the association was larger and considered small to moderate in magnitude. In moderator analyses, stronger associations were shown for studies using device-based measures of sedentary behaviour and in studies judged as higher quality. These authors concluded that while sedentary behaviour and physical activity were associated in young people, the association was weak. The two behaviours appear to be somewhat independent of each other. Similar findings were reported in a review of adults. Mansoubi et al. [22] reviewed 26 studies where associations were reported between sedentary behaviour and physical activity. TV viewing was the most commonly assessed sedentary behaviour and showed inverse associations with physical activity that were small (50%), moderate (25%), and, in one paper only, large. TV viewing was inversely associated in all five papers studying 'exercise'. Total sedentary time was inversely associated with light physical activity and MVPA. Additional analyses showed that larger associations were evident for studies using device-based measures, and studies of higher quality, similar to Pearson et al. [21]. However, most associations across the full review revealed small-to-moderate associations only.

From these two reviews, sedentary behaviour and physical activity seem to be associated, but this association is generally small, somewhat dependent on measurement and study quality, and may be a function of context or type of sedentary behaviour.

A second, and more recent, approach is where studies have investigated what the consequences might be for replacing one behaviour with another. Such 'compositional analyses' are predicated on the view that sedentary behaviour, alongside light, moderate, and vigorous physical activity, as well as sleep, is part of a 24-h composite—that is, they are interdependent across the full day. Most of the studies using this approach tend to focus on the health outcomes of replacing sedentary behaviour with more active behaviours [16, 18]. These studies suggest that individual behaviours, such as low energy sitting, cannot be seen in isolation of different intensities of physical activity. For example, Chastin et al.'s [18] analysis of the 2005–2006 National Health and Nutrition Examination Survey accelerometer data showed that different combinations of time spent in sedentary behaviour and various intensities of physical activity were associated with similar risk for all-cause mortality. They concluded that 'producing evidence on different combinations of physical activity and sedentary behaviour associated with the same health benefits could open the door to more flexible recommendations to suit an individual's circumstances and abilities' (p. 635).

In summary, while early studies showed that the association between sedentary and active behaviours was small, more recent approaches show the interdependence of the two types of behaviours across the continuum of movement behaviours during a finite period of time, such as 24 h.

16.4 Sedentary Behaviour and Associations with Other Lifestyle Factors

Extensive epidemiological research, as well as laboratory studies, shows that higher levels of sedentary behaviour can have adverse health consequences [23–25]. However, one question is whether this link is mediated by the co-existence of other health behaviours. For example, do those who watch a great deal of TV also have high

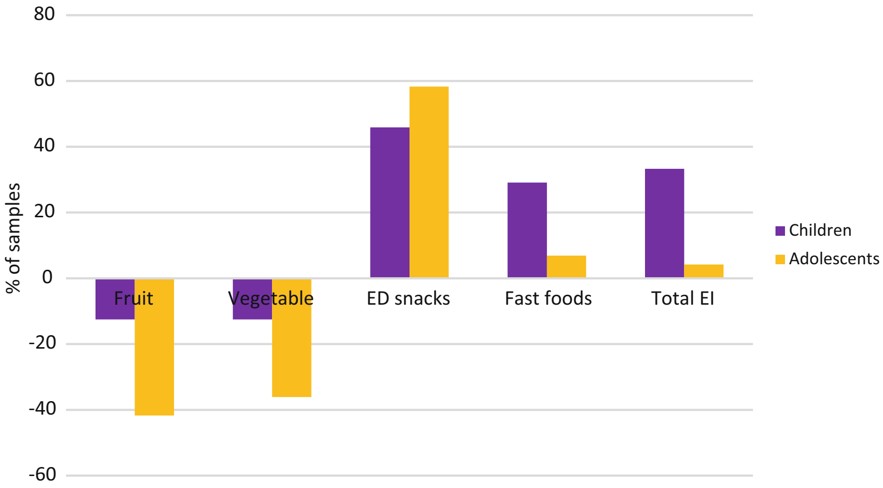

Fig. 16.2 Relationships between sedentary behaviour and dietary patterns in young people (data from Ref. [26])

levels of unhealthy snack consumption? The first review summarising the association between sedentary behaviour and diet was reported by Pearson and Biddle [26]. A total of 53 studies and 111 independent samples were analysed for adolescents (72 samples), children (24 samples), and adults (14 samples). Studies predominantly had a measure of screen time (mainly TV viewing) or total sedentary behaviour. A range of dietary outcomes was assessed, including fruit and vegetable consumption, energy-dense snacks, fast foods, and total energy intake.

Figure 16.2 shows the results for children and adolescents for five key dietary outcomes. This figure is drawn to show the direction of association between dietary variables and time in sedentary behaviours. Higher levels of sedentary behaviour are associated with a less healthy diet, including lower fruit and vegetable consumption, higher consumption of energy-dense snacks and fast foods, and a higher total energy intake. The strength of association between sedentary behaviour and diet across all age groups, including adults (not shown in Fig. 16.2), was mainly small to moderate. Moreover, many studies only assessed TV viewing, although this particular sedentary behaviour does seem to be a key context for unhealthy eating, such as snacking; hence, it is recommended to eat meals away from the TV set. More evidence is needed on whether changes to sedentary behaviour produce changes in healthy eating.

One possible explanation for these associations centres on the nature of TV viewing. This is a behaviour that is quite passive and may encourage energy consumption in the form of ‘mindless eating’ or ‘grazing’. Other screen use behaviours, such as computer use, are slightly more ‘active’, such as the use of hand movements and requiring more cognitive effort, and may encourage less of these eating patterns. Consistent with this, a review by Ghobadi et al. [27] found that eating while watching TV was positively associated with being ‘overweight’ in

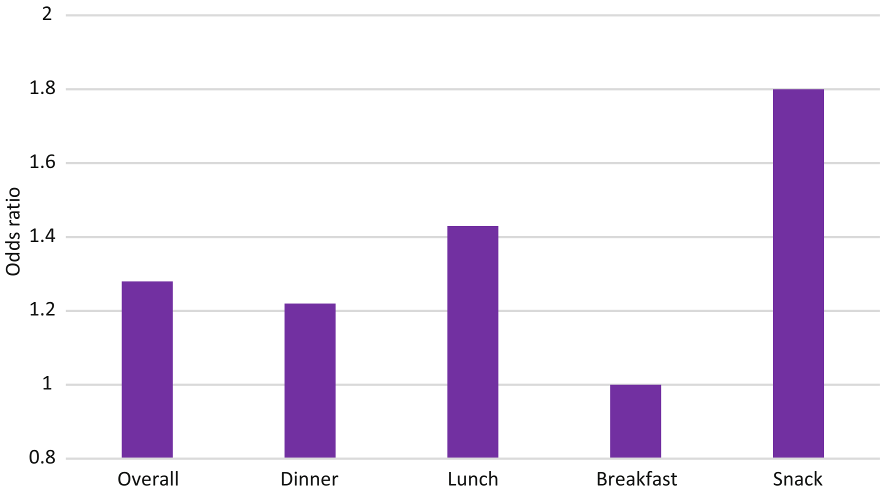

Fig. 16.3 Odds of being overweight when engaging in sedentary behaviours while eating different meals (data from Ref. [27])

children and adolescents. The odds ratios for this overall effect, and additional sub-group analyses, are shown in Fig. 16.3. The largest associations were for snacking, with no effect suggested for breakfast.

Less evidence is available on the association of sedentary behaviours with other health behaviours. However, there is indicative evidence concerning alcohol consumption and smoking. Keadle et al. [28] reported large-scale population-level data from the NIH-AARP Diet and Health Study. This is a prospective cohort study of over 220,000 Americans aged 50–71 years with 14-year follow-up. Associations were analysed for TV viewing and various health markers, including alcohol consumption. At baseline there was higher alcohol consumption for those who watched more TV, increasing from 11 g/day for those watching less than 1 h/day to 13.6 for those with 7 or more hours per day. The increase was linear, and showing a similar trend for smoking prevalence. However, the variability around the mean alcohol values was very high, leading to a very small effect size when comparing the lowest with highest TV viewers.

The COVID-19 pandemic has been implicated in increased sedentary behaviour [29, 30], and this may be particularly associated with restrictions during 'lockdowns' and an increased prevalence of conducting work from the home environment and home schooling of children (see Section 'A Health Economic Perspective on Sedentary Behaviour'). Deterioration in mental health has also been implicated during this period, including increased consumption of alcohol and recreational drug use [31]. At this stage, it is not possible to link these trends, but they are noteworthy. Other issues also require consideration, such as socio-economic status and its known association with some sedentary behaviours and co-occurring health behaviours [32]. The importance of finding practical and sustainable solutions to these recent trends in sedentary behaviour becomes more acute (see Sect. 16.7).

16.5 Individual Barriers to Reducing Sedentary Behaviour

The study of the correlates or determinants of sedentary behaviour is now quite extensive, but somewhat surprisingly there is a paucity of well-documented evidence concerning the barriers to doing less sedentary behaviour. Minges et al. [33] conducted a qualitative 'metasynthesis' of research regarding the barriers to reducing screen time in young people. Three main themes emerged: youth norms of use, family dynamics and parental roles, and resources and environment. The first theme—youth norms of use—suggested that screen time is a routine part of the lives of young people and not necessarily seen as 'excessive'. That said, there was also evidence for the addictive nature of some screen time activities. Similarly, screen time was perceived as enjoyable and entertaining and was seen to have elements of developing confidence and communication. This theme, therefore, shows that sedentary screen viewing in young people is highly routinised and 'ingrained' in their lives, suggesting it is a habit that may be difficult to change. Moreover, the other two themes reported by Minges et al. show that powerful social and environment pressures are also at play.

A recent interview-based study by Thomas et al. [34] supported some of these findings. Data from interviews with nine girls and seven boys in Australia, aged 14–16 years, revealed time spent on contemporary screens such as smartphones and tablets. Extensive engagement was evident in varied, and somewhat newer, forms of digital media (e.g. communicating online, social networking, and streaming online). It was also reported that less time was spent using conventional TV sets. Interviews suggested that the high amount of time spent on smartphones was partly related to the multiple functions that these devices offered. For example, one 14-year-old girl said that 'I use my smartphone for everything; take photos, contact friends, watch YouTube videos, scroll through social media and play games.' This suggests that while screen use can be seen as problematic, although not necessarily sedentary, devices such as smartphones provide multiple functions, some of which may have positive uses. Equally, the ubiquitous nature of smartphones will be a barrier to reducing overall sedentary screen use.

There seems to be a paucity of systematic evidence concerning barriers to reducing other sedentary behaviours or in diverse contexts, such as the workplace. In a study of the feasibility and acceptability of changing sedentary behaviour at work, De Cocker and colleagues [35] said that several barriers were reported. These included productivity concerns, impracticality, awkwardness of standing (see [36] for a qualitative study on this), and the habitual nature of sitting for ambulatory adults [37].

16.6 Application of Models and Theories to Sedentary Behaviour at the Individual Level

Individual-level theories of health behaviours have been applied to physical activity but less so to sedentary behaviour. A theory has been defined as 'a set of interrelated constructs (concepts), definitions, and propositions that present a systematic view of phenomena by specifying relations among variables, with the purpose of explaining and predicting the phenomena' ([38], p. 9); it is a 'coherent description of process' ([39], p. 22). Indeed, guidelines concerning the development and conduct of complex behavioural interventions propose that a theoretical understanding of the likely process of change is needed in the early stages of planning an intervention, and will help in the understanding of 'how change is brought about, including the interplay of mechanisms and context' ([40], p. 3). A review of theory-based interventions designed to increase physical activity showed that small-to-medium size effects were evident for such approaches but with no one theory being superior. Interventions using a single theory tended to achieve stronger effects than those using multiple theories [41].

In physical activity research, it has been common to adopt intra-individual and inter-personal theories that have a cognitive and reflective focus—utilising the so-called type 2 cognitive and reflective approach. Social and environmental theories are less commonly used [7, 42–45], but more automatic approaches are becoming better recognised. The latter adopt the 'type 1' approach that is less cognitive and more automatic, with cues to action from the environment and affect.

It is questionable whether reflective intra-individual theories are wholly applicable to sedentary behaviour, but some theories or elements may have utility [46]. Nevertheless, recent trends show a greater recognition of the more automatic processing models alongside the conventional cognitive approaches. This 'dual-process' approach (reflective and automatic) seems highly relevant for the study of sedentary behaviour where an interaction of individual and environmental influences is evident, alongside greater recognition of affective processes [47–49].

Overviews of the key theories applied to physical activity are available elsewhere [7, 44]. This section summarises key approaches, and comments will be provided about their applicability to sedentary behaviour.

16.6.1 Reflective Approaches

While the Health Belief Model could be considered a key historical approach to health behaviour theory [50], it has been more common in physical activity research to use social cognitive theory (SCT; [51]), the transtheoretical model (TTM; [52, 53]), the theory of planned behaviour (TPB; [54]), self-determination theory (SDT; [55]), and the health action process approach (HAPA; [56]). Behavioural choice theory (BECT; [57, 58]) has also been identified as having good applicability to sedentary behaviour as well as physical activity. Each of the approaches listed has a particular emphasis, such as beliefs and attitudes (TPB) or perceptions of competence (SCT), while others are based on different stages of decision-making or behaviour, while retaining elements of other theories (e.g., TTM, HAPA).

Social Cognitive Theory Bandura's social cognitive theory (SCT) [51] suggests that we learn and modify our behaviours through an interaction between personal, behavioural, and environmental influences. We reflect on the consequences of our behaviours ('outcome expectancies') and our own capabilities ('efficacy expectancies'). Thinking about consequences in sedentary behaviour could be simply considering the benefits and costs of being less sedentary. For capabilities, we could ask ourselves 'can I do this behaviour?'—this reflects one's self-efficacy, which is a key element of SCT.

Bandura [51] defines perceived self-efficacy as 'people's judgements of their capabilities to organise and execute courses of action required to attain designated types of performances. It is concerned not with the skills one has but with judgements of what one can do with whatever skills one possesses' (p. 391). The main sources of self-efficacy beliefs include prior success and performance attainment, imitation and modelling, and verbal and social persuasion. For example, modelling of non-sedentary behaviour, such as seeing others stand in a meeting, may influence behaviour. In a recent review of children's screen time interventions [59], social cognitive theory was applied in 41% of studies.

Theory of Planned Behaviour The TPB proposes that intention is the immediate antecedent of behaviour and that intention is predicted from attitude, subjective norms (normative beliefs), and perceptions of behavioural control. Ajzen and Fishbein [60] suggested that the attitude component of the model is constructed from the beliefs held about the specific behaviour, as well as the value perceived from the likely outcomes. Such beliefs can be instrumental (e.g. 'being less sedentary helps me feel more alert') and affective (e.g. 'moving more and sitting less is satisfying'). It is important to recognise that attitudes have both cognitive and affective elements. The affective elements of attitude have usually been shown to be superior for behaviour change [61]. To this end, we need more work on testing how we can elicit positive feelings associated with less sedentary behaviour when many such behaviours are designed for apparent 'pleasure', such as comfortable chairs and interesting or even 'addictive' TV programs and series. In Australia, for example, the TV and movie streaming service 'Binge' claims that a subscription allows you to 'binge over 10,000 h'!

Normative beliefs ('subjective norm') comprise the beliefs of significant others and the extent that one wishes to comply with such beliefs. Perceived behavioural control (PBC) is defined by Ajzen [62] as 'the perceived ease or difficulty of performing the behaviour' (p. 132). Sedentary behaviour is seen as very easy to do with few obstacles, hence the challenge of achieving successful behaviour change.

The TPB has been applied to sedentary behaviour. For example, Prapavessis and colleagues [63] conducting a web-based survey of over 350 adults in which they were asked a number of questions reflecting the main constructs of the TPB as well as questions concerning their 'general' sedentary behaviour and weekday and weekend contexts. The authors concluded that their finding 'indicates that cognitive/rational processes play an important role in sedentary behaviour and that sitting is not solely a habitual behaviour engaged in by "default"' (p. 29). However, no measure of habit was included.

Self-Determination Theory Self-determination theory (SDT) has become a popular approach in physical activity and health psychology [45, 64, 65], but little has been said about its likely use or relevance to sedentary behaviour other than computer gaming [66]. It is a multi-faceted theory concerning reasons for adopting a behaviour (intrinsic and extrinsic motivation) and the satisfying of psychological needs. An optimal intrinsic motivational state is derived from various intra-individual and social contextual influences, including an autonomy-supportive environment, the satisfying of the needs for competence, autonomy and social relatedness, and reasons for behavioural involvement that are more self-determined rather than controlling [67, 68]. These might all apply to a range of leisure-time sedentary behaviours, such as computer use. For sedentary screen behaviour, however, we need to know more about what functions screens and devices serve to better understand these motivational processes.

Transtheoretical Model and HAPA The transtheoretical model is a stage-based approach, whereas SCT and TPB are best described as more continuous or 'linear' theories. The TTM proposes that behaviour change involves moving through a set of stages and is a framework that encompasses both the 'when' (stages) and the 'how' of behaviour change. Elements of the TTM include both 'processes' (strategies) of change and 'moderators' of change, such as decisional balance (weighing up the pros and cons of change) and self-efficacy. Research concerning the TTM in sedentary behaviour is lacking.

The HAPA framework also uses stages (non-intentional, intentional, action), alongside continuous constructs from other theories. The model combines stages with self-efficacy, pros and cons, risk perception, intentions, and goal-setting, and has been tested in physical activity research [69] but not sedentary behaviour.

Behavioural Choice Theory Behavioural choice theory (BECT) is based on behavioural economics and is a theoretical approach that attempts to understand how time and resources are allocated given a choice between two or more alternatives [57]. Taking the example of a ubiquitous sedentary behaviour, TV viewing, BECT contends that choosing to watch TV is a function of (a) the accessibility of the behaviour, (b) the availability of alternatives, and (c) the reinforcement value ('appeal' or 'enjoyment') of the behaviour. For example, when physically active and sedentary options are equally accessible, children tend to select the sedentary option. According to Epstein [57], the choice of sedentary behaviours is very responsive to 'cost' and effort, and therefore making access more difficult, such as keeping video games machines in the box when not being used, or removing devices from the room, may lead to reductions in sedentary behaviour.

Availability of alternatives refers to whether or not there are attractive and positively reinforcing alternative behaviours available. Although people may choose the sedentary option, a different decision may be made if the alternative behaviour (s) are highly desirable (e.g. trip to the park). Reinforcement value refers to the appeal of the behaviour. This could be targeted through rewards and praise for choosing alternative non-sedentary behaviours.

The challenge of health behaviour interventions is often to shift the choice from an unhealthy but highly reinforcing behaviour (e.g. sedentary screen viewing) to potentially less immediately reinforcing but healthier alternatives (e.g. physical activity). Under the BECT perspective, it is considered possible to shift behaviour from sedentary screen viewing by making non-screen viewing activities more appealing (reinforcement value) and easy to do (accessible and available) relative to sedentary screen viewing.

Epstein and colleagues have used BECT as a framework for the study of sedentary behaviour and physical activity in children [70]. This work has shown that by making alternative active behaviours more accessible, and sedentary pursuits less reinforcing, reductions in sedentary behaviour and increases in physical activity are possible [70, 71]. However, with the rapidly changing technological landscape, this remains a challenge.

16.6.2 Dual-Process Approaches

As stated, dual-process theories or approaches recognise both reflective and automatic processes. This is illustrated in Fig. 16.4. The emphasis in physical activity research has been on reflective approaches, but this is now changing and includes greater use of automatic approaches for sedentary behaviour too [72] (see the next section). In fact, it could be argued that it makes even more sense to adopt automatic approaches (or at least dual-process models) for sedentary behaviour given that these behaviours appear to have a high degree of automaticity and environmental cueing. Indeed, automatic approaches have strong links to both ‘habit’ and affective processing. Quick, relatively automatic, actions can take place due to ingrained environmental cues (akin to habit), and relatively unconscious affective processing or ‘likes’ and ‘dislikes’.

The affective-reflective theory (ART) of physical inactivity and exercise is a dual-process model that is firmly grounded in exercise psychology research [49]. The theory has been proposed to explain behaviour in situations in which people remain in a state of inactivity or they initiate physical activity. These authors claim that the ART differs from other theories in at least three ways: it has a focus on affect and automaticity, it is based on the known affective reactions to exercise, and it can explain the ‘thoughtless maintenance’ of physical inactivity or sedentary behaviour (see Fig. 16.5).

The automatic affective valuation is a result of prior experiences which may be mediated by cognitive appraisals (e.g. pride, embarrassment). Automatic affective

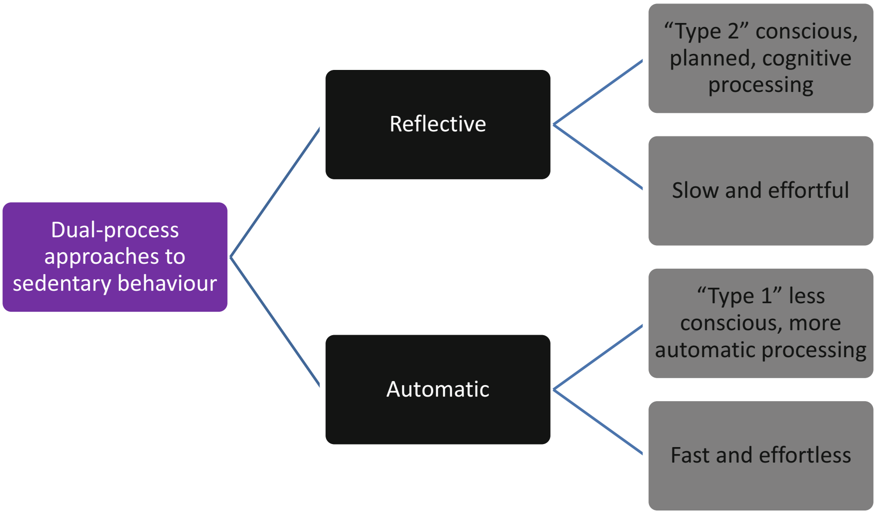

Fig. 16.4 Dual-process approaches to sedentary behaviour

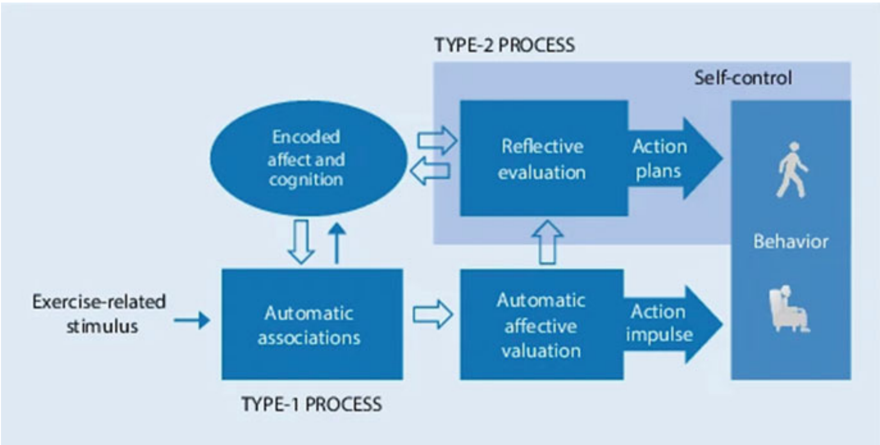

Fig. 16.5 The affective-reflective theory of physical inactivity and exercise. From [49]. Reproduced under terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0)

valuation is the fast inherently type 1 process mentioned earlier (see Fig. 16.4). Importantly, this theory suggests that the reason for why many people are physically inactive reflects this issue—'the core affective valence associated with being physically inactive is more positive than the affective valance associated with exercise' (Brand and Ekkekakis [49], p. 56). This 'gut feeling' potentially delivers a strong action impulse to move or not move.

The automatic affective valuation can serve as the basis for a slower, controlled, reflective evaluation (type 2 process; see Fig. 16.4) if self-control resources are available. This reflective evaluation draws on propositions about exercise and physical inactivity derived from previous experience and recall (e.g. anticipation of the affective consequence of physical activity). Higher-level cognitive operations, such as thoughts about self-efficacy, may also contribute to this process. This is where traditional social-cognitive based theories could be applied (e.g. social cognitive theory).

This theory assumes that the action impulse will generally prevail when sufficient motivation, opportunities, or self-regulatory resources (e.g. willpower) are low [49]. Brand and Ekkekakis conclude by saying the ART 'is a dual-process theory that emphasises the importance of automatic positive and negative associations of subsequent physical inactivity or exercise' (p. 56).

Another dual-process approach applied to active and sedentary behaviours is that of TEMPA—'theory of effort minimisation in physical activity' [47]. As the authors of this framework state, 'humans have evolved to be physically active but, more importantly, physically efficient. TEMPA integrates the processes underlying these opposite forces acting on human movement-based behaviours in a single framework' ([47], p. 172). TEMPA proposes that internal and external cues, such as the movement itself and physiological effort needed, will lead to both reflection and automaticity regarding perceived effort. Decisions are made as to whether effort is expended or not. Consistent with more automatic approaches that might rely on environmental cues, TEMPA recognises that 'promoting physical activity requires the development of an environment that triggers a spontaneous engagement in behaviours associated with higher rather than lower energy expenditure' (p. 176). This means that reductions in sedentary behaviour should consider environmental manipulation or restructuring for substituting in more active behaviours. This can then reduce the cognitive effort required for behaviour change (see Sect. 16.7).

16.6.3 Automatic Processing Approaches

Automatic processing is associated with notions of 'habit' [73]. The goal of nearly all health behaviour change is to make the desired behaviour a 'habit', or we wish to eliminate 'bad habits', such as excessive sedentary behaviour. Habits involve behavioural patterns learned through context-dependent repetition. A mental association is made between the situation and behaviour. Sedentary behaviour is an obvious example where the behaviour is strongly driven by habit. When a particular context is encountered, such as arriving home after work, it is often sufficient to automatically cue the habitual response of, say, sitting on the sofa and turning on the TV.

In novel contexts, behaviour is more likely to be regulated by conscious decisions through intentions (reflective processing), but in familiar contexts behaviour will be much more affected by habit (automatic processing). Given the high frequency of many sedentary behaviours, such as passively sitting at a desk at work or in front of the TV, it is easy to see how habitual such behaviours become. Moreover, these behaviours might also be driven by having them appear to be attractive and accessible. For example, contemporary home-based entertainment is exactly that, including modern furniture and wide-screen, multi-channel, high definition TVs. This will make the behaviour of sedentary sitting more habitual and will lessen the need for reflective decision-making.

These arguments and examples are consistent with behavioural choice theory, as already discussed. Behavioural choices are made on the assessment of the accessibility of the behaviour and the liking (reinforcement value) of the behaviour. Kremers et al. [74] demonstrated that sedentary behaviour in the form of screen viewing has a habitual component. Dutch adolescents completed questionnaires assessing screen viewing and 'habit strength' for screen viewing, and there was a moderately strong correlation between the two. As habits are formed through repetition, it is going to require time and repetition to break one habit and replace it with another. Lally and Gardner [75] have made some suggestions on how to do this, including identifying the cues for specific behaviours through self-monitoring. This way they can identify situations in which they perform unwanted sedentary behaviour. The cue can then either be avoided or strategies can be developed so that when the cue occurs, the behavioural response to the cue is something less sedentary.

Based on behavioural economics, the concept of 'nudging' has been proposed [76]. Behavioural economics is closely aligned with what psychologists understand as behaviour analysis, with its roots in Skinnerian conditioning. Behavioural economics 'seeks to combine the lessons from psychology with the laws of economics' ([77], p. 12) and is 'designed to understand factors that influence choice among alternatives' ([78], p. 1011).

Nudging is when behaviours are encouraged through little or no incentives rather than through highly directive or so-called nannying approaches, such as government policies and legislation. Nudging is referred to as the influence of 'choice architecture' and affective judgements and responses (essentially 'gut reactions' of likes and dislikes). Choice architecture often involves altering small-scale social and physical environments to cue desired behaviours [79]. This approach might not be considered 'individual' in its orientation, although it is difficult to separate environmental drivers from individual responses.

A typology by Hollands et al. [79, 80] proposed that choice architecture interventions could involve altering properties or the placement of objects or stimuli, or both of these in combination. Altering properties, for example, might involve changing the physical ambience, labels (e.g. food), or size of a product. Altering placement might involve changing the availability or proximity of a product. Priming and prompting could involve changes to both properties and placement.

In an analysis of various health behaviours using a choice architecture approach, Hollands et al. [79] found that over 70% of studies focused on diet, with just under 20% on physical activity, the majority of which tried to nudge behaviour through changes to the ambience and design of the environment. Little has been done on sedentary behaviour, although the use of sit-to-stand desks is an environmental manipulation that could be seen, in part, as a choice architecture strategy.

Nudging and behavioural economics informs us that affective responses are also important. Delayed consequences of our behaviour, such as long-term health benefits, are often 'discounted' and seen as less important, whereas more immediate reinforcement can powerfully shape behaviour [81]. More automatic forms of motivation can be strongly influenced by simple 'likes' and 'dislikes'. This is where behaviours follow quick and less reflective processes. For example, we may choose to buy a product (e.g. smartphone) based on looks and 'feel' as much as functionality. In the same way, we may choose a certain sedentary behaviour, such as TV viewing, based on little conscious decision-making but a simple 'liking' for this leisure-time pursuit alongside alternatives. Of course, if alternatives are highly attractive, TV viewing may be less likely. This is why we must seek to find ways of making physical activity attractive and 'affectively pleasing', and sedentary alternatives less so. A reduced emphasis on longer term health outcomes is also recommended [82, 83], thus questioning the 'exercise is medicine' mantra.

16.7 Individual-Level Approaches to Reduce Sedentary Behaviour

Interventions designed to reduce sedentary behaviour have proliferated over the past decade [84–87]. Early work focused on young people's leisure time, and primarily TV viewing and then screen use [88], and subsequent intervention work has expanded into the community [89], workplace [90, 91], schools [92], and use of technology [93]. Some adopt strategies that are more environmental, such as provision of a sit-to-stand desk, while others focus on individual behaviour change techniques, such as self-monitoring.

16.7.1 Interventions for Young People

One of the first randomised controlled trials (RCT) for sedentary behaviour reduction in children was reported by Robinson [94] more than two decades ago. This has been an influential paper with over 1500 citations (as of September 12, 2023). The rationale for the study was obesity reduction. Children aged 8–9 years were randomly allocated by school to intervention and control conditions, with 92 and 100 participants respectively being available for post-intervention assessments. The intervention comprised a mix of educational, behavioural, and environmental strategies. The main strategy was education, with the children being exposed to 18 classroom lessons in standard school time. Self-monitoring was included and the children were challenged to take part in a 10 day period of screen time abstinence.

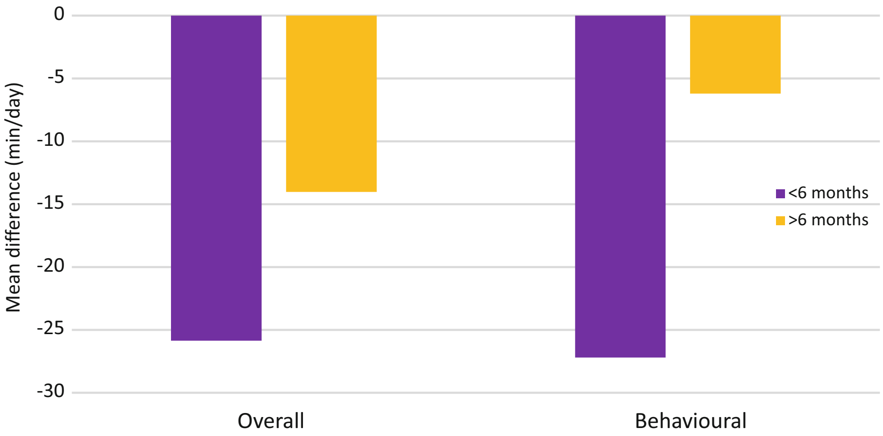

Fig. 16.6 Shorter and longer intervention effects on sedentary behaviour in young people (data from Ref. [85])

Although no formal process evaluation was undertaken, 90% of the children available at baseline participated in some days of screen time abstinence, with 67% completing all 10 days. In addition, the intervention group children were provided with a TV monitoring device, although data suggested that its use was mixed.

This RCT showed a clear reduction in TV hours per week for the intervention group, although the effect size just for this group was moderate due to large variability in the data. Raw BMI data showed that both intervention and control groups increased their BMI over the time course of the trial, which is not an unexpected trend for this age group. However, an effect in favour of the intervention group was shown through differences in BMI change between the two groups after adjustment for baseline and confounders. Overall, however, while the trial showed changes in sedentary behaviour, the intervention itself is very extensive, with many weeks of education and participation in total avoidance of screen time. Therefore, it is questionable how feasible this is to roll out. Nevertheless, this was an important initial trial in the field and appeared to have influenced further interventions designed to reduce screen time in young people.

The majority of interventions for young people have been with children rather than adolescents, and with a focus on TV viewing and screen time. There is very little on 'newer' devices such as smartphones. A review of reviews has shown that intervention effects are modest across a range of interventions [88]. A recent systematic review by Blackburn et al. [85] included both children (84 interventions) and adults (77 interventions). For children's interventions that compared intervention groups to inactive controls, sedentary behaviour was reduced by 27 min/day overall when assessed within 6 months, but only 14 min/day after 6 months follow-up. These effects were broadly similar for interventions that were 'behavioural' in focus at <6 months (e.g. reminders, prompts, planning, and reinforcement), but greater than longer term follow-ups, as shown in Fig. 16.6. This suggests that behavioural interventions require additional strategies, or more follow-ups, for behavioural maintenance.

A comprehensive meta-analysis of 186 studies on screen time interventions in young people reported a small overall intervention effect [59]. Similar effects were seen across intervention clusters grouped by behaviour change techniques (BCTs)—social comparison, knowledge and consequences, behavioural repetition/practice, and goals, feedback, and planning. The most frequently reported individual BCTs were social support, information on the behaviour–health link, and instruction. All showed similar effects. It is not yet known whether such small effects are meaningful in a practical or clinical sense.

16.7.2 Interventions for Adults

There has been a considerable increase in interest concerning interventions for reducing sedentary behaviour adults. Much of this has centred on the context of the workplace, including changes to the office environment, such as provision of sit-to-stand desks. Interventions have also used a number of individual approaches. The increase in research on sedentary behaviour interventions for adults has led to a concomitant increase in relevant systematic reviews.

Martin et al. [84] conducted a review of 51 sedentary behaviour interventions, including 36 suitable for meta-analysis. Conclusions drawn were (a) sedentary behaviour in intervention groups was reduced by 22 min/day; (b) interventions focusing on sedentary behaviour only showed the greatest reduction in sedentary time of around 42 min/day, although there were few studies and quality was low; (c) intervention durations up to 3 months and interventions targeting men and mixed genders showed significant reductions in sedentary behaviour; and (d) intervention effects were evident up to 12 months.

The large review reported earlier by Blackburn et al. [85] also included data on adults. Behavioural and environmental interventions showed good effectiveness over 6 months, compared to inactive controls, with about a 1 h reduction for intervention groups. Blackburn et al. suggested that 'interventions based on environmental restructuring, persuasion or education were most effective' (p. 12). For older adults, it has been reported that 'individual behaviour change interventions show promise for reducing sedentary time in the short term' [95].

A popular setting for conducting sedentary behaviour reduction trials is the workplace. An early approach was to employ prompting software on desk computers with 'pop-up' advice windows timed to appear at regular intervals reminding users to either sit less or move more, or both. But the most popular approach has been the use of sit-to-stand workstations, or 'standing desks'. A Cochrane review by Shrestha et al. [90] synthesised evidence for 37 workplace interventions designed to reduce sedentary behaviour. The most successful type of intervention was the sit-to-stand workstation which showed a reduction in sitting of about 100 min/workday over three months.

Neuhaus et al. [96] reviewed evidence for the use of 'activity-permissive' workstations. These included treadmill desks, cycle ergometers, and pedal devices fitted underneath a desk. All can be used while typical desk-based tasks are undertaken. Sit-to-stand workstations were also investigated. An overall reduction in sedentary time of about 77 min/day was reported. Whether substituting physical activity in place of sedentary time has sufficient acceptability and feasibility is yet to be tested. Replacing sitting with standing may be more acceptable to ambulatory office workers, but further work is required on this to achieve a balanced combination of sitting, standing, and moving at work [97].

The 'Stand More at Work' ('SMArT Work') study was a cluster RCT using a multicomponent intervention designed to reduce workplace sitting [98, 99]. Desk-based workers were recruited. At baseline, participants sat for 73% (6 h) of their working day. The intervention group ($n = 77$) were offered intervention approaches and multicomponent strategies derived from developmental work using the behaviour change wheel (see [100]). In addition to organisational strategies (e.g. management support through newsletter and encouragement) and environmental strategies (e.g. sit-to-stand desk), individual and group strategies were implemented. These included a 30-min educational workshop, feedback from participant's baseline data using the activPAL accelerometer device (data on sitting, standing, and stepping), an action plan and goal-setting booklet, self-monitoring/prompting using an office chair 'Darma cushion' synced through Bluetooth to the participant's mobile device, and brief coaching sessions throughout.

The intervention group reduced their occupational sitting time at 12 months by 72 min/day while controls showed a slight increase in work time sitting. Some measures associated with job performance, musculoskeletal conditions, and mental health showed small positive changes. Process evaluation data suggested that behaviour change was facilitated by the sit-to-stand desk, the educational workshop, behavioural feedback, and regular contact with research staff [101].

16.8 Use of Behaviour Change Techniques

BCTs are important 'active ingredients' that individuals may use to reduce their sedentary or other health behaviours. A review has synthesised data on the use of BCTs in 26 sedentary behaviour interventions in adults [102]. Interventions were also rated as being 'very promising' (39%), 'quite promising' (21%), or 'non-promising' (39%), depending on the outcomes of the intervention.

Results showed that several individually focused techniques might be effective, including problem-solving, self-monitoring, feedback, and information on health consequences. These elements can act as part of a feedback loop whereby people monitor their sedentary time and receive feedback as part of their engagement in problem-solving. Given the earlier discussion, it is noteworthy how 'reflective' these BCTs are.

16.9 Translation of Individual-Level Approaches

Individual-level interventions are important as they represent the proximal interface between an intervention strategy and the individual attempting behaviour change. However, such changes will only occur in the context of social and physical environments, and the success of interventions will be affected by all levels. For example, the success of a technology-based individual intervention, such as through self-monitoring, will be less successful if individuals are trying to reduce their sedentary behaviour in the face of a non-supportive social climate or physical environment. Fortunately, sedentary behaviour is an inherently practical issue—it involves a high-frequency behaviour that is embedded in social and cultural norms. This makes it open to many possible issues of 'translation' from research labs into ecologically valid settings. The barriers discussed in this chapter suggest that there are challenges in achieving widespread behaviour change, but equally there is a groundswell of interest and change that continues to make inroads into individual, social, and environmental changes, thus allowing for some success, including at the individual level. The adoption of sedentary behaviour reduction strategies in work and school environments is testament to this momentum. However, most of these strategies only manage to achieve a transition from sitting to standing; increases in light ambulation or MVPA remain more difficult to achieve [99]. Changes to physical activity without disrupting work or learning time continue to be a challenge.

16.10 Summary

Sedentary behaviour research has gained huge momentum over the past two decades [103]. We have good data on many aspects of the topic relevant to this chapter, including measures, documentation of health outcomes, correlates, interventions, and translation. Of course, more can be done, and the main challenge appears to be how we secure initial and ongoing individual behaviour change in the face of social, cultural, and physical environments that encourages long periods of passive sitting and lack of movement.

References

1. Salmon J, Hesketh KD, Arundell L, Downing KL, Biddle SJH. Changing behavior using ecological models. In: Hagger MS, Cameron LD, Hamilton K, Hankonen N, Lintunen T, editors. The handbook of behavior change. cambridge handbooks in psychology. Cambridge: Cambridge University Press; 2020. p. 237–50.
2. Sallis JF, Owen N. Physical activity and behavioral medicine. Thousand Oaks, CA: Sage; 1999.

3. Carty C, van der Ploeg HP, Biddle SJH, Bull F, Willumsen J, Lee L, et al. Response to "Commentary on: The First Global Physical Activity and Sedentary Behavior Guidelines for People Living With Disability". J Phys Act Health. 2021;18:350–1.
4. Smith B, Mallick K, Monforte J, Foster C. Disability, the communication of physical activity and sedentary behaviour, and ableism: a call for inclusive messages. Br J Sports Med. 2021;55(20):1121–2.
5. Carty C, van der Ploeg HP, Biddle SJH, Bull F, Willumsen J, Lee L, et al. The first global physical activity and sedentary behavior guidelines for people living with disability. J Phys Act Health. 2021;18(1):86–93.
6. DiPietro L, Al-Ansari SS, Biddle SJH, Borodulin K, Bull FC, Buman MP, et al. Advancing the global physical activity agenda: recommendations for future research by the 2020 WHO physical activity and sedentary behavior guidelines development group. Int J Behav Nutr Phys Act. 2020;17(1):143.
7. Biddle SJH, Mutrie N, Gorely T, Faulkner G. Psychology of physical activity: determinants, well-being and interventions. 4th ed. London: Routledge; 2021.
8. Arundell L, Fletcher E, Salmon J, Veitch J, Hinkley T. The correlates of after-school sedentary behavior among children aged 5–18 years: a systematic review. BMC Public Health. 2016;16(1):1–10.
9. Kaye LK, Orben A, Ellis DA, Hunter SC, Houghton S. The conceptual and methodological mayhem of "screen time". Int J Environ Res Public Health. 2020;17(10):3661.
10. Stierlin A, De Lepeleere S, Cardon G, Dargent-Molina P, Hoffmann B, Murphy M, et al. A systematic review of determinants of sedentary behaviour in youth: a DEDIPAC-study. Int J Behav Nutr Phys Act. 2015;12(1):133.
11. Biddle SJH, Biddle GJH. Obesity and sedentary time at work and home. In: Bray G, Bouchard C, editors. Handbook of obesity, 1: epidemiology, etiology, and physiopathology. 5th ed. New York: CRC Press. In press.
12. O'Donoghue G, Perchoux C, Mensah K, Lakerveld J, van der Ploeg H, Bernaards C, et al. A systematic review of correlates of sedentary behaviour in adults aged 18-65 years: a socio-ecological approach. BMC Public Health. 2016;16:163.
13. Chastin S, Buck C, Freiberger E, Murphy M, Brug J, Cardon G, et al. Systematic literature review of determinants of sedentary behaviour in older adults: a DEDIPAC study. Int J Behav Nutr Phys Act. 2015;12(1):127.
14. Thomas G, Bennie JA, De Cocker K, Castro O, Biddle SJH. A descriptive epidemiology of screen-based devices by children and adolescents: a scoping review of 130 surveillance studies since 2000. Child Indic Res. 2020;13:935–50.
15. Leask CF, Harvey JA, Skelton DA, Chastin SF. Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). Eur Rev Aging Phys Act. 2015;12:4.
16. Biddle GJH, Henson J, Biddle SJH, Davies MJ, Khunti K, Rowlands AV, et al. Modelling the reallocation of time spent sitting into physical activity: isotemporal substitution vs compositional isotemporal substitution. Int J Environ Res Public Health. 2021;18(12)
17. Chastin S, McGregor D, Palarea-Albaladejo J, Diaz KM, Hagströmer M, Hallal PC, et al. Joint association between accelerometry-measured daily combination of time spent in physical activity, sedentary behaviour and sleep and all-cause mortality: a pooled analysis of six prospective cohorts using compositional analysis. Br J Sports Med. 2021;55:1277–85.
18. Chastin SFM, McGregor DE, Biddle SJH, Cardon G, Chaput J-P, Dall PM, et al. Striking the right balance: evidence to inform combined physical activity and sedentary behavior recommendations. J Phys Act Health. 2021;18(6):631–7.
19. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary behavior research network (SBRN): terminology consensus project process and outcome. Int J Behav Nutr Phys Act. 2017;14
20. Dempsey PC, Owen N, Biddle SJH, Dunstan DW. Managing sedentary behaviour to reduce the risk of diabetes and cardiovascular disease. Curr Diab Rep. 2014;14(9):522.

21. Pearson N, Braithwaite RE, Biddle SJH, van Sluijs EMF, Atkin AJ. Associations between sedentary behaviour and physical activity in children and adolescents: a meta-analysis. Obes Rev. 2014;15:666–75.
22. Mansoubi M, Pearson N, Biddle SJH, Clemes S. The relationship between sedentary behaviour and physical activity in adults: a systematic review. Prev Med. 2014;69:28–35.
23. Saunders TJ, Atkinson HF, Burr J, MacEwen B, Skeaff CM, Peddie MC. The acute metabolic and vascular impact of interrupting prolonged sitting: a systematic review and meta-analysis. Sports Med. 2018;48(10):2347–66.
24. Saunders TJ, McIsaac T, Douillette K, Gaulton N, Hunter S, Rhodes RE, et al. Sedentary behaviour and health in adults: an overview of systematic reviews. Appl Physiol Nutr Metab. 2020;45(10 (Suppl 2)):S197–217.
25. Prince SA, Rasmussen CL, Biswas A, Holtermann A, Aulakh T, Merucci K, et al. The effect of leisure time physical activity and sedentary behaviour on the health of workers with different occupational physical activity demands: a systematic review. Int J Behav Nutr Phys Act. 2021;18(1):100.
26. Pearson N, Biddle SJH. Sedentary behaviour and dietary intake in children, adolescents and adults: a systematic review. Am J Prev Med. 2011;41(2):178–88.
27. Ghobadi S, Hassanzadeh-Rostami Z, Salehi-Marzijarani M, Bellissimo N, Brett NR, Totosy de Zepetnek JO, et al. Association of eating while television viewing and overweight/obesity among children and adolescents: a systematic review and meta-analysis of observational studies. Obes Rev. 2018;19:313–20.
28. Keadle SK, Moore SC, Sampson JN, Xiao Q, Albanes D, Matthews CE. Causes of death associated with prolonged TV viewing: NIH-AARP diet and health study. Am J Prev Med. 2015;49(6):811–21.
29. Stockwell S, Trott M, Tully M, Shin J, Barnett Y, Butler L, et al. Changes in physical activity and sedentary behaviours from before to during the COVID-19 pandemic lockdown: a systematic review. BMJ Open Sport Exerc Med. 2021;7(1):e000960.
30. Runacres A, Mackintosh KA, Knight RL, Sheeran L, Thatcher R, Shelley J, et al. Impact of the COVID-19 pandemic on sedentary time and behaviour in children and adults: a systematic review and meta-analysis. Int J Environ Res Public Health. 2021;18(21):11286.
31. Gruber J, Prinstein MJ, Clark LA, Rottenberg J, Abramowitz JS, Albano AM, et al. Mental health and clinical psychological science in the time of COVID-19: challenges, opportunities, and a call to action. Am Psychol. 2021;76(3):409–26.
32. Mackenbach JD, de Groot R, Lakerveld J, De Cocker K, Cardon G, De Bourdeaudhuij I, et al. What factors explain socioeconomic inequalities in adults' television-related sitting time? Eur J Public Health. 2019;29(2):248–54.
33. Minges KE, Owen N, Salmon J, Chao A, Dunstan DW, Whittemore R. Reducing youth screen time: qualitative metasynthesis of findings on barriers and facilitators. Health Psychol. 2015;34(4):381–97.
34. Thomas G, Bennie JA, De Cocker K, Biddle SJH. Exploring contemporary screen time in Australian adolescents: a qualitative study. Health Promot J Austr. 2021;32(S2):238–47.
35. De Cocker K, Veldeman C, De Bacquer D, Braeckman L, Owen N, Cardon G, et al. Acceptability and feasibility of potential intervention strategies for influencing sedentary time at work: focus group interviews in executives and employees. Int J Behav Nutr Phys Act. 2015;12(22)
36. Mansfield L, Hall J, Smith L, Rasch M, Reeves E, Dewitt S, et al. "Could you sit down please?" A qualitative analysis of employees' experiences of standing in normally-seated workplace meetings. PloS One. 2018;13(6):e0198483.
37. Gardner B, Flint S, Rebar AL, Dewitt S, Quail SK, Whall H, et al. Is sitting invisible? Exploring how people mentally represent sitting. Int J Behav Nutr Phys Act. 2019;16(1):85.
38. Kerlinger F. Foundations of behavioral research. New York: Holt, Rinehart & Winston; 1973.
39. Michie S, West R, Campbell R, Brown J, Gainforth H. ABC of behaviour change theories. London: Silverback Publishing; 2014.

40. Skivington K, Matthews L, Simpson SA, Craig P, Baird J, Blazeby JM, et al. A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. BMJ. 2021;374:n2061.
41. Gourlan M, Bernard P, Bortolon C, Romain AJ, Lareyre O, Carayol M, et al. Efficacy of theory-based interventions to promote physical activity. A meta-analysis of randomised controlled trials. Health Psychol Rev. 2016;10(1):50–66.
42. Biddle SJH, Hagger MS, Chatzisarantis NLD, Lippke S. Theoretical frameworks in exercise psychology. In: Tenenbaum G, Eklund RC, editors. Handbook of sport psychology. 3rd ed. Hoboken, NJ: Wiley; 2007. p. 537–59.
43. Bartholomew LK, Parcel GS, Kok G, Gottlieb NH. Intervention mapping: designing theory- and evidence-based health promotion programs. Mountain View, CA: Mayfield; 2001.
44. Rhodes RE, McEwan D, Rebar AL. Theories of physical activity behaviour change: a history and synthesis of approaches. Psychol Sport Exerc. 2019;42:100–9.
45. Rhodes RE, Nasuti G. Trends and changes in research on the psychology of physical activity across 20 years: a quantitative analysis of 10 journals. Prev Med. 2011;53(1–2):17–23.
46. Rollo S, Gaston A, Prapavessis H. Cognitive and motivational factors associated with sedentary behavior: a systematic review. AIMS Public Health. 2016;3(4):956–84.
47. Cheval B, Boisgontier MP. The theory of effort minimization in physical activity. Exerc Sport Sci Rev. 2021;49(3):168–78.
48. Brand R, Cheval B. Theories to explain exercise motivation and physical inactivity: ways of expanding our current theoretical perspective. Front Psychol. 2019;10(1147)
49. Brand R, Ekkekakis P. Affective–reflective theory of physical inactivity and exercise. Ger J Exerc Sport Res. 2018;48:48–58.
50. Becker MH, Haefner DP, Kasl SV, Kirscht JP, Maiman LA, Rosenstock IM. Selected psychosocial models and correlates of individual health-related behaviours. Med Care. 1977;15(Supplement):27–46.
51. Bandura A. Social foundations of thought and action: a social cognitive theory. Englewood Cliffs, NJ: Prentice Hall; 1986.
52. Prochaska JO, Marcus BH. The transtheoretical model: application to exercise. In: Dishman RK, editor. Advances in exercise adherence. Champaign, IL: Human Kinetics; 1994. p. 161–80.
53. Prochaska JO, Norcross JC, DiClemente CC. Changing for good. New York: Avon; 1994.
54. Ajzen I. The theory of planned behavior. Organ Behav Hum Decis Process. 1991;50:179–211.
55. Deci EL, Ryan RM, editors. Handbook of self-determination research. Rochester: The University of Rochester Press; 2002.
56. Schwarzer R. Self-efficacy in the adoption and maintenance of health behaviors: theoretical approaches and a new model. In: Schwarzer R, editor. Self-efficacy: thought control of action. Bristol, PA: Taylor & Francis; 1992. p. 217–43.
57. Epstein LH. Integrating theoretical approaches to promote physical activity. Am J Prev Med. 1998;15(4):257–65.
58. Epstein LH, Saelens B. Behavioral economics of obesity: food intake and energy expenditure. In: Bickel WK, Vuchinich RE, editors. Reframing health behavior change with behavioral economics. New York: Routledge; 2009. p. 293–311.
59. Jones A, Armstrong B, Weaver RG, Parker H, von Klinggraeff L, Beets MW. Identifying effective intervention strategies to reduce children's screen time: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2021;18(1):126.
60. Ajzen I, Fishbein M. Understanding attitudes and predicting social behaviour. Englewood Cliffs, NJ: Prentice-Hall; 1980.
61. Rhodes RE, Fiala B, Conner M. A review and meta-analysis of affective judgments and physical activity in adult populations. Ann Behav Med. 2009;38:180–204.
62. Ajzen I. Attitudes, personality and behaviour. Milton Keynes: Open University Press; 1988.
63. Prapavessis H, Gaston A, DeJesus S. The theory of planned behavior as a model for understanding sedentary behavior. Psychol Sport Exerc. 2015;19:23–32.

64. Sheeran P, Wright CE, Avishai A, Villegas ME, Lindemans JW, Klein WMP, et al. Self-determination theory interventions for health behavior change: meta-analysis and meta-analytic structural equation modeling of randomized controlled trials. J Consult Clin Psychol. 2020;88(8):726–37.
65. Ntoumanis N, Ng JYY, Prestwich A, Quested E, Hancox JE, Thøgersen-Ntoumani C, et al. A meta-analysis of self-determination theory-informed intervention studies in the health domain: effects on motivation, health behavior, physical, and psychological health. Health Psychol Rev. 2021;15(2):214–44.
66. Ryan RM, Rigby CS, Przybylski A. The motivational pull of video games: a self-determination theory approach. Motiv Emot. 2006;30:347–63.
67. Ryan RM, Deci EL. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. Am Psychol. 2000;55:68–78.
68. Ryan RM, Deci EL. Intrinsic and extrinsic motivations: classic definitions and new directions. Contemp Educ Psychol. 2000;25:54–67.
69. Lippke S, Ziegelmann JP, Schwarzer R. Stage-specific adoption and maintenance of physical activity: testing a three-stage model. Psychol Sport Exerc. 2005;6(5):585–603.
70. Epstein LH, Roemmich JN. Reducing sedentary behaviour: role in modifying physical activity. Exerc Sport Sci Rev. 2001;29:103–8.
71. Epstein LH, Saelens BE, O'Brien JG. Effects of reinforcing increases in active behavior versus decreases in sedentary behavior for obese children. Int J Behav Med. 1995;2(1):41–50.
72. Conroy DE, Berry TR. Automatic affective evaluations of physical activity. Exerc Sport Sci Rev. 2017;45(4):230–7.
73. Hagger MS. Habit and physical activity: theoretical advances, practical implications, and agenda for future research. Psychol Sport Exerc. 2019;42:118–29.
74. Kremers SPJ, van der Horst K, Brug J. Adolescent screen-viewing behaviour is associated with consumption of sugar-sweetened beverages: the role of habit strength and parental norms. Appetite. 2007;48:345–50.
75. Lally P, Gardner B. Promoting habit formation. Health Psychol Rev. 2015;9(3):277–95.
76. Marteau TM, Ogilvie D, Roland M, Suhrcke M, Kelly MP. Judging nudging: can nudging improve population health? Br Med J. 2011;342:d228.
77. Dolan P, Hallsworth M, Halpern D, King D, Vlaev I. Mindspace: influencing behaviour through public policy. London: Cabinet Office; 2010.
78. Roemmich JN, Barkley JE, Lobarinas CL, Foster JH, White TM, Epstein LH. Association of liking and reinforcing value with children's physical activity. Physiol Behav. 2008;93:1011–8.
79. Hollands GJ, Shemilt I, Marteau T, Jebb S, Kelly M, Nakamura R, et al. Altering micro-environments to change population health behaviour: towards an evidence base for choice architecture interventions. BMC Public Health. 2013;13(1):1218.
80. Hollands GJ, Bignardi G, Johnston M, Kelly MP, Ogilvie D, Petticrew M, et al. The TIPPME intervention typology for changing environments to change behaviour. Nat Hum Behav. 2017;1:0140.
81. Marlatt GA. Foreword. In: Bickel WK, Vuchinich RE, editors. Reframing health behavior change with behavioral economics. New York: Routledge; 2000. p. ix–xix.
82. Ekkekakis P, Dafermos M. Exercise is a many-splendored thing, but for some it does not feel so splendid: staging a resurgence of hedonistic ideas in the quest to understand exercise behavior. In: Acevedo EO, editor. The Oxford handbook of exercise psychology. New York: Oxford University Press; 2012. p. 295–333.
83. Ekkekakis P, Vazou S, Bixby WR, Georgiadis E. The mysterious case of the public health guideline that is (almost) entirely ignored: call for a research agenda on the causes of the extreme avoidance of physical activity in obesity. Obes Rev. 2016;17(4):313–29.
84. Martin A, Fitzsimons C, Jepson R, Saunders DH, van der Ploeg HP, Teixeira PJ, et al. Interventions with potential to reduce sedentary time in adults: systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1056–63.

85. Blackburn NE, Wilson JJ, McMullan II, Caserotti P, Giné-Garriga M, Wirth K, et al. The effectiveness and complexity of interventions targeting sedentary behaviour across the lifespan: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2020;17(1):53.
86. Shrestha N, Grgic J, Wiesner G, Parker A, Podnar H, Bennie JA, et al. Effectiveness of interventions for reducing non-occupational sedentary behaviour in adults and older adults: a systematic review and meta-analysis. Br J Sports Med. 2019;53(19):1206–13.
87. Barnett TA, Kelly AS, Young DR, Perry CK, Pratt CA, Edwards NM, et al. Sedentary behaviors in today's youth: approaches to the prevention and management of childhood obesity—a scientific statement from the American Heart Association. Circulation. 2018;138 (11):e142–e59.
88. Biddle SJH, Petrolini I, Pearson N. Interventions designed to reduce sedentary behaviours in young people: a review of reviews. Br J Sports Med. 2014;48:182–6.
89. Thraen-Borowski KM, Ellingson LD, Meyer JD, Cadmus-Bertram L. Nonworksite interventions to reduce sedentary behavior among adults: a systematic review. Transl J Am Coll Sports Med. 2017;2(12):68–78.
90. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Pedisic Z. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2018;6
91. Healy GN, Goode AD, Abbott A, Burzic J, Clark BK, Dunstan DW, et al. Supporting workers to sit less and move more through the web-based BeUpstanding program: protocol for a single-arm, repeated measures implementation study. JMIR Res Protoc. 2020;9(5):e15756.
92. Chen Y-L, Tolfrey K, Pearson N, Bingham DD, Edwardson C, Cale L, et al. Stand out in class: investigating the potential impact of a sit–stand desk intervention on children's sitting and physical activity during class time and after school. Int J Environ Res Public Health. 2021;18 (9)
93. Ellingson LD, Meyer JD, Cook DB. Wearable technology reduces prolonged bouts of sedentary behavior. Transl J Am Coll Sports Med. 2016;1(2):10–7.
94. Robinson TN. Reducing children's television viewing to prevent obesity: a randomized controlled trial. JAMA. 1999;282(16):1561–7.
95. Dogra S, Ashe MC, Biddle SJH, Brown WJ, Buman MP, Chastin S, et al. Sedentary time in older men and women: an international consensus statement and research priorities. Br J Sports Med. 2017;51:1526–32.
96. Neuhaus M, Eakin EG, Straker L, Owen N, Dunstan DW, Reid N, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. Obes Rev. 2014;15(10):822–38.
97. Holtermann A, Mathiassen SE, Straker L. Promoting health and physical capacity during productive work: the goldilocks principle. Scand J Work Environ Health. 2019;45(1):90–7.
98. O'Connell SE, Jackson BR, Edwardson CL, Yates T, Biddle SJH, Davies M, et al. Providing NHS staff with height-adjustable workstations and behaviour change strategies to reduce workplace sitting time: protocol for the stand more AT (SMArT) work cluster randomised controlled trial. BMC Public Health. 2015;15(1219)
99. Edwardson CL, Yates T, Biddle SJH, Davies MJ, Dunstan DW, Esliger DW, et al. Effectiveness of the stand more AT (SMArT) work intervention: cluster randomised controlled trial. BMJ. 2018;363:k3870.
100. Munir F, Biddle SJH, Davies MJ, Dunstan D, Esliger D, Gray LJ, et al. Stand more AT work (SMArT work): using the behaviour change wheel to develop an intervention to reduce sitting time in the workplace. BMC Public Health. 2018;18(1):319.
101. Biddle SJH, O'Connell SE, Davies MJ, Dunstan D, Edwardson CL, Esliger DW, et al. Reducing sitting at work: process evaluation of the SMArT work (stand more at work) intervention. Trials. 2020;21(1):403.

102. Gardner B, Smith L, Lorencatto F, Hamer M, Biddle SJH. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. Health Psychol Rev. 2016;10(1):89–112.
103. Owen N, Healy GN, Dempsey PC, Salmon J, Timperio A, Clark BK, et al. Sedentary behavior and public health: integrating the evidence and identifying potential solutions. Annu Rev Public Health. 2020;41(1):265–87.

Chapter 17
Specific Interventions Targeting Sedentary Behaviour in Children and Adolescents

Jo Salmon, Harriet Koorts, Lauren Arundell, and Anna Timperio

Abstract It has been over two decades since the first interventions to reduce children's sedentary behaviour were published. However, child and adolescent engagement in sedentary behaviour remains high. Interventions to reduce children's and adolescents' screen time have been most common, but with rapid advances in technology these initiatives fall out of date quickly. Effectiveness of reducing sitting in the school setting via active breaks, an active curriculum, and environmental changes in the classroom (e.g. sit-stand desks) is mixed. Strategies to reduce or break up sitting in home and transport settings have been infrequently studied, and ways of ensuring sustainable implementation are unclear. Given the pervasiveness of sitting and reclining while at home during waking hours (for homework, hobbies, entertainment, and other purposes) and passive forms of transport such as car travel among children and youth, there is much scope to reduce sitting in these settings. Very few efficacious interventions have been translated into policy or practice. If these interventions are to have a sustained impact on child and adolescent populations, greater consideration of factors facilitating and/or hindering their incorporation into policy and practice is necessary. To successfully implement sedentary behaviour programs and help children and adolescents meet sedentary behaviour public health recommendations, replication of successful interventions at scale is required. Ideally, cost-effective efficacious strategies need to achieve system level changes and target not just the individual but sociocultural norms and physical, organisational, and policy environments to effect lasting and wholesale changes in sedentary behaviour at a population level.

J. Salmon (✉) · H. Koorts · L. Arundell · A. Timperio
Institute for Physical Activity and Nutrition, Deakin University, Geelong, VIC, Australia
e-mail: jo.salmon@deakin.edu.au; h.koorts@deakin.edu.au; lauren.arundell@deakin.edu.au; anna.timperio@deakin.edu.au

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_17

What Is New?

- The variety of technology in most aspects of daily life means that not all screen use poses the same risk; digital platforms have the potential to be used to reduce sedentary behaviour and promote physical activity.
- While sedentary transport interventions remain limited, effective strategies include mapping travel plans or routes to school, adopting active travel school policies, working to address safety concerns of schools and parents, and educational approaches.
- School-based interventions to reduce children's sitting time have targeted changes in pedagogy and in the environment within and outside the classroom; however, few studies have considered key elements for successful implementation at scale.
- Theoretical models and frameworks for guiding effective implementation are underutilised in scale-up studies of sedentary behaviour interventions.
- Future research on the implementation of interventions at scale, including identification of strategies and mechanisms that influence outcomes, will greatly advance our knowledge of this area.

17.1 Introduction

Objective measures show that children and adolescents are sedentary (sit or recline while expending less than 1.5 metabolic equivalents of task) for more than 60% of their waking hours [1, 2]. Please refer to Sect. 2.2 for more information on the prevalence of sedentary behaviour in children and adolescents. While rest is physiologically important for recovery after exertion, excessive periods of sitting throughout the day can be harmful to health. The health effects of total volumes of sitting are still emerging for child and adolescent populations [3]; however, there is more consistent evidence of adverse effects from engaging in excessive amounts of particular sedentary behaviours (e.g. different types of screen time) [4, 5]. This evidence has been recognised by many government agencies who have subsequently released public health guidelines to limit and break up long periods of sitting and limit the amount of time children and adolescents spend in electronic media (screen time) for non-educational purposes to 2 h per day (or 1 h per day for preschool-aged children) [4, 6–9].

A major challenge for government in implementing these guidelines is the pervasiveness of sedentary behaviour in the everyday lives of youth in developed nations around the world. The 2011–2012 Australian Health Survey reported that only one in four 2–4-year-olds and fewer than one in three (28.7%) 5–17-year-olds met the screen-time recommendations [10]. In North America, self-reported media use doubled from the early 1960s (37 h/week) to 2009 (75 h/week) [11]. Clearly, there is a need for effective interventions in child and adolescent populations.

The slow integration of evidence-based interventions into health practice substantially limits our ability to make public health recommendations on effective ways to reduce child and adolescent sedentary behaviours. Implementing and sustaining effective behavioural interventions in real-world settings is a lengthy and complex process involving multiple phases of program diffusion: dissemination (e.g. how well information on the program is spread); adoption (e.g. whether the setting choses to uptake the program); implementation (e.g. how well the program is delivered during trials); and sustainability (e.g. whether the program can be maintained over time) [12]. If sedentary behaviour interventions are to have a sustained impact on child and adolescent populations, greater consideration of factors facilitating and/or hindering their delivery in practice is necessary. To successfully inform public health recommendations on ways to reduce child and adolescent sedentary behaviour, replication of successful intervention effects in real-world settings, and at scale, is required [13].

17.2 Pathway of Steps for Sedentary Behaviour Interventions

There is a need in the physical activity field for policy-relevant research and programs that align with organisational policies and targets and the political will of the government [14]. If research placed greater focus on intervention effectiveness, reach and adoption, resource/cost demands, contextual factors, and implementation requirements, the useability of research for policymakers would likely increase and the uptake of interventions in practice would improve (i.e. political will) [15]. Ideally, for maximum impact and effectiveness at the population level, sedentary behaviour interventions must align with relevant systems (e.g. health, education, local government) and have scope to be scalable, sustainable, cost-effective, and policy-relevant [16]. Scalability can be defined as being able to implement an efficacious program under real-world conditions with a representative percentage of the population and retain effectiveness [15]. In addition, programs should focus on key settings or contexts in which children and adolescents spend considerable amounts of their time sitting, for example, in the home, at school, in transportation, and the community.

While the physical activity intervention field to date has been substantially guided by intrapersonal theories of behaviour change that have underlying assumptions of rational choice, planning, and decision-making [17], these theories are often not useful for understanding and influencing child and adolescent sedentary behaviours. One reason for this is that sedentary behaviours tend to occur habitually and automatically, without conscious thought. Habitual sitting behaviours are likely to be established from a young age. Cues or environments that trigger automatic sitting behaviours are pervasive (e.g. chairs and seated height tables), and children are often guided by the expectations of parents/carers, teachers, and other adults who are

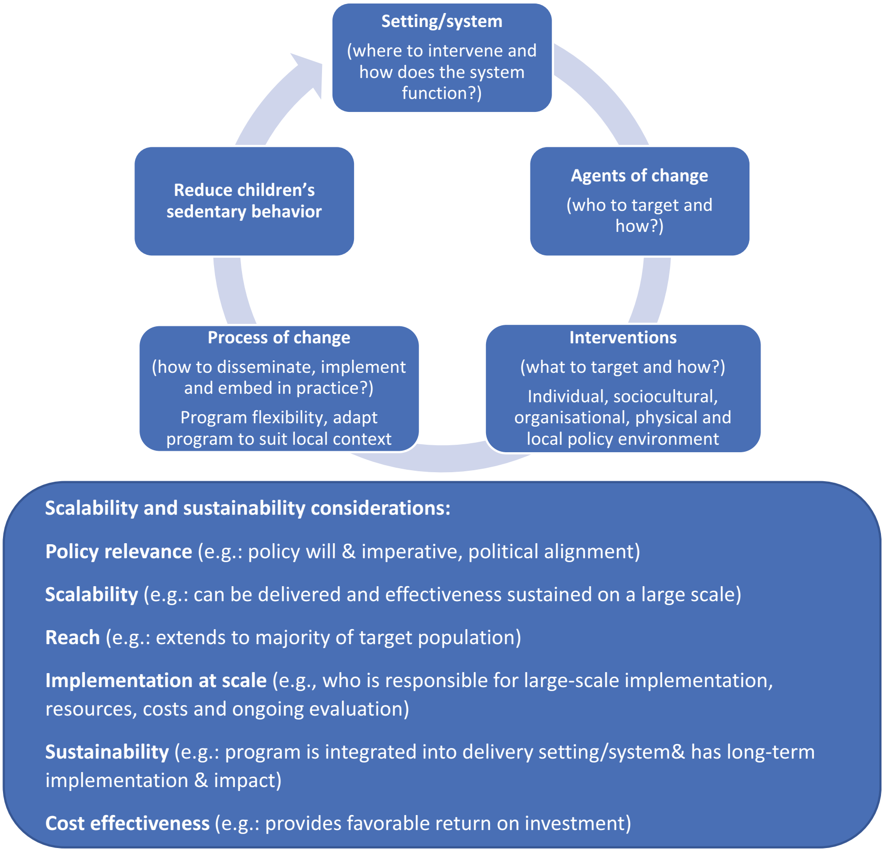

Fig. 17.1 Pathway of steps for development of potentially scalable and policy-relevant interventions to reduce children's and adolescents' sedentary behaviors

responsible for their care, for example, the expectation of a teacher for children to sit in class, encouragement by a busy parent for their child to sit in front of the television, and parents chauffeuring their children to and from school by car rather than taking more active options. Strategies that support children to break sitting habits, and normalise standing and moving in settings traditionally associated with sitting behaviours, are needed.

Figure 17.1 depicts a simple pathway of steps for guiding sedentary behaviour interventions that acknowledges the importance of program relevance in terms of political will (i.e. policy relevance of the intervention) and from the outset the potential for implementation at the population level. In order to achieve reductions in population prevalence of children's sedentary behaviour, it is necessary to develop interventions that remain effective when implemented at scale, retain accessibility (i.e. high reach), remain equitable and do not increase disparities among population groups at risk, achieve a long-term sustained impact, and are cost-effective (i.e. the "investment" provides a good return).

Suitable *settings and/or systems* in which to intervene need to be identified; that is, where do children spend much of their time sitting and what system needs to be engaged? An obvious example is the school setting within the education system. This informs which *agents of change* to engage (e.g. school principals, teachers, parents) and the context of the change (ideally a program will be flexible to suit different populations and situations). *Interventions* should consider individual (e.g. habit), sociocultural (e.g. norms, parental/carer and teacher influences), organisational (e.g. organisational readiness to change), physical environmental (e.g. no alternative to sitting in class), and policy aspects.

The process of change is related to program flexibility and improved implementation, ensuring initiatives are more likely to fit the users' and organisation's existing needs and practices [12]. Providing information on how to adapt an intervention for improved contextual fit is a critical aspect of a dissemination strategy [18]. For instance, children's sitting habits could be modified through changes to pedagogical approaches to curriculum delivery in school (e.g. active lessons) which teachers can align with the recommended curriculum for their state or region. Embedding active pedagogy in everyday teaching practice would require sociocultural changes that make it acceptable and "normal" for children to stand and move during class lessons. Physical and local (school) policy environment interventions would support and facilitate such changes.

There are many ways to change an individual's health behaviour. Ideally, for impact at a population level, strategies need to be implemented as part of existing systems to change not just the individual but sociocultural norms and existing ways of doing things at an organisational level. The following sections provide an overview of strategies to reduce children's sedentary behaviour and consider whether these approaches have considered potential scalability and policy relevance.

17.3 Interventions to Reduce Children's Sedentary Behaviour

It has been more than two decades since the first interventions to reduce children's and adolescents' sedentary behaviour, targeting television viewing time, were published [19, 20]. There have been numerous systematic and narrative reviews synthesising evidence of the effectiveness of interventions to reduce children's sedentary behaviour [21], many with a focus on health outcomes such as overweight and obesity [22–24]. The majority of these reviews have reported on evidence of the effectiveness of strategies to reduce children's screen time. More recent reviews and commentaries have synthesised the growing literature on reducing children's daily sitting, particularly during school hours. The specific features and focus of interventions to reduce children's sedentary behaviour are summarised in the following sections.

17.3.1 Screen Time and the Home Environment

The number of interventions targeting screen time among children and youth (≤18 years) has grown substantially. To bring together this growing body of evidence, one umbrella review synthesised evidence from 10 reviews (consisting of 194 studies) [25] and another umbrella review brought together evidence from 29 reviews (consisting of 394 studies) [26] which focused on interventions to reduce sedentary behaviour or screen time. Small but significant intervention effects on screen time have been shown [25, 26]. Interventions were typically delivered via the home or school setting and those that include family involvement and screen monitoring or control devices showed effectiveness. Jones and colleagues reviewed 204 interventions targeting young people's (0–18 years) screen time to identify effective behaviour change techniques [27]. The inclusion of goals, feedback, and planning were positively associated with intervention effectiveness.

Two reviews of screen time interventions targeting young children (0–5 years) found that effective interventions used promising behaviour change techniques [28] and interventions were most effective when delivered in the home, pre-school, or community settings [29]. As with older children, effective intervention strategies for young children typically included family involvement, often consisting of parental education component such as resources and information on health behaviours delivered as written materials, via phone calls or face-to-face [29]. Promising behaviour change techniques included self-efficacy, role modelling, and developmental outcomes and included "behaviour substitution", "demonstration of the behaviour" as well as information on the social and environmental consequences, goal setting, action planning, behaviour feedback, and self-monitoring [28].

The home and family environment has an important influence on children's screen time [30]. Changes to the home environment, such as the introduction of electronic monitoring devices, contingent feedback systems (e.g. access to television dependent on the child's stepcount), and facilitating parent involvement and support through educational materials (e.g. newsletters and information sessions), are strategies that have been shown to effectively reduce children's screen time [31]. However, the challenges in engaging families and the costs associated with supplying monitoring devices may limit wider scale-up. The changing use of technology and its infusion into most aspects of life also require important consideration that not all screen use poses the same risk. For example, using digital platforms to support adolescents' physical activity is associated with greater likelihood of them meeting physical activity recommendations [32], and educational screen time is associated with better educational outcomes [33]. There is emerging evidence that a composite measure of "screen time" should not be used [34] and instead specific screen behaviours should be targeted and examined.

Digital technologies or mobile health (mHealth) strategies have emerged as a wide-reaching method for screen time intervention delivery. Ludwig et al. [35] reviewed the effectiveness of text message interventions for improvement in adolescents' (10–19 years) physical activity and sedentary behaviour. Of the four interventions targeting screen time, all resulted in a decrease in screen behaviours [35] with one study among adolescent girls finding an increase on weekdays but a decrease on weekends [36]. The interventions had an additional school or online component and sent text messages up to three times per week. Digital applications (apps) offer another method of intervention delivery that has been used among adults and are beginning to be used among children and adolescents. A systematic review of interventions that used apps to improve health behaviours (diet, physical activity, and sedentary behaviour) [37] identified only one intervention that used an app to improve children's screen time among racial and ethnic minority girls, which did not result in significant changes in screen time [38]. The development of purpose-designed apps may overcome the limitations of commercial apps targeting health behaviours in children and adolescents as they rarely focus on screen time [39]. While most popular commercial apps contain behaviour change techniques (e.g. educational materials, rewards/awards, and gamification), they lack theoretical basis, are rarely aligned with sedentary behaviour guidelines, and score poorly for information quality and engagement [39].

Effective, scalable, and theoretically based screen time intervention strategies are required. Further, they need to target specific screen behaviours and keep pace with the evolution of the technology environment and the varying reasons children and adolescents engage in screen time.

17.3.2 Sedentary Transport

There have been well-documented increases in the proportion of children driven to school by car and declines in active travel (walking and cycling) to school over the past few decades [40–42]. A number of systematic reviews of interventions for promoting active transport to school have been published since 2010 [43–47], incorporating evidence from more than 45 studies between them. Most of the studies used quasi-experimental designs and were described as having a weak quality rating. The most common strategies incorporated into interventions targeting active school travel relate to preparation (strategy development), promotion (education and encouragement), and organised activities. Strategies involving policy and physical changes to the environment were less common [43, 47]. Overall, most studies reported small effects on active transport (walking and/or cycling) to school, with those incorporating changes to the physical environment holding additional promise. However, few intervention studies have reported on changes to sedentary transport.

Several interventions that reported on changes to sedentary transport included school-based activities such as mapping travel plans or routes to school, adopting active travel school policies, working to address safety concerns of schools and parents, and educational strategies (with teachers, children, and parents). A pilot study with primary school children at one school in Sydney, Australia, by Zaccari et al. [48] also used a travel diary, engaged local media, and held a school assembly to coincide with a statewide walk to school initiative, and the local council conducted a safety audit of all key travel routes to school and identified potential road safety improvements. A small reduction in car trips to schools and a corresponding increase in walking to school were reported; however, there was no comparison group.

Wen and colleagues [49] also sought to improve the local neighbourhood by working with local councils in addition to school-based activities in 12 schools. A 42% decrease in the number of children travelling to school by car in the intervention group was reported compared to a 32% decrease among those attending control schools, but the difference was not statistically different. In Canada, an evaluation of Safe Routes to Schools in 12 schools (with physical improvements for road safety and enforcement of speed and parking policies at some schools) reported that in 13% of parents surveyed the intervention "resulted in less driving" [50]. That study did not include a comparison group. A one-year intervention conducted in China that targeted multiple health behaviours via curriculum, school environment support, and family involvement in health classes and fun events showed that those who travelled to school by sedentary transport at baseline were more likely to shift to walking and cycling following the intervention compared to similar participants in the control group [51].

An intervention involving curriculum delivery at school and interactive travel planning resources for use at home resulted in a mean decreased distance travelled to school by car in the intervention school compared to a control school in Scotland [52]. In Spain, a two-term intervention involving activities delivered in the classroom (e.g. awareness) and the neighbourhood surrounding school (e.g. urban features, road safety, pedestrian/driver behaviour) resulted in no differences in change in sedentary transport (car, motorbike, or bus) at a 6-month follow-up, compared to the control group, despite an increase in frequency of walking [53]. However, immediately post-intervention, travel by car and bus were stable among the intervention group and had increased among the control group [54]. Walking school bus [55] and single-day promotional events [56] did not result in changes in car travel.

These few studies are limited to primary school settings and report diverse intervention strategies. Results are mixed. Further research on the effectiveness of strategies to reduce sedentary transport is clearly needed, along with more in-depth consideration of changes in travel, particularly among adolescents.

17.3.3 Sitting at School

As noted in the introduction, young people spend prolonged periods sitting throughout the day. A study with Australian adolescents used an accelerometer worn on the thigh and found that 68% of waking hours (70% of the school day, 75% of class time, and 65% of outside school time) were spent sitting [2]. Innovative, effective, and scalable strategies in the school and home settings are needed to reduce young people's sedentary behaviour. A systematic review of 84 child sedentary behaviour studies (62 RCTs) found 62% of interventions were conducted in school settings with most reporting effectiveness in the short term (<6-months follow-up) [57]. An umbrella review of 29 previous reviews of sedentary behaviour interventions in adolescents also found that most reviews reported effective strategies for reducing sedentary behaviour and the most common intervention setting was schools, which included education and environmental approaches (e.g. height adjustable desks in class) [26].

Studies have used a variety of furniture in the classroom that provide the opportunity for children to stand during class lessons including stand-biased, sit-stand, or height-adjustable desks [58, 59]. Some desks are at a fixed height with a tall stool for children to sit on, while others raise and lower to a normal seated height. Some studies fitted out whole classrooms with the desks, while others placed a single row of desks at the back of the classroom. Many of the interventions were treated as "natural experiments" with little or no direction from researchers to the teachers and students about frequency of standing versus sitting. In their review, Minges et al. [58] identified eight studies most of which reported small-to-moderate effect sizes on reducing children's sitting time (0.27–0.49), some for up to an hour less a day, and stronger effects on increasing children's time spent standing (0.38–0.71).

There have also been pedagogical approaches to reducing sitting in class through active curriculum [60, 61]. While studies have reported beneficial effects from training teachers to deliver standing and active lessons and regular "active" breaks to children during what would normally be time spent sitting in class [62], evidence regarding how effective these strategies are in reducing and breaking up children's sitting in class and throughout the day is still equivocal [60, 61]. Nevertheless, a recent review concluded that alongside active travel and after-school clubs, active classrooms were among the most promising strategies for promoting children's physical activity and reducing sedentary behaviour [63].

In summary, few interventions have examined the longer-term effectiveness of interventions to reduce sedentary behaviour in children and adolescents. The quality of studies has been reported in most reviews to be moderate or low. In contrast to the pathway illustrated in Fig. 17.1, few studies have considered all elements important for successful implementation and even fewer have examined or tested suitability of implementation of these strategies "at scale" [64].

17.4 Intervention Implementation and Scalability

Taking a successful intervention from a controlled research condition and testing it within a real-world environment is the crucial step for scalability [15]. Intervention efficacy under controlled research conditions provides an indication of impact.

Intervention impact alone does not predict effective implementation in practice or replicability at scale [65]. While large-scale implementation trials are recommended as a way to examine population impact [66], in physical activity research, for example, the effects of interventions observed under controlled intervention conditions are shown to reduce when delivered at scale [67].

The Dutch Obesity Intervention in Teenagers (DOiT) was a multi-component school-based obesity prevention program targeting adolescents aged 12–16 years in the Netherlands that was tested at scale [68]. The program included classroom and environmental components to prevent adolescent weight gain and demonstrated efficacy through positive reductions in some measures of adiposity, reducing in sugar-sweetened beverage consumption and screen time in an efficacy trial [68]. However, following the large-scale implementation of DOiT in a real-world context, the intervention did not have significant effects on screen time [69]. These reduced effects were attributed in part to challenges with implementation fidelity and adaptations to the program following the dissemination process. For example, organisational "buy-in" to the intervention and consistent implementation of intervention and implementation strategies were key elements of success when translating an intervention from ideal conditions to real-world scenarios. For even the most rigorous and efficacious research to be implemented in practice, an "enabling environment" is required [15, 18].

"Switch-Play" was an efficacious school-based intervention to prevent unhealthy weight gain, reduce screen time, promote physical activity, and improve fundamental movement skills tested in 311 5th Grade children in disadvantaged areas of Melbourne, Australia [70]. The real-world translatability of this program was tested as a modified intervention, "Switch-2-Activity", in 2009 among 1566 9–12-year-old children [71]. In comparison to the initial Switch-Play controlled trial, Switch-2-Play demonstrated fewer outcomes among participants overall. These differences were attributed to a reduced intervention dose in Switch-2-Play (e.g. absence of fundamental movement skills focus), changes to intervention delivery (e.g. real-world teacher delivery as opposed to the specialist research team), and changes to reporting measures. Nevertheless, this modified program was subsequently adopted by the Department of Health and Human Services in Victoria, Australia, and offered to schools as an online program over an eight-year period.

Differences in the effects of sedentary behaviour interventions when delivered in practice can, in some part, be attributed to challenges of implementation. However, beyond the difficulties of achieving effective intervention implementation in practice, when interventions are implemented "at scale", the impact of political and environmental influences can be amplified [16, 72]. As the scaling process is non-linear and can involve highly complex interactions between factors that are variable by context [73], challenges are often unpredictable. For example, Action Schools! BC is a school-based physical activity and healthy eating program that has been sustainably implemented across British Columbia, Canada, for over a decade [74]. Ongoing investment and engaged cross-sectoral partnerships all enhanced the sustainability of implementation at scale; however, the rapidly changing social context for political action on physical activity and healthy eating in British Columbia meant that a continuous process of adaptation and reflexivity was required [74].

Theoretical models and frameworks for guiding effective implementation are recommended as a tool to plan and evaluate program translation [75], yet they are underutilised in scale-up studies of sedentary behaviour interventions [76]. The PRACTical planning for Implementation and Scale-up (PRACTIS) guide provides a process for planning implementation and scale-up of evidence-based interventions, drawing on recommendations from key implementation frameworks to prioritise implementation and scale-up considerations during early planning stages of interventions [16]. However, research has shown that theories and frameworks for effective dissemination and implementation are more frequently used to evaluate implementation outcomes, as opposed to informing implementation across all study phases [76]. This, in part, may contribute to explaining why so few sedentary behaviour interventions are successfully implemented in real-world practice and sustained at scale for population health improvement. In summary, few interventions targeting children's sedentary behaviour have been implemented at scale. Even fewer have reported the cost-effectiveness [77], reach, or sustainability of the program, and theories, models, and frameworks that can underpin all stages of implementation and scale-up have been underutilised [76]. As the evidence base of efficacious programs to reduce children's sedentary behaviour grows, these are clearly areas requiring further research in the future.

17.5 What Are the Gaps and Future Directions?

With the exception of screen time, and a growing evidence base in school settings, there have been few interventions that have attempted to reduce or break up overall sitting among children and youth. Most home-based sedentary behaviour interventions focus on reducing screen time, and transport settings have rarely been targeted. There is much scope to reduce sitting in these settings given the prevalence of sitting and reclining at home and passive forms of transport such as car travel among children and youth.

The majority of sedentary behaviour interventions have focused on children rather than adolescents. Teachers and parents have been the most commonly targeted agents of change, and programs have mainly used educational approaches targeting individual- and social-level factors, such as self-monitoring and parental rules about screen time. More research on reducing adolescents' sustained sitting throughout the day is needed, as is testing the efficacy of targeting policy and organisational change via school principals and school boards, or government departments (at any level of government). Innovative research working with industry, architecture, and interior design that facilitates the engineering of opportunities to reduce children's and adolescents' sitting and promote more opportunities to move throughout the day is also required.

Although the majority of efficacy evidence in children's sedentary behaviour interventions lies in the area of screen time, a challenge for these programs is to remain relevant. New technologies for entertainment, educational, and social connection purposes are constantly coming on the market. Television viewing appears to be declining in some countries [11, 78], and alternative screen-based behaviours such as digital tablet and smart phone use are now prevalent [79]. Some interventions have examined the effectiveness of exchanging sedentary electronic games for more active ones; however, there seems to have been limited success with this approach [80]. There is scope for interventions to harness new technologies to deliver and support strategies to reduce children's screen time. For example, using timer devices to limit screen time, monitoring device- and content-specific time use, and providing intervention materials online (e.g. through apps). Technologies can also be used to reduce sitting time, for example, using wearable devices to monitor sitting time, chair sensors that assess sitting in real time and prompt the user to stand, and automated regular screen prompts on the computer or smart watch reminding the user to stand up and take a break. Given the pervasiveness of screens for many aspects of a child's life (e.g. leisure time, education, social connections), it is crucial that interventions are theoretically based and consider how to reach children/families and maintain engagement to maximise potential effectiveness and scalability. New technologies are here to stay; it may be better to employ these technologies to manage time use than try to eliminate them from children's lives altogether.

An under-studied area identified in this chapter is sedentary transport. While active transport to school initiatives for primary school travel are common and have shown increases in active travel [44–47], few studies report the impact on sedentary travel to or from school, whether by car, public transport, or any other sedentary mode. In addition, few interventions are designed to reduce the perceived convenience of driving [81]. On the most part it could be expected that interventions resulting in increases in active transport would contribute to corresponding decreases in sedentary travel; however, this may not always be the case [81]. Uptake of active travel modes among those using sedentary modes and changes in frequency or volume of active modes are not always examined. Interventions could also result in mode shifts between walking and cycling (rather than passive and active modes). It is also possible that shifts from car to public transport use could result in more sedentary travel if public transport routes are less direct or less sedentary travel if routes are direct given public transport is rarely door to door.

Interventions targeting sedentary travel to school among adolescents are surprisingly rare, despite adolescents having greater autonomy and independent mobility, and potentially being able to walk or cycle longer distances. Also critically overlooked is the development of interventions to reduce sedentary travel to destinations other than school. It has been suggested that reducing sedentary travel to destinations other than school could cumulatively add up to more opportunity to reduce sedentary travel than school trips [81]. Consistent with this view, Loh and colleagues [82] found that approximately 8% of car trips made by adolescents could feasibly be replaced by walking and more than 40% with cycling and that trips made for shopping and social purposes were more likely to be short enough to be replaced than trips made for education. Focusing on reducing sedentary travel or on substituting these trips with active forms of travel is important, regardless of the destination.

Various studies have explored the complex process of implementing evidence-based programs in the school setting [25], yet there is far less research regarding the most effective approach for systematically translating evidence-based programs into practice, specifically the mechanisms that underpin effective implementation strategies to improve intervention uptake and delivery in real-world settings and ways of leveraging opportunities to enhance scale-up outcomes [73]. Previous attempts at implementing evidence-based interventions in real-world settings have been criticised for lacking consideration of end users and variability in their environmental and/or organisational contexts [16, 66]. Cost-effectiveness and sustainability are rarely reported and scale-up studies typically rely on retrospective evaluations of "what went on". The lack of research which tests the real-world applicability and relevance of sedentary behaviour interventions makes replication and generalisability to other contexts difficult. Currently, we know less about the core components required for intervention success and the extent that programs can be modified to suit local contexts while retaining positive outcomes [12] than we do about the efficacy of strategies to reduce children's and adolescents' sedentary behaviour. Future research which systematically tests the implementation of interventions at scale, including identifying strategies that influence scale-up outcomes and the mechanisms that underpin them [73], will greatly advance our knowledge of this area. This is necessary if the field is genuine about reducing population prevalence of sedentary behaviour and benefiting the current and future health of our youth.

References

1. Ridgers ND, Timperio A, Cerin E, Salmon J. Within- and between-day associations between children's sitting and physical activity time. BMC Public Health. 2015;15:950.
2. Arundell L, Salmon J, Koorts H, Contardo Ayala AM, Timperio A. Exploring when and how adolescents sit: cross-sectional analysis of activPAL-measured patterns of daily sitting time, bouts and breaks. BMC Public Health. 2019;19(1):653.
3. Cliff DP, Hesketh K, Vella SA, Hinkley T, Tsiros MD, Ridgers ND, et al. Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis. Obes Rev. 2016;
4. Tremblay MS, LeBlanc AG, Kho ME, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Act. 2011;8:98.
5. Sanders T, Parker PD, del Pozo-Cruz B, et al. Type of screen time moderates effects on outcomes in 4013 children: evidence from the longitudinal study of Australian children. Int J Behav Nutr Phys Act. 2019;16:117.
6. Commonwealth of Australia. Australia's physical activity and sedentary behaviour guidelines. Canberra: Australian Government Department of Health; 2014.
7. Department of Health, editor. UK physical activity guidelines. Fact sheet 3: children and young people (5–18 years). London: Department of Health; 2011.
8. Ministry of Health NZ. Physical activity guidelines: children and young people (5–18 years). Auckland: Ministry of Health; 2015.

9. Australian Government Department of Health. Australia's physical activity and sedentary behaviour guidelines and the Australian 24-hour movement guidelines. Canberra: Commonwealth of Australia; 2019.
10. Australian Bureau of Statistics. Australian health survey: physical activity, 2011–12. Canberra: Commonwealth of Australia; 2013.
11. Saunders TJ, Chaput JP, Tremblay MS. Sedentary behaviour as an emerging risk factor for cardiometabolic diseases in children and youth. Can J Diabetes. 2014;38:53–61.
12. Durlak JA, DuPre EP. Implementation matters: a review of research on the influence of implementation on program outcomes and the factors affecting implementation. Am J Community Psychol. 2008;41:327–50.
13. Milat AJ, Bauman AE, Redman S, Curac N. Public health research outputs from efficacy to dissemination: a bibliometric analysis. BMC Public Health. 2011;11(1):1–9.
14. Giles-Corti B, Sallis JF, Sugiyama T, Frank LD, Lowe M, Owen N. Translating active living research into policy and practice: one important pathway to chronic disease prevention. J Public Health Policy. 2015;36:231–43.
15. Milat AJ, King L, Bauman AE, Redman S. The concept of scalability: increasing the scale and potential adoption of health promotion interventions into policy and practice. Health Promot Int. 2013;28:285–98.
16. Koorts H, Eakin E, Estabrooks P, Timperio A, Salmon J, Bauman A. Implementation and scale up of population physical activity interventions for clinical and community settings: the PRACTIS guide. Int J Behav Nutr Phys Act. 2018;15:51.
17. Brown H, Pearson N, Hume C, Salmon J. A systematic review of intervention effects on potential mediators of children's physical activity. BMC Public Health. 2013;13(1):165.
18. Meyers DC, Durlak JA, Wandersman A. The quality implementation framework: a synthesis of critical steps in the implementation process. Am J Community Psychol. 2012;50:462–80.
19. Gortmaker SL, Peterson K, Wiecha J, Sobol AM, Dixit S, Fox MK, et al. Reducing obesity via a school-based interdisciplinary intervention among youth. Arch Pediatr Adolesc Med. 1999;153: 409–18.
20. Robinson TN. Reducing children’s television viewing to prevent obesity. A randomised controlled trial. JAMA. 1999;282(16):1561–7.
21. Campbell KJ, Hesketh KD. Strategies which aim to positively impact on weight, physical activity, diet and sedentary behaviours in children from zero to five years. A systematic review of the literature. Obes Rev. 2007;8(4):327–38.
22. DeMattia L, Lemont L, Meurer L. Do interventions to limit sedentary behaviors change behavior and reduce childhood obesity? A critical review of the literature. Obes Rev. 2006;8: 69–81.
23. Rey-Lopez JP, Vicente-Rodriguez G, Biosca M, Moreno LA. Sedentary behaviour and obesity development in children and adolescents. Nutr Metab Cardiovasc Dis. 2008;18(3):242–51.
24. Kamath CC, Vickers KS, Ehrlich A, McGovern L, Johnson J, Singhal V, et al. Clinical review: behavioral interventions to prevent childhood obesity: a systematic review and metaanalyses of randomized trials. J Clin Endocrinol Metab. 2008;93(12):4606–15.
25. Biddle SJH, Petrolini I, Pearson N. Interventions designed to reduce sedentary behaviours in young people: a review of reviews. Br J Sports Med. 2014;48:182–6.
26. dos Santos PC, Barbosa Filho VC, Aragoni da Silva J, da Silva BA, Minatto G, Samara da Silva K. What works in sedentary behavior interventions for youth: a review of reviews. Adolescent Res Rev. 2019;4:267–92.
27. Jones A, Armstrong B, Weaver RG, Parker H, von Klinggraeff L, Beets MW. Identifying effective intervention strategies to reduce children’s screen time: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2021;18(1):126.
28. Lewis L, Povey R, Rose S, Cowap L, Semper H, Carey A, et al. What behavior change techniques are associated with effective interventions to reduce screen time in 0–5 year olds? A narrative systematic review. Prev Med Rep. 2021;23:101429.

29. Downing KL, Hnatiuk JA, Hinkley T, Salmon J, Hesketh KD. Interventions to reduce sedentary behaviour in 0–5-year-olds: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 2018;52(5):314.
30. Rhodes RE, Guerrero MD, Vanderloo LM, Barbeau K, Birken CS, Chaput J-P, et al. Development of a consensus statement on the role of the family in the physical activity, sedentary, and sleep behaviours of children and youth. Int J Behav Nutr Phys Act. 2020;17(1):74.
31. dos Santos PC, Barbosa Filho VC, da Silva JA, Bandeira AS, Minatto G, da Silva KS. What works in sedentary behavior interventions for youth: a review of reviews. Adolescent Res Rev. 2019;4(3):267–92.
32. Parker K, Uddin R, Ridgers ND, Brown H, Veitch J, Salmon J, et al. The use of digital platforms for adults' and adolescents' physical activity during the COVID-19 pandemic (our life at home): survey study. J Med Internet Res. 2021;23(2):e23389.
33. Sanders T, Parker PD, del Pozo-Cruz B, Noetel M, Lonsdale C. Type of screen time moderates effects on outcomes in 4013 children: evidence from the longitudinal study of Australian children. Int J Behav Nutr Phys Act. 2019;16(1):117.
34. Kaye LK, Orben A, Ellis DA, Hunter SC, Houghton S. The conceptual and methodological mayhem of "Screen Time". Int J Environ Res Public Health. 2020;17(10)
35. Ludwig K, Arthur R, Sculthorpe N, Fountain H, Buchan DS. Text messaging interventions for improvement in physical activity and sedentary behavior in youth: systematic review. JMIR Mhealth Uhealth. 2018;6(9):e10799.
36. Lubans DR, Morgan PJ, Okely AD, Dewar D, Collins CE, Batterham M, et al. Preventing obesity among adolescent girls: one-year outcomes of the nutrition and enjoyable activity for teen girls (NEAT girls) cluster randomized controlled trial. Arch Pediatr Adolesc Med. 2012;166(9):821–7.
37. Schoeppe S, Alley S, Van Lippevelde W, Bray NA, Williams SL, Duncan MJ, et al. Efficacy of interventions that use apps to improve diet, physical activity and sedentary behaviour: a systematic review. Int J Behav Nutr Phys Act. 2016;13(1):127.
38. Nollen NL, Mayo MS, Carlson SE, Rapoff MA, Goggin KJ, Ellerbeck EF. Mobile technology for obesity prevention: a randomized pilot study in racial- and ethnic-minority girls. Am J Prev Med. 2014;46(4):404–8.
39. Schoeppe S, Alley S, Rebar AL, Hayman M, Bray NA, Van Lippevelde W, et al. Apps to improve diet, physical activity and sedentary behaviour in children and adolescents: a review of quality, features and behaviour change techniques. Int J Behav Nutr Phys Act. 2017;14(1):83.
40. Larouche R. Last child walking? Prevalence and trends in active transport. In: Larouche R, editor. Children's active transportation. Amsterdam: Elsevier; 2018. p. 53–75.
41. van der Ploeg HP, Merom D, Corpuz G, Bauman AE. Trends in Australian children traveling to school 1971–2003: burning petrol or carbohydrates? Prev Med. 2008;46:60–2.
42. UK Office for National Statistics. Social trends no. 40. Office for National Statistics. London: Pelgrave Macmillan; 2010.
43. Chillón P, Evenson KR, Vaughn A, Ward DS. A systematic review of interventions for promoting active transportation to school. Int J Behav Nutr Phys Act. 2011;8:10.
44. Jones RA, Blackburn NE, Woods C, Byrne M, van Nassau F, Tully MA. Interventions promoting active transport to school in children: a systematic review and meta-analysis. Prev Med. 2019;123:232–41.
45. Larouche R, Mammen G, Rowe DA, Faulkner G. Effectiveness of active school transport interventions: a systematic review and update. BMC Public Health. 2018;18:206.
46. Pang B, Kubacki K, Rundle-Thiele S. Promoting active travel to school: a systematic review (2010-2016). BMC Public Health. 2017;17(1):638.
47. Villa-González E, Barranco-Ruiz Y, Evenson KR, Chillón P. Systematic review of interventions for promoting active school transport. Prev Med. 2018;111:115–34.
48. Zaccari V, Dirkis H. Walking to school in inner Sydney. Health Promot J Austr. 2003;14:137–40.

49. Wen LM, Fry D, Merom D, Rissel C, Dirkis H, Balafas A. Increasing active travel to school: are we on the right track? A cluster randomised controlled trial from Sydney, Australia. Prev Med. 2008;47:612–8.
50. Buliung R, Faulkner G, Beesley T, Kennedy J. School travel planning: mobilizing school and community resources to encourage active school transportation. J Sch Health. 2011;81:704–12.
51. Xu F, Ware RS, Leslie E, Tse LA, Wang Z, Li J, et al. Effectiveness of a randomized controlled lifestyle intervention to prevent obesity among Chinese primary school students: CLICK-obesity study. PloS One. 2015;10:e0141421.
52. McKee R, Mutrie N, Crawford F, Green B, et al. Promoting walking to school: results of a quasi-experimental trial. J Epidemiol Community Health. 2007;61(9):818–23.
53. Villa-González E, Ruiz JR, Ward DS, Chillón P. Effectiveness of an active commuting school-based intervention at 6-month follow-up. Eur J Public Health. 2016;26:272–6.
54. Villa-González E, Ruiz JR, Mendoza JA, Chillón P. Effects of a school-based intervention on active commuting to school and health-related fitness. BMC Public Health. 2017;17:20.
55. Mendoza JA, Levinger DD, Johnston BD. Pilot evaluation of a walking school bus program in a low-income, urban community. BMC Public Health. 2009;9:122.
56. Bungum TJ, Clark S, Aguilar B. The effect of an active transport to school intervention at a suburban elementary school. Am J Health Educ. 2014;45:205–9.
57. Blackburn NE, Wilson JJ, McMullan II, Caserotti P, Giné-Garriga M, Wirth K, et al. The effectiveness and complexity of interventions targeting sedentary behaviour across the lifespan: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2020;17:53.
58. Minges KE, Chao AM, Irwin ML, Owen N, Park C, Whittemore R, et al. Classroom standing desks and sedentary behavior: a systematic review. Pediatrics. 2016;137(2):1–18.
59. Hinckson E, Salmon J, Benden M, Clemes SA, Sudholz B, Barber SE, et al. Standing classrooms: research and lessons learned from around the world. Sports Med. 2016;
60. Watson A, Timperio A, Brown H, Best K, Hesketh KD. Effect of classroom-based physical activity interventions on academic and physical activity outcomes: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2017;14:114.
61. McMichan L, Gibson A, Rowe DA. Classroom-based physical activity and sedentary behavior interventions in adolescents: a systematic review and meta-analysis. J Phys Act Health. 2018;15 (5):383–93.
62. Lander N, Koorts H, Mazzoli E, Moncrieff K, Salmon J. The feasibility and impact of embedding pedagogical strategies targeting physical activity within undergraduate teacher education: transform –Ed! Pilot Feasibility Stud. 2019;5:125.
63. Jones M, Defever E, Letsinger A, Steele J, Mackintosh KA. A mixed-studies systematic review and meta-analysis of school-based interventions to promote physical activity and/or reduce sedentary time in children. J Sport Health Sci. 2020;9(1):3–17.
64. Cassar S, Salmon J, Timperio A, Naylor P-J, van Nassau F, Contardo-Ayala AM, et al. Adoption, implementation and sustainability of school-based physical activity and sedentary behaviour interventions in real-world settings: a systematic review. Int J Behav Nutr Phys Act. 2019;16:120.
65. Koorts H, Maple JL, Eakin E, Lawrence M, Salmon J. Complexities and context of scaling up: a qualitative study of stakeholder perspectives of scaling physical activity and nutrition interventions in Australia. Front Public Health. 2022;10:771235
66. Glasgow RE, Green LW, Taylor MV, Stange KC. An evidence integration triangle for aligning science with policy and practice. Am J Prev Med. 2012;42:646–54.
67. Lane C, McCrabb S, Nathan N, Naylor PJ, Bauman A, Milat A, et al. How effective are physical activity interventions when they are scaled-up: a systematic review. Int J Behav Nutr Phys Act. 2021;18(1):16.
68. Singh AS, Chinapaw MJ, Brug J, van Mechelen W. Dutch obesity intervention in teenagers: effectiveness of a school-based program on body composition and behavior. Arch Pediatr Adolesc Med. 2009;163:309–17.

69. van Nassau F, Singh AS, Cerin E, Salmon J, van Mechelen W, Brug J, et al. The Dutch obesity intervention in teenagers (DOiT) cluster controlled implementation trial: intervention effects and mediators and moderators of adiposity and energy balance-related behaviours. Int J Behav Nutr Phys Act. 2014;11:158.
70. Salmon J, Ball K, Hume C, Booth M, Crawford D. Outcomes of a group randomised trial to prevent excess weight gain, reduce screen behaviours, and promote physical activity in 10-year-old children: switch-play. Int J Obes (Lond). 2008;32:601–12.
71. Salmon J, Jorna M, Hume C, Arundell L, Chahine N, Tienstra M, et al. A translational research intervention to reduce screen behaviors and promote physical activity among children: Switch-2-activity. Health Promot Int. 2011;26:311–21.
72. Milat AJ, Newson R, King L. Increasing the scale of population health interventions: a guide. Sydney: NSW Ministry of Health: Centre for Epidemiology and Evidence; 2014.
73. Koorts H, Cassar S, Salmon J, Lawrence M, Salmon P, Dorling H. Mechanisms of scaling up: combining a realist perspective and systems analysis to understand successfully scaled interventions. Int J Behav Nutr Phys Act. 2021;18(1):42.
74. McKay HA, Macdonald HM, Nettlefold L, Masse LC, Day M, Naylor PJ. Action Schools! BC implementation: from efficacy to effectiveness to scale-up. Br J Sports Med. 2015;49(4):210–8.
75. Tabak RG, Khoong EC, Chambers DA, Brownson RC. Bridging research and practice: models for dissemination and implementation research. Am J Prev Med. 2012;43(3):337–50.
76. Cassar S, Salmon J, Timperio A, Naylor P, van Nassau F, Contardo Ayala AM, et al. Adoption, implementation and sustainability of school-based physical activity and sedentary behaviour interventions in real-world settings: a systematic review. Int J Behav Nutr Phys Act. 2019;16(1):120.
77. Campbell K, Lioret S, McNaughton S, Crawford D, Salmon J, Ball K, et al. A parent-focused intervention to reduce infant obesity risk behaviors: a randomized trial. Pediatrics. 2013;131(4):652–60.
78. Li S, Treuth MS, Wang Y. How active are American adolescents and have they become less active? Obes Rev. 2010;11(12):847–62.
79. Arundell L, Parker K, Salmon J, Veitch J, Timperio A. Informing behaviour change: what sedentary behaviours do families perform at home and how can they be targeted? Int J Environ Res Public Health. 2019;16:4565.
80. LeBlanc AG, Chaput JP, McFarlane A, Colley RC, Thivel D, Biddle SJH, et al. Active video games and health indicators in children and youth: a systematic review. PloS One. 2013;8(6):e65351.
81. Larouche R, Sarmiento OL, Stewart T. Active transportation—is the school hiding the forest? In: Larouche R, editor. Children's active transportation. Amsterdam: Elsevier; 2018. p. 243–58.
82. Loh V, Sahlqvist S, Veitch J, Carver A, Contardo Ayala AM, Cole R, et al. Substituting passive for active travel—what is the potential among adolescents? Int J Sustain Transp. 2021;16:84–93.

Chapter 18
Workplace Programs Aimed at Limiting Occupational Sitting

Genevieve N. Healy, Samantha K. Stephens, and Ana D. Goode

Abstract On a typical working day, 50% of waking hours is spent working. This means that over the course of a lifetime, for most adults, a lot of time is spent at work. The workplace has been identified as a key setting for health promotion, with many of the influences on behaviour, including sedentary behaviour, able to be addressed within this setting. This chapter provides an overview on the workplace as a setting for addressing prolonged sitting time and programs that have addressed this behaviour. Specifically, this chapter summarises evidence on how much workers sit, outlines best practice approaches for addressing prolonged workplace sitting time, provides an overview of interventions that have targeted workplace sedentary time, and identifies key gaps and opportunities in the field. The terms workplace sitting, occupational sitting, and occupational sedentary behaviour will be used interchangeably throughout the chapter to mean sedentary time accrued while undertaking work.

What Is New?

- Updated evidence on effective approaches to reduce prolonged sitting time at work
- Consideration of the impact of workplace-delivered intervention on activity outside of work hours
- Acknowledgement of the impact of major work disruptors—such as the COVID-19 pandemic—on understanding and influencing behaviour during work time

G. N. Healy (✉)
School of Human Movement and Nutrition Sciences, The University of Queensland, St Lucia, Australia
e-mail: g.healy@uq.edu.au

S. K. Stephens · A. D. Goode
School of Public Health, The University of Queensland, Herston, Australia
e-mail: samantha.stephens@uq.edu.au; a.goode@sph.uq.edu.au

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_18

18.1 How Much Do Adults Sit at Work?

The workplace has a direct influence on the physical, economic, mental, and social well-being of workers and in turn the broader community [1]. Moreover, many of the influences on behaviour, including on sedentary behaviour, can be addressed within this setting [2, 3]. Given this, the workplace has been identified by the World Health Organization as a priority setting for health promotion [1]. Since the 1960s, there has been a considerable increase (>40% for many countries) in time spent sedentary [4, 5]. Here, increased computerisation and modernisation of work tasks has seen rapid changes in the activity profiles of workers, with the mean daily energy expenditure due to work-related activity estimated to have dropped by more than 100 calories in this time [6]. This is of particular importance as workplace sitting time is a large contributor to overall sedentary exposure, with one study reporting that 48.5% of total weekly sedentary time was accrued at the workplace [7].

Traditionally, occupational activity has been broadly classified by job role, or other relatively crude categorical measures [8]. This has limited our understanding of individual-level variations in workplace activity, and associated impacts on health [9–11] and work outcomes. Recent advances in measurement technology, including wearable devices, have strengthened understanding of time spent in different activities and postures, as well as when the activities are occurring [12–14]. Coupled with context-specific data (such as electronic diaries of work times), this has provided valuable insights into workers' activity both in and out of the workplace. This technology has also enabled understanding of the impacts of major work disrupters, such as the widespread shift to work from home resulting from the COVID-19 pandemic [15]. For more information regarding sedentary behaviour during the COVID-19 pandemic, please refer to Sect. 27.2.2.

Much of the activity-monitor evidence to date has been from desk-based workers. Using postural-based monitors, it has been observed that, on average, over two-thirds of the workday for desk-based workers is spent sitting, with the remainder of time primarily spent standing or in light-intensity activities [16]. However, there are large individual variations in levels. This is demonstrated in Fig. 18.1, which shows the percentage of worktime spent sitting, measured objectively using the activPAL activity monitor, in 496 participants (all desk-based workers) from four organisations who were participating in the Stand Up Australia program of research [17–20]. Although there is relatively little variation by organisation (overall mean 76%, standard deviation (SD) 10.6%), there are large individual differences with some individuals sitting less than 25% of their working day, and others sitting over 90%. Activity monitors have also provided insights into how work sitting time is accumulated, which is particularly important given the increasing evidence on the links between prolonged, unbroken sedentary time and poor cardio-metabolic [10, 21] and musculoskeletal health [22]. In desk-based workers, it has been observed that a considerable proportion of work sitting time (52%) is accrued in prolonged, unbroken bouts of at least 30 min [23]. As highlighted later in this chapter, this prolonged, unbroken sitting time is a key behaviour change target for

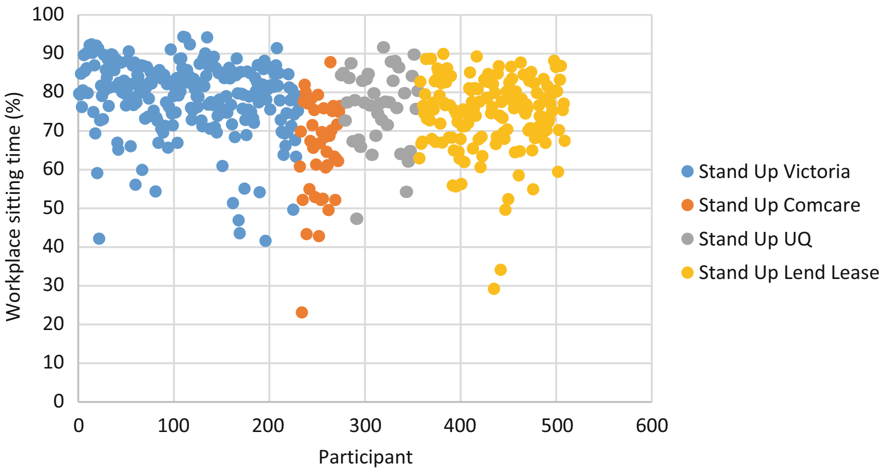

Fig. 18.1 Variations in total workplace sitting time (% of total worktime) in 496 participants from four organisations who participated in the Stand Up Australia program [17–20]

work-based interventions. However, similar to what was observed for total sitting time, there is large individual variability in this, as highlighted in Fig. 18.2. Here, on average, 50.5% (SD 19.2%) of work sitting time was accrued in prolonged, unbroken bouts of at least 30 min in the 496 participants. However, some participants accrued less than 10% of their work sitting time in this form, whereas for others, more than 85% of their work sitting was accrued this way. When considered across all working hours, 40% of work hours on average (SD 18%) were spent in sitting bouts 30 min or greater in this group of participants ($n = 496$).

Activity monitor data have also been used to compare sedentary time of various occupational categories. In 2019, a systematic review and meta-analyses looking at device-measured physical activity and sedentary time across work domains found that, on average, working adults spent approximately 60% of the workday (during and outside of work hours) sedentary and only 4% of the day in moderate-vigorous physical activity [16]. This review demonstrated that workers in occupations that largely involved sitting (e.g. desk-based office or call centre workers) engaged in the highest amount of sedentary time (72.5%) and the lowest amount of light-intensity physical activity (13.2%) at work compared to all other workers [16]. Conversely, occupations such as teachers, labourers, and health care workers had the lowest amount of sedentary time and tended towards higher step counts and higher levels of light-intensity activity [16]. In 191 blue-collar workers (including assembly workers, cleaners, construction workers, garbage collectors), the observed proportion of worktime spent sitting was 39.4% (SD 19.2%), with 7.0% (SD 9.3%) of total work accrued in bouts greater than 30 min [24]. In comparison, 65.3% (SD 11.8%) of leisure time was spent sedentary, with 31.9% (SD 15.3%) of this total time accrued in prolonged bouts [24]. Collectively, this evidence suggests that exposure to sedentary time is high across multiple occupations, including both

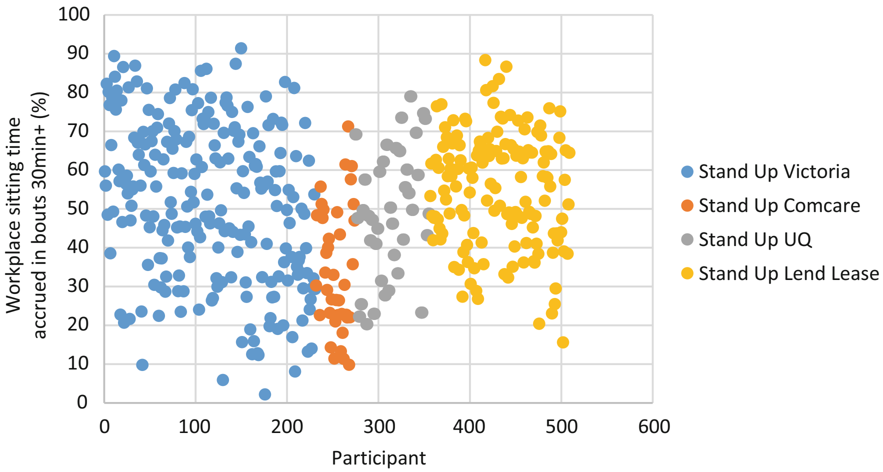

Fig. 18.2 Variations in prolonged workplace sitting time (% of total workplace sitting time) in the Stand Up Australia program [17–20]

traditional white- and blue-collar fields. Indeed, occupational sitting time has been identified as an emerging occupational health and safety hazard [25]. In response to the rapidly accruing evidence base and increasing public awareness on the health impacts of too much sitting, an expert statement was published in 2015 reviewing the evidence on occupational sitting and providing initial broad recommendations for employers and staff [26]. The recommendations highlight the importance of regular changes in posture, including the avoidance of prolonged standing as well as prolonged sitting [26]. They also set a specific initial target of 25% of the workday (2 h per 8-h workday) to be spent in standing and light ambulatory activity during working hours, with this progressing to 50% of the workday [26]. Of key importance to note is that the evidence informing these recommendations remains relatively preliminary, and further high-quality evidence is required.

18.2 Best Practice Approaches to Address Prolonged Workplace Sitting

The ultimate aim of a workplace sitting reduction program is for the dynamic workplace to become the norm, that is, for regular postural change to be a habitual, sub-conscious behaviour enabled by good workplace design, relevant organisational policies, high levels of knowledge, and a supportive organisational culture. To achieve this, interventions should be designed with consideration to successful buy-in, delivery, and sustainability. Achieving effective buy-in and implementation is likely to rely heavily on the perceived value of the intervention, the capacity to deliver the program (including resources and job demands), and situational/organisational factors—all of which can be changeable and non-static [27].

Program design factors to support buy-in, implementation, and sustainability include allowing flexibility to adapt the program to best suit organisational needs (including work for home), the context, and the level of organisational readiness for change [27]. For example, information seminars to raise awareness on the health impacts of too much sitting may be critical for workplaces which are in the early stages of readiness, whereas team coaching for championing change may be more appropriate for workplaces which already have high levels of awareness and strong leadership support that needs to be mobilised. The program should also have processes and mechanisms to be able to rapidly incorporate and implement new knowledge as the evidence base advances [28]. Examples to achieve this include through communication tools such as a web page, a scientific blog [29], and/or ongoing collaboration with researchers in the field [30].

Workplace health promotion models [31–33] provide an important framework for designing, implementing, and evaluating programs to address prolonged sitting in the workplace. The World Health Organizations' Healthy Workplace model details the five keys to healthy workplaces: leadership commitment and engagement, involving workers and their representatives, ensuring legal and ethical compliance, instilling a process of continuous improvement, and developing a plan for sustainability and integration [34]. Table 18.1 provides examples of how a sedentary behaviour intervention could address these five areas. Of note is that there are multiple influences on an employees' activity level at work in addition to individual-level factors such as fitness, fatigue, and age. These include job tasks, the physical environment, the social environment, and organisational norms and policies [2, 3]. Some influences are more modifiable than others, and some are likely to have a greater impact on activity than others. Any program targeting sustained changes in workplace sitting needs to acknowledge and address these multiple influences, taking into consideration that the key levers for change are likely to vary amongst organisations and individuals.

In addition to considering the effects of the intervention in the primary intervention setting (e.g. workplace), it is also important to understand how a workplace sitting reduction intervention may impact sitting and activity outside of work hours [36–39]. To date, there is limited evidence to support that either generalisation (e.g. workplace-delivered intervention leading to reductions in sitting during leisure time) or compensation (e.g. reducing workplace sitting leading to increased leisure time sitting or reduced levels of physical activity) occurs [36, 38], with most intervention effects from workplace-delivered interventions observed during work hours only [39]. This does have implications for programs that aim to influence behaviour across the whole day, with additional targeted behaviour change strategies likely to be needed for addressing non-work time [40].

Table 18.1 Examples of how a sedentary behaviour program can address the five keys to a health workplace as outlined by the World Health Organization (adapted from [34])

Keys to a health workplace	Possible application to a workplace program targeting reductions in sedentary behaviour
Key 1: Leadership commitment and engagement	• Present a business case for the introduction of a program to gain upper management support • Establish the resources available to be committed to the program (e.g. sit-stand desks, headphones to enable standing telephone calls) • Evaluate and, where appropriate, adapt current policies and practices to support the program (e.g. standing meetings, accessible stairwells) • Secure and formalise management and stakeholders' commitment to initiatives in writing and ensure staff are aware of support (e.g. via email/ internal memo/ newsletter from CEO) • Identify role models and spokespersons to advocate the program across multiple levels of the organisation
Key 2: Involve workers and their representatives	• Actively involve workers in all stages of the program including planning, delivery, and evaluation • Allow flexibility and tailoring to enable workers/employees to choose strategies most appropriate for their workplace/team • Explore perceived barriers and concerns of staff and facilitate problem solving and solution generation • Ensure representation across multiple levels (e.g. general staff, team leader, senior management) on program committees • Create both informal and formal opportunities for staff to share experiences and provide feedback on the program (e.g. monthly morning teas where staff can share successes and challenges)
Key 3: Business ethics and legality	• Educate on the potential benefits and harms of standing up, sitting less, and moving more. This includes raising awareness of the potential harms of static postures (either sitting or standing), and the importance of "listening to your body." Allow the broader community to participate in information and awareness raising seminars and workshops as appropriate • Allow flexibility in choice of working environments to facilitate regular postural transitions. This can include environmental support (e.g. sit-stand workstations) and/or allowing for unstructured (rather than structured) breaks. Follow available guidelines on the choice and use of

(continued)

Table 18.1 (continued)

Keys to a health workplace	Possible application to a workplace program targeting reductions in sedentary behaviour
	sit-stand workstations [35] • Recommend gradual changes to sitting time
Key 4: Use a systematic, comprehensive process to ensure effectiveness and continual improvement	• Regularly (at least annually) evaluate organisational policies and practices related to the program and employee knowledge and use of program strategies • Regularly evaluate the impact of the program on economic (e.g. productivity), health and well-being (e.g. stress), and social (e.g. collaborations) factors, as well as activity levels • Establish future goals for the program, including project action plans. Ensure that there is input from representatives across multiple levels within the organisation • Ensure program approaches are evidence-based. Consult industry experts in program design and evaluation as appropriate and enable mechanisms for the integration of new evidence • Provide publicly accessible reports on the impact of the program • Collaborate and consult with other workplaces to discuss how they are delivering and evaluating programs to address prolonged sitting
Key 5: Sustainability and integration	• Maintain and enhance knowledge through incorporating evidence-based findings into scheduled staff training (e.g. annual OHS training) and staff induction manuals • Integrate the program into organisation-wide health and well-being initiatives • Set program-specific targets as part of annual reviews • Review and modify the program to suit the level of organisational readiness and existing culture

18.3 Interventions Targeting Prolonged Sitting: What Has Been Tried?

Until recently, much of the research on occupational sitting has been from the ergonomic field, with a focus on reducing musculoskeletal symptoms through addressing time spent in prolonged, static postures including prolonged sitting [41]. The increased interest in the public health impacts of too much sitting has seen a surge in workplace interventions specifically examining the impact of interventions on behaviour-based outcomes, as well as indicators of health, well-being, and work performance. The aim of these interventions is to decrease sitting time, or specifically prolonged sitting time (i.e. through increasing regular breaks or interruptions in sitting). Strategies to achieve this aim have included raising awareness/knowledge, creating a supportive environment (both the physical and social environment), and/or building a supportive culture for change.

Although public health guidelines and recommendations are increasingly including specific recommendations regarding reducing and breaking up prolonged sedentary time [11, 21, 42, 43], the general awareness and knowledge of the health impacts of too much sitting is still likely to be lower than that regarding the benefits of regular participation in physical activity. Preliminary evidence suggests that providing information and tailored advice is acceptable and can result in behaviour change for some participants [44]. Prompts delivered via the computer [45, 46] or through the chair [47] can also be used to raise awareness, and have been shown to elicit reductions in prolonged, unbroken workplace sitting time [45, 47]. Wearable technologies [20] and smartphone applications [48] also offer potential for real-time behaviour prompts, and use as an intervention tool. Notably, interventions that target the individual should be undertaken with consideration to the multiple influences on behaviour, as highlighted above.

The physical environment can also have a strong impact on activity levels. Increasingly, workplaces are shifting toward "activity-permissive" or dynamic work environments that allow for more movement, more often. Features of these designs include visible, easily accessible, and appealing stairwells and amenities such as showers and bike storage racks [49]. Findings from natural experiments have shown that moving to these more activity-permissive buildings may have beneficial impacts on activity [50–53]. Notably, studies that have evaluated these moves have recommended that they be accompanied with education campaigns to increase awareness of the potential benefits of moving more and sitting less, as well as prompts (e.g. posters, computer prompts) [50, 51, 54]. Changes to the physical environment can also be made on a smaller scale, for example, centralising waste-paper baskets or providing access to stairwells. A descriptive study examining the prevalence of activity-supporting factors within the workplaces signing up to sit-less, move more intervention found almost all workplace had some room for improvement in terms of activity-supportive factors [55]. Importantly, however, many of these opportunities could be considered "easy-wins"—i.e. both modifiable and low or no cost [55].

One physical environment intervention rapidly gaining attention that is not low cost is the activity-permissive workstation: i.e. a workstation that enables the worker to sit, stand, walk, and/or pedal while at their usual computer and other desk-based job tasks. Several systematic reviews have now concluded activity-permissive workstations can significantly reduce sitting time [56–59]. For example, in the meta-analysis by Neuhaus and colleagues [56], the pooled effect size for the reduction in workplace sitting time following installation of an activity-permissive workstation was 77 min per 8-h workday. These reviews also suggest that overall, the impact of the interventions involving activity-permissive workstations on health outcomes is generally beneficial, with minimal [56, 58] or beneficial change to work performance [60]. Interventions involving sit-stand workstations have also been shown to be cost-effective [61–63].

Most interventions evaluating an activity-permissive workstation have examined the impact of sit-stand workstations: that is, workstations that allow the user to easily and quickly change between a sitting and standing posture. Designs can include full desk models (electronic or manual), as well as retrofitted models that sit on top of existing desks. The increasing affordability of these workstations (models are now available <$US300), accompanied by the increased media attention on the health impacts of too much sitting, has seen rapid uptake in their use. Organisations who have invested in sit-stand workstations perceive them to be effective in reducing discomforts and increasing employee productivity and satisfaction [64]. However, it is important to note that any potential benefits of sit-stand workstations are likely to be considerably greater when their installation is accompanied by strategies targeting other influences on sitting time (i.e. knowledge, organisational policies, and workplace norms). This was highlighted in an intervention study which compared changes in sitting time across three groups: one who received a multicomponent intervention incorporating strategies targeting influences at the organisational, environmental (including sit-stand workstations), and individual level; one who received the sit-stand workstations only; and a control group [18]. At 3 months, the multicomponent group had a nearly threefold greater reduction in workplace sitting time (−89 min/8-h workday) compared to the workstation only group (−33 min/8-h workday), with differences maintained at the 12-month assessment [18, 65]. It is important to ensure that choice and installation of an activity-permissive workstation is done with appropriate consideration to factors such as job design, existing office layout, privacy (e.g. noise, visibility), and equity. Guidelines are now available to support choice and use of sit-stand workstations [35, 66].

Although less tangible than the physical environment, creating a supportive social environment is likely to be key for program uptake and sustained change. Strategies for addressing the social environment include ensuring a participative approach, where employees are engaged in the changes, enlisting program champions to role model the strategies and promote the program, and demonstrated upper management support such as through participation in the program, and relevant modifications to policies and practices (e.g. modifying dress codes to support the wearing of more “activity-friendly” footwear).

Increased computerisation has meant that time spent in job tasks that required some activity (e.g. walking to the printer, filing papers) has substantially decreased [67]. Rather than postural changes occurring naturally through work tasks, it may be that additional support is needed to promote and maintain such changes. Unstructured breaks, which are chosen or planned by the individual, are preferable to structured breaks (e.g. set time for the breaks); structured breaks may interrupt work tasks, and do not allow for individual variability in posture preferences. Selecting strategies that are appropriate to the work environment and usual work tasks has been shown to be important, with the aim of creating multiple opportunities to stand and move throughout the day to achieve behavioural improvement [68]. Activity substitution is also commonly adopted as a strategy [17, 68], for example, walking to see a colleague rather than emailing or having standing or walking (rather than sitting) meetings [68]. In addition to potentially increasing levels of incidental activity [69], promotion and visible use of such strategies are likely to be an important component of generating and sustaining a dynamic workplace culture. Potential barriers to implementing these strategies [70–72] should be identified, and where possible, addressed.

A 2018 review compared the impact of these different strategies and approaches to addressing workplace sitting time, concluding that there was preliminary evidence that sit-stand desks can reduce sitting time at work, but the impacts of other interventions, including information and counselling, multicomponent interventions, and policy changes, were mostly inconsistent [59]. The review noted the low-quality evidence informing the field to date and highlighted the need for more high-quality cluster-randomised controlled trials testing the effect of different interventions on sitting time. Since the review, findings from two more high-quality cluster-randomised trials have been published [73, 74] in addition to the findings from the Stand Up Victoria trial [75], with all of these interventions demonstrating that a multicomponent intervention that included sit-stand workstations, along with education and organisation support elements, could achieve significant reductions in workplace sitting time at 1 year. Two of the trials have also published on the cost data, showing cost-effectiveness [61] and cost benefit [62]. All three interventions have now been adapted to enable more wide-scale implementation, with the adapted interventions currently being evaluated [40, 76, 77]. Excitingly, preliminary evidence suggests that significant reductions in workplace sitting can still be achieved with these scalable approaches [78], and that such approaches are feasible and acceptable for workplaces [78, 79].

18.4 Key Gaps and Opportunities for Workplace Programs Addressing Prolonged Sitting

The rapidly accruing evidence base and increasing public awareness of the health impacts of too much sitting have seen strong industry interest in addressing this issue. For example, the Global CMO network identified addressing prolonged sitting through the creation of dynamic workplaces as one of the key recommendations for sustainably improving workplace health [80], while Safe Work Australia identified excessive sedentary time as an emergent work health and safety issue [25]. However, a 2017 review found that there were no existing national and international occupational safety and health policies specifically relating to occupational sedentary behaviour [81]. There is an ideal opportunity to capitalise on this strong industry interest to generate practice-based evidence to address the several gaps that remain in this rapidly emerging field to help inform such policies. These gaps include:

- Obtaining more detailed understanding of the activity profiles of workers and how they vary across and within occupational sectors as well as across time and location (e.g. work from home, workplace) through the use of postural-based activity monitors

- Updating understanding of existing policies and practices regarding addressing prolonged sitting across various occupational sectors
- Rigorous, high-quality cluster-randomised controlled trial evidence on effectiveness, acceptability, and sustainability across a range of different intervention approaches, including those with low resource implications and those that support flexible working arrangements
- Understanding organisational and individual-level differences in how programs are taken up, implemented, and sustained to inform what works best and for whom
- Evidence on the impact of programs on a range of factors in addition to activity, including knowledge and awareness, organisational culture, policies and practice, health outcomes, and work outcomes to support the business case for uptake into practice
- Determination of the relative cost benefits of various strategies

Addressing these gaps is critical for building the business case for change and providing evidence on return on investment for workplaces for sitting reduction programs. There are several opportunities to achieve this. For example, the increasing availability, affordability, and sophistication of wearable monitors provide an opportunity to rapidly advance our understanding of activity profiles of individuals and how they vary within and across organisations. Wearable technologies also provide opportunities as an intervention and/or self-monitoring tool and could be utilised as an affordable adjunct to support intervention messages. Models such as the Dynamic Sustainability Framework [82], the Consolidated Framework of Implementation Research [83], and RE-AIM [84–87] provide a foundation to evaluate how interventions are translated into practice and adapted, implemented, and sustained over time to suit the context and the broader ecological system within which they exist. Use of such models will be integral for interpreting the success (or not) of programs to reduce prolonged sitting at work. As noted above, there are now evaluations underway that will provide practice-based evidence on the uptake, implementation, effectiveness, and costs of these programs when delivered at scale [40, 76, 77]. Finally, a multidisciplinary approach will be needed to maximise change. For example, physical activity researchers could work with architects and town planners to ensure building design codes enable active choices to be the easy choices [50, 88]. It will be critical that the messages to reduce prolonged sitting are consistent across these multiple stakeholders.

18.5 Summary

The workplace has been identified as a key setting in which to address prolonged sitting. Exposure to sitting is high across many occupational sectors, with sitting during work time a major contributor to daily sitting time. Intervention trials targeting prolonged sitting have achieved substantial reductions in sitting time, particularly when the individual physical environment supports regular postural changes such as through the provision of sit-stand workstations. However, several questions and evidence gaps remain to be addressed, including those regarding the sustainability of these changes and the ability of programs to adapt to major work disruptors such as what was seen during the COVID-19 pandemic. With the strong industry interest in this area, there are key opportunities to address the identified gaps, translate research into practice, and generate practice-based evidence. Utilising a multidisciplinary approach and incorporating a best practice framework will be critical for achieving sustainable success.

References

1. World Health Organization. Workplace Health Promotion: World Health Organization; 2016 [Available from: http://www.who.int/occupational_health/topics/workplace/en/.
2. Owen N, Salmon J, Koohsari MJ, Turrell G, Giles-Corti B. Sedentary behaviour and health: mapping environmental and social contexts to underpin chronic disease prevention. Br J Sports Med. 2014;48:174–7.
3. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. Am J Prev Med. 2011;41(2):189–96.
4. Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. Obes Rev. 2012;13(8):659–80.
5. Du Y, Liu B, Sun Y, Snetselaar LG, Wallace RB, Bao W. Trends in adherence to the physical activity guidelines for Americans for aerobic activity and time spent on sedentary behavior among US adults, 2007 to 2016. JAMA Netw Open. 2019;2(7):e197597.
6. Church TS, Thomas DM, Tudor-Locke C, Katzmarzyk PT, Earnest CP, Rodarte RQ, et al. Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. PLoS One. 2011;6(5):e19657.
7. Parry S, Straker L. The contribution of office work to sedentary behaviour associated risk. BMC Public Health. 2013;13:296.
8. Castillo-Retamal M, Hinckson EA. Measuring physical activity and sedentary behaviour at work: a review. Work. 2011;40(4):345–57.
9. van Uffelen JG, Wong J, Chau JY, van der Ploeg HP, Riphagen I, Gilson ND, et al. Occupational sitting and health risks: a systematic review. Am J Prev Med. 2010;39(4):379–88.
10. Saunders TJ, McIsaac T, Douillette K, Gaulton N, Hunter S, Rhodes RE, et al. Sedentary behaviour and health in adults: an overview of systematic reviews. Appl Physiol Nutr Metab 2020;45(10 Suppl 2):S197-S217.
11. Katzmarzyk PT, Powell KE, Jakicic JM, Troiano RP, Piercy K, Tennant B, et al. Sedentary behavior and health: update from the 2018 Physical Activity Guidelines Advisory Committee. Med Sci Sports Exerc. 2019;51(6):1227–41.
12. Matthews CE, Kozey Keadle S, Moore SC, Schoeller DS, Carroll RJ, Troiano RP, et al. Measurement of active and sedentary behavior in context of large epidemiologic studies. Med Sci Sports Exerc. 2018;50(2):266–76.
13. Sanders JP, Loveday A, Pearson N, Edwardson C, Yates T, Biddle SJ, et al. Devices for self-monitoring sedentary time or physical activity: a scoping review. J Med Internet Res. 2016;18 (5):e90.
14. Rosenberger ME, Fulton JE, Buman MP, Troiano RP, Grandner MA, Buchner DM, et al. The 24-hour activity cycle: a new paradigm for physical activity. Med Sci Sports Exerc. 2018;51 (3):454–64.

15. Hallman DM, Januario LB, Mathiassen SE, Heiden M, Svensson S, Bergstrom G. Working from home during the COVID-19 outbreak in Sweden: effects on 24-h time-use in office workers. BMC Public Health. 2021;21(1):528.
16. Prince SA, Elliott CG, Scott K, Visintini S, Reed JL. Device-measured physical activity, sedentary behaviour and cardiometabolic health and fitness across occupational groups: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2019;16(1):30.
17. Healy GN, Eakin EG, Lamontagne AD, Owen N, Winkler EA, Wiesner G, et al. Reducing sitting time in office workers: short-term efficacy of a multicomponent intervention. Prev Med. 2013;57(1):43–8.
18. Neuhaus M, Healy GN, Dunstan DW, Owen N, Eakin EG. Workplace sitting and height-adjustable workstations: a randomized controlled trial. Am J Prev Med. 2014;46(1):30–40.
19. Dunstan DW, Healy GN, Owen N, Eakin EG, Lamontagne AD, Moodie M. Reducing prolonged workplace sitting time in office workers: a cluster-randomised controlled trial. NHMRC. 2011–2013;
20. Brakenridge CL, Fjeldsoe BS, Young D, Winkler EAH, Dunstan DW, Straker LM, et al. Organisational-level strategies with or without an activity tracker to reduce office workers' sitting time: rationale and study design of a pilot cluster randomised controlled trial. JMIR Res Protoc. 2016;5(2):e17.
21. Ross R, Chaput JP, Giangregorio LM, Janssen I, Saunders TJ, Kho ME, et al. Canadian 24-hour movement guidelines for adults aged 18-64 years and adults aged 65 years or older: an integration of physical activity, sedentary behaviour, and sleep. Appl Physiol Nutr Metab. 2020;45(10 (Suppl 2)):S57–S102.
22. Baker R, Coenen P, Howie E, Williamson A, Straker L. The short term musculoskeletal and cognitive effects of prolonged sitting during office computer work. Int J Environ Res Public Health. 2018;15(8)
23. Ryan CG, Dall PM, Granat MH, Grant M. Sitting patterns at work: objective measurement of adherence to current recommendations. Ergonomics. 2011;54(6):531–8.
24. Hallman DM, Mathiassen SE, Gupta N, Korshoj M, Holtermann A. Differences between work and leisure in temporal patterns of objectively measured physical activity among blue-collar workers. BMC Public Health. 2015;15:976.
25. Straker L, Coenan P, Dunstan DW, Gilson N, Healy GN. Sedentary work—evidence an emergent work health and safety issue—final report. Canberra: Safe Work Australia; 2016.
26. Buckley JP, Hedge A, Yates T, Copeland RJ, Loosemore M, Hamer M, et al. The sedentary office: an expert statement on the growing case for change towards better health and productivity. Br J Sports Med. 2015;49(21):1357–62.
27. Weiner BJ. A theory of organizational readiness for change. Implement Sci. 2009;4:67.
28. Haines A, Kuruvilla S, Borchert M. Bridging the implementation gap between knowledge and action for health. Bull World Health Organ. 2004;82(10):724–31. discussion 32
29. BeUpstanding™. BeUpstanding™ Blog Brisbane QLD: The University of Queensland; 2021 [Available from: http://beupstanding.blog/].
30. Healy GN, Goode A, Schultz D, Lee D, Leahy B, Dunstan DW, et al. The BeUpstanding program: scaling up the stand up Australia workplace intervention for translation into practice. AIMS Public Health. 2016;3(2):341–7.
31. Department of Health and Human Services. Essential elements of effective workplace programs and policies for improving worker health and wellbeing. Atlanta, GA: Centers for Disease Control and Prevention & National Institute for Occupational Safety and Health; 2008 October. Report No.: Publication No. 2010-125 Contract No.: Publication No. 2010-125.
32. Carnethon M, Whitsel LP, Franklin BA, Kris-Etherton P, Milani R, Pratt CA, et al. Worksite wellness programs for cardiovascular disease prevention: a policy statement from the American Heart Association. Circulation. 2009;120(17):1725–41.
33. World Health Organization. Healthy workplaces: A model for action for employers, workers, policymakers and practitioners. Geneva: WHO; 2010 [www.public-health.uiowa.edu/hwce/

employer/healthy_workplaces_model-WHO.pdf (accessed 13 Aug 2012)]. Available from: www.public-health.uiowa.edu/hwce/employer/healthy_workplaces_model-WHO.pdf

34. World Health Organization. Healthy workplaces: a model for action for employers, workers, policymakers and practitioners Geneva: WHO; 2010 [http://www.who.int/occupational_health/healthy_workplaces/en/]. Available from: www.public-health.uiowa.edu/hwce/employer/healthy_workplaces_model-WHO.pdf
35. Queensland Government Workplace Health and Safety Electrical Safety Office Workers' Compensation Regulator. Guidelines for the selection and use of sit to stand computer workstations [Available from: https://www.worksafe.qld.gov.au/injury-prevention-safety/hazardous-manual-tasks/office-workstations/guidelines-for-the-selection-and-use-of-sit-to-stand-computer-workstations.
36. Mansoubi M, Pearson N, Biddle SJ, Clemes SA. Using sit-to-stand workstations in offices: is there a compensation effect? Med Sci Sports Exerc. 2016;48(4):720–5.
37. Larisch LM, Bojsen-Møller E, Nooijen CFJ, Blom V, Ekblom M, Ekblom Ö, et al. Effects of two randomized and controlled multi-component interventions focusing on 24-hour movement behavior among office workers: a compositional data analysis. Int J Environ Res Public Health. 2021;18(8)
38. Bort-Roig J, Chirveches-Pérez E, Giné-Garriga M, Navarro-Blasco L, Bausà-Peris R, Iturrioz-Rosell P, et al. An mHealth workplace-based "Sit Less, Move More" program: impact on employees' sedentary and physical activity patterns at work and away from work. Int J Environ Res Public Health. 2020;17(23)
39. Stephens SK, Winkler EAH, Eakin EG, Clark BK, Owen N, Moodie M, et al. Temporal features of sitting, standing and stepping changes in a cluster-randomised controlled trial of a workplace sitting-reduction intervention. Int J Behav Nutr Phys Act. 2019;16(1):111.
40. Edwardson CL, Biddle SJH, Clarke-Cornwell A, Clemes S, Davies MJ, Dunstan DW, et al. A three arm cluster randomised controlled trial to test the effectiveness and cost-effectiveness of the SMART Work & Life intervention for reducing daily sitting time in office workers: study protocol. BMC Public Health. 2018;18(1):1120.
41. Healy GN, Lawler SP, Thorp A, Neuhaus M, Robson EL, Owen N, et al. Reducing prolonged sitting in the workplace (an evidence review: full report). Available at: http://www.vichealth.vic.gov.au/Publications/Economic-participation/Creating_Healthy_Workplaces.aspx. Melbourne, Australia: Victorian Health Promotion Foundation; 2012.
42. Australian Government Department of Health. Australia's Physical Activity and Sedentary Behaviour Guidelines 2014 [Available from: http://www.health.gov.au/internet/main/publishing.nsf/Content/fs-18-64years. Accessed: 2017-11-05. (Archived by WebCite® at http://www.webcitation.org/6ulSxyR1d).
43. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54(24):1451–62.
44. De Cocker K, De Bourdeaudhuij I, Cardon G, Vandelanotte C. Theory-driven, web-based, computer-tailored advice to reduce and interrupt sitting at work: development, feasibility and acceptability testing among employees. BMC Public Health. 2015;15:959.
45. Evans RE, Fawole HO, Sheriff SA, Dall PM, Grant PM, Ryan CG. Point-of-choice prompts to reduce sitting time at work: a randomized trial. Am J Prev Med. 2012;43(3):293–7.
46. Swartz AM, Rote AE, Welch WA, Maeda H, Hart TL, Cho YI, et al. Prompts to disrupt sitting time and increase physical activity at work, 2011-2012. Prev Chronic Dis. 2014;11:E73.
47. Gilson ND, Ng N, Pavey TG, Ryde GC, Straker L, Brown WJ. Project energise: using participatory approaches and real time computer prompts to reduce occupational sitting and increase work time physical activity in office workers. J Sci Med Sport. 2016;19(11):926–30.
48. van Dantzig S, Geleijnse G, T. vHA. Toward a persuasive mobile application to reduce sedentary behavior. Pers Ubiquit Comput. 2013;17(6):1237–46.

49. Zimring C, Joseph A, Nicoll GL, Tsepas S. Influences of building design and site design on physical activity: research and intervention opportunities. Am J Prev Med. 2005;28(2 Suppl 2):186–93.
50. Jancey JM, McGann S, Creagh R, Blackford KD, Howat P, Tye M. Workplace building design and office-based workers' activity: a study of a natural experiment. Aust N Z J Public Health. 2016;40(1):78–82.
51. Gorman E, Ashe MC, Dunstan DW, Hanson HM, Madden K, Winkler EA, et al. Does an 'activity-permissive' workplace change office workers' sitting and activity time? PLoS One. 2013;8(10):e76723.
52. Jindo T, Kai Y, Kitano N, Wakaba K, Makishima M, Takeda K, et al. Impact of activity-based working and height-adjustable desks on physical activity, sedentary behavior, and space utilization among office workers: a natural experiment. Int J Environ Res Public Health. 2019;17(1)
53. Engelen L, Dhillon HM, Chau JY, Hespe D, Bauman AE. Do active design buildings change health behaviour and workplace perceptions? Occup Med (Lond). 2016;
54. Zhu W, Gutierrez M, Toledo MJ, Mullane S, Stella AP, Diemar R, et al. Long-term effects of sit-stand workstations on workplace sitting: a natural experiment. J Sci Med Sport. 2018;21 (8):811–6.
55. Hadgraft N, Winkler E, Goode A, Gunning L, Dunstan D, Owen N, et al. How supportive are workplace environments for sitting less and moving more? A descriptive study of Australian workplaces participating in the BeUpstanding program. Prev Med Rep. 2021;24:101616.
56. Neuhaus M, Eakin EG, Straker L, Owen N, Dunstan DW, Reid N, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. Obes Rev. 2014;15(10):822–38.
57. Tew GA, Posso MC, Arundel CE, McDaid CM. Systematic review: height-adjustable workstations to reduce sedentary behaviour in office-based workers. Occup Med (Lond). 2015;65 (5):357–66.
58. Torbeyns T, Bailey S, Bos I, Meeusen R. Active workstations to fight sedentary behaviour. Sports Med. 2014;44(9):1261–73.
59. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Pedisic Z. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2018;12:CD010912.
60. Peterman JE, Healy GN, Winkler EA, Moodie M, Eakin EG, Lawler SP, et al. A cluster randomized controlled trial to reduce office workers' sitting time: effect on productivity outcomes. Scand J Work Environ Health. 2019;45(5):483–92.
61. Gao L, Flego A, Dunstan DW, Winkler EA, Healy GN, Eakin EG, et al. Economic evaluation of a randomized controlled trial of an intervention to reduce office workers' sitting time: the "Stand Up Victoria" trial. Scand J Work Environ Health. 2018;44(5):503–11.
62. Munir F, Miller P, Biddle SJH, Davies MJ, Dunstan DW, Esliger DW, et al. A cost and cost-benefit analysis of the stand more AT work (SMArT work) intervention. Int J Environ Res Public Health. 2020;17(4)
63. Gao L, Nguyen P, Dunstan D, Moodie M. Are office-based workplace interventions designed to reduce sitting time cost-effective primary prevention measures for cardiovascular disease? A systematic review and modelled economic evaluation. Int J Environ Res Public Health. 2019;16 (5)
64. Zerguine H, Johnston V, Healy GN, Abbott A, Goode AD. Usage of sit-stand workstations: benefits and barriers from decision makers' perspective in Australia. Appl Ergon. 2021;94:103426.
65. Neuhaus M. Reducing office workers' sedentary time: The University of Queensland; 2015.
66. WorkSafe Queensland. Working with computers Brisbane QLD: Queensland Government; 2021 [Available from: https://www.worksafe.qld.gov.au/safety-and-prevention/hazards/hazardous-manual-tasks/working-with-computers.
67. Straker L, Mathiassen SE. Increased physical work loads in modern work—a necessity for better health and performance? Ergonomics. 2009;52(10):1215–25.

68. Stephens SK, Eakin EG, Clark BK, Winkler EAH, Owen N, LaMontagne AD, et al. What strategies do desk-based workers choose to reduce sitting time and how well do they work? Findings from a cluster randomised controlled trial. Int J Behav Nutr Phys Act. 2018;15(1):98.
69. Gilson ND, Puig-Ribera A, McKenna J, Brown WJ, Burton NW, Cooke CB. Do walking strategies to increase physical activity reduce reported sitting in workplaces: a randomized control trial. Int J Behav Nutr Phys Act. 2009;6:43.
70. De Cocker K, Veldeman C, De Bacquer D, Braeckman L, Owen N, Cardon G, et al. Acceptability and feasibility of potential intervention strategies for influencing sedentary time at work: focus group interviews in executives and employees. Int J Behav Nutr Phys Act. 2015;12:22.
71. Cole JA, Tully MA, Cupples ME. "They should stay at their desk until the work's done": a qualitative study examining perceptions of sedentary behaviour in a desk-based occupational setting. BMC Res Notes. 2015;8:683.
72. Wong JY, Gilson ND, Bush RA, Brown WJ. Patterns and perceptions of physical activity and sedentary time in male transport drivers working in regional Australia. Aust N Z J Public Health. 2014;38(4):314–20.
73. Edwardson CL, Yates T, Biddle SJH, Davies MJ, Dunstan DW, Esliger DW, et al. Effectiveness of the stand more AT (SMArT) work intervention: cluster randomised controlled trial. BMJ. 2018;363:k3870.
74. Pereira MA, Mullane SL, Toledo MJL, Larouche ML, Rydell SA, Vuong B, et al. Efficacy of the 'Stand and Move at Work' multicomponent workplace intervention to reduce sedentary time and improve cardiometabolic risk: a group randomized clinical trial. Int J Behav Nutr Phys Act. 2020;17(1):133.
75. Healy GN, Eakin EG, Owen N, LaMontagne AD, Moodie M, Winkler EA, et al. A cluster RCT to reduce office workers' sitting time: impact on activity outcomes. Med Sci Sports Exerc. 2016;48(9):1787–97.
76. Healy GN, Goode AD, Abbott A, Burzic J, Clark BK, Dunstan DW, et al. Supporting workers to sit less and move more through the web-based BeUpstanding program: protocol for a single-arm, repeated measures implementation study. JMIR Res Protoc. 2020;9(5):e15756.
77. Buman M, Pereira M, Martin M, Oakes M, Estabrooks P, Michaud T, et al. Stand & move at work II: effectiveness and implementation (1RO1CA250527-01A1). USA: National Institute of Health (NIH-USA); 2020–2025.
78. Healy GN, Winkler EAH, Goode AD. A RE-AIM evaluation in early adopters to iteratively improve the online BeUpstanding™ program supporting workers to sit less and move more. BMC Public Health. 2021;21(1):1916.
79. Goode AD, Hadgraft NT, Neuhaus M, Healy GN. Perceptions of an online 'train-the-champion' approach to increase workplace movement. Health Promot Int. 2019;34(6):1179–90.
80. Global Chief Medical Officer. Health: our business: Bupa; 2015 [Available from: https://www.bupa.com/corporate/our-purpose/workplaces/health-our-business.
81. Coenen P, Gilson N, Healy GN, Dunstan DW, Straker LM. A qualitative review of existing national and international occupational safety and health policies relating to occupational sedentary behaviour. Appl Ergon. 2017;60:320–33.
82. Chambers DA, Glasgow RE, Stange KC. The dynamic sustainability framework: addressing the paradox of sustainment amid ongoing change. Implement Sci. 2013;8:117.
83. Kirk MA, Kelley C, Yankey N, Birken SA, Abadie B, Damschroder L. A systematic review of the use of the consolidated framework for implementation research. Implement Sci. 2016;11:72.
84. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. Implement Sci. 2009;4:50.
85. Glasgow RE, Harden SM, Gaglio B, Rabin B, Smith ML, Porter GC, et al. RE-AIM planning and evaluation framework: adapting to new science and practice with a 20-year review. Front Public Health. 2019;7:64.

86. Rabin BA, McCreight M, Battaglia C, Ayele R, Burke RE, Hess PL, et al. Systematic, multimethod assessment of adaptations across four diverse health systems interventions. Front Public Health. 2018;6:102.
87. Glasgow RE, Vogt TM, Boles SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. Am J Public Health. 1999;89(9):1322–7.
88. McGann S, Jancey J, Tye M. Taking the stairs instead: the impact of workplace design standards on health promotion strategies. Australas Med J. 2013;6(1):23–8.

Chapter 19
Approaches to Decrease Sedentary Behaviour Among the Elderly

Ann M. Swartz and Whitney A. Welch

Abstract The elderly are one of the most sedentary segments of the population and they have the highest rates of chronic acquired disease and disability. Research suggests a positive association between time spent being sedentary and ill health, poor physical function, and a diminished quality of life. Therefore, there is a significant need to understand how to decrease the amount of sedentary behaviour in which an elderly individual engages. To date, a relatively small number of studies have attempted to reduce sedentary time in the elderly, with the majority focusing on reducing sedentary time, while others focus on increasing physical activity or changing both sedentary and physical activity behaviour. Within these interventions, there are a variety of different study designs applied to decrease or disrupt sedentary behaviour. Additionally, variation in methodology such as tools used to measure sedentary behaviour, the theoretical grounding of the interventions, and the interventional structures are apparent. Study results have been mixed, with some studies showing that sedentary behaviour can change, while others show no change in time spent sedentary. Successful interventions have demonstrated decreases in sedentary behaviours to be about 30–60 min, or about 3–6% of the waking day. Changes in sedentary behaviour can happen rapidly, but it remains unclear whether these behaviour changes can be sustained beyond the reported intervention length. As we continue to study best practices to decrease sedentary time in older adults, studies should focus on determining which intervention attributes are the most effective and which will produce long-term change.

A. M. Swartz (✉)
University of Wisconsin-Milwaukee, Milwaukee, WI, USA
e-mail: aswartz@uwm.edu

W. A. Welch
Medical College of Wisconsin, Milwaukee, WI, USA
e-mail: wmorelli@mcw.edu

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_19

What Is New?

- The number of interventions that aim to reduce sedentary behaviour in the elderly has more than doubled since the last version of this book.
- More high-quality study designs were employed to evaluate interventions to decrease or disrupt sedentary time.
- The literature that examined the impact of reductions in sedentary behaviour on health variables shifted in focus from cardiometabolic markers to functional and quality of life indicators.
- The interventions that focused on changing sedentary behaviour showed more substantial changes in behaviour than previous studies.

19.1 Introduction

Our waking hours are spent in both sedentary and active behaviours such as walking, sitting, eating, socialising with friends, or engaging in household or caregiving tasks. We are either active or sedentary depending on what we need to accomplish, what constraints we have on our time, the habits we have formed, the people we surround ourselves with, the environment we live in, and the policies and infrastructure of our community. Elderly adults are a unique segment of our population. A large majority of the elderly population are retired, and therefore have lower levels of occupational physical activity and occupational sitting and have more choice in how to spend their time. Having control over their full daily schedule allows elderly adults to make choices to be active, or to be sedentary. Now that they have the time, they may choose to spend the day playing 18 holes of golf, or kayaking in a lake, finish reading the book that they started earlier that week, watch a television program, or start a hobby they have always wanted to try but never had the time. The environment they live in, and in particular their residence, also plays a large role in their decision to be active or sedentary by providing opportunities to be active or encourages one into sedentary pursuits. The elderly have developed habits over their lifetime that have evolved out of necessity, or from their experiences in their country, city/town/village, and home with their family, friends, and acquaintances. This lifetime of experience paired with knowledge, habits, and current life situation has cultivated into their current lifestyle behaviours and determine how they interact with the world on a regular basis.

On average, elderly adults spend approximately 60–70% of their waking day (approximately 15 h) in sedentary pursuits such as watching television, reading, and working on the computer [1]. This means that elderly adults are moving for only about 6 h per day and remaining idle for the other (approximately) 9 h of the day that they are awake [1]. It is important to remember that these data provide a time allocation picture for the average elderly individual. When looking at distributions of sitting time from meta-prevalence data showing that about 60% of elderly adults sit for 4 h or more, 27% sit for 6 h or more, and 5% sit for more than 10 h/day [2], we are reminded that some will remain sedentary for more than 9 h, and some will move more than 6 h per day. Additionally, it is important to note that sedentary behaviour has been shown to increase with age, increasing by approximately 5% each year after age 65 [3]. For more information regarding the prevalence of sedentary behaviour in elderly adults, please refer to Sect. 2.2.

As has been shown in this book, higher levels of sedentary behaviour are associated with higher rates of chronic acquired diseases, poorer physical functioning, and higher rates of disability which can lead to an inability to complete activities of daily living and instrumental activities of daily living [4–6]. These negative health complications that result from too much sedentary behaviour appear to be independent of health enhancing physical activity, in the adult [4, 7–11] and elderly adult population [6].

Because of the large amount of time spent being sedentary and the potential for negative health consequences, scientists, health care providers, and public health officials have begun to intervene on the amount of time that elderly adults spend in sedentary pursuits. However, work in this area has just begun and there is much to learn. This chapter aims to review the current knowledge focusing on approaches to reduce sedentary behaviour among the elderly. Specifically, this chapter details the characteristics of interventions that aim to reduce sedentary behaviour as well as interventions that aim to increase physical activity, but also assess the impact on sedentary behaviour.

19.2 Interventions to Reduce Sedentary Behaviour in Elderly Adults

Despite the large portion of the day that the elderly spend in sedentary behaviour and the ill effects of sitting that have been documented, there are relatively few interventions that aim to reduce sedentary behaviour in this segment of the population. Within these interventions, there were similarities in design of the study as well as primary outcome of the study. However, variation in methodology such as measurement tools used to assess sedentary behaviour, theoretical grounding of the interventions, and interventional structure is also present. Considering the disparities in intervention characteristics, it is encouraging; to date, interventions to reduce sedentary behaviour have been successful.

19.2.1 Design of Studies to Reduce Sedentary Behaviour

Early interventions which focused on changing sedentary behaviour were largely pre-post experimental designs [12–18], assessing within subject change over time in response to the intervention. More recent studies have employed stronger research designs including randomised-controlled studies [12, 19–23] and randomised comparison trials [24–28], allowing more robust conclusions to be drawn regarding the effectiveness of the intervention. In addition, because this area of inquiry is relatively new, there are a large number of studies designed to determine the feasibility of an intervention to reduce sedentary behaviour [13–18, 20, 27–29], which is an important first step in interventional research before applying the intervention to a larger group. As the field continues to evolve, more studies have been completed which specifically aim to reduce sedentary behaviour in the elderly, rather than examining sedentary behaviour as a secondary outcome to physical activity or another health-focused variable. However, only one study has included a follow-up period (4 weeks) to examine whether changes in sedentary behaviour are sustained over time [17]. As this area of inquiry continues to develop, it is important for scientists to continue to use high-quality study designs and to examine whether changes in sedentary behaviour are maintained after the intervention is completed, allowing for robust findings that will inform clinical and public health practice.

The majority of published interventions aimed at reducing sedentary behaviour have included sample sizes of less than 75 individuals, with one study including 75–100 participants [21], five including 50–75 participants [16, 19, 23, 30, 31], eight studies including 26–50 participants [12, 20, 22, 24, 25, 28, 29, 32], and six including 25 or fewer participants [14, 15, 17, 18, 26, 27]. The majority of studies included samples with a mean age of 65 years or older [12–15, 17–30], while a few studies reported a mean age between 55 and 64 years [16, 32]. A preponderance of studies included a majority (>70%) of females, ranging from 70% to 100% of the participant sample [13, 15–19, 21, 22, 24–26, 28, 30], with the other studies having approximately half the sample being female [12, 14, 20, 27, 29, 32]. Few studies (25% of those included here) explicitly recruited sedentary individuals [13, 15, 19, 22, 23]. Finally, the majority of studies recruited community-dwelling participants with only four studies recruiting from continuing care retirement communities [30], care home/nursing home [20], independent living [18], and sheltered housing [26]. Diversity in intervention location such as housing status (community-dwelling vs continuing care retirement communities) naturally introduces important differences when addressing elderly health and lifestyle behaviour change such as access to safe spaces to reduce sedentary behaviours. Further, individuals living in continuing care retirement communities may have higher rates of frailty or lower mobility status. Studies have begun to explore interventions to reduce or disrupt sedentary time in individuals that are frail or lower functioning; however, more work needs to be done. Therefore, interpretation of the results of these studies must take into account the participant characteristics. Future studies should screen for time spent in sedentary behaviour to ensure that those in need of a reduction in sedentary behaviour are the recipients of the interventions. Additionally, there is little data examining the effect of interventions to reduce or disrupt sedentary time in males and individuals that live in continuing care retirement communities.

19.2.2 Methodologies Utilised to Assess Sedentary Behaviour Intervention Response

Sedentary behaviour can be a difficult behaviour to measure, because individuals do not choose to be sedentary for the purpose of being sedentary; it is usually performed for another reason: enjoyment of watching their favourite television show, rest and rejuvenation, or sitting to visit with friends. In addition, it is crucial to consider which component of sedentary behaviour is of greatest interest when developing a sedentary behaviour reduction intervention. There are four common components of sedentary behaviour that can be measured: total time spent sedentary, the type of sedentary behaviour (e.g. watching television), the frequency of breaking time spent sedentary, and the duration of each bout of sedentary time. Therefore, the tool used to assess sedentary behaviour and changes in sedentary behaviour as a response to intervention is important.

In the studies that intervened to reduce sedentary behaviour in the elderly, a variety of subjective and objective assessments were employed, with more recent studies favouring the use of objective tools. Objective tools used to measure sedentary behaviour included the ActiGraph accelerometer [13, 15, 22, 27] and the activPAL inclinometer/accelerometer [14, 15, 20, 23, 26, 29, 30, 32], a combination of activPAL and ActiGraph [17, 19], GENEActive accelerometer [24, 25], Accusplit pedometer and Jawbone UP [18], and the Omron accelerometer [21]. The measurement device is an important consideration when evaluating the results of studies. Given the accepted definition of sedentary behaviour includes an energy expenditure component and a postural component [33], it is important to note that only the activPAL inclinometer/accelerometer provides a measure of posture, and all devices provide a surrogate measure of energy expenditure through acceleration. These measures are best at capturing data related to total time spent sedentary, frequency of breaking sedentary time, and the duration of each sedentary bout.

Subjective tools also varied, with the most used questionnaire being the Measure of Older Adults' Sedentary Time [16, 19, 27, 28]. Other subjective tools included the Sedentary Behavior Questionnaire [14], the International Physical Activity Questionnaire (IPAQ) [12, 15], and a diary often paired with an objective device [12, 20, 29]. Given variation in the validity of the objective and subjective sedentary behaviour assessment methods (see Chap. 3), comparisons of intervention responsiveness and efficacy become difficult and warrant consideration. These measures are best suited when the type of sedentary activity is of interest.

19.2.3 Theories Employed in Sedentary Behaviour Interventions

Most current interventions designed to disrupt sedentary behaviour have been guided by theories developed to change behaviours. The social cognitive [13, 15, 16, 18, 19, 23, 28, 30] theory was the most widely used. Behavioural choice [13, 15], theories of problem solving, theory of planned behavior [18], self-regulation [17, 19], trans-theoretical model [26], empowerment theory [12], habit formation [23], the social-ecological model [14, 23], behavioral intervention technology model [29, 32], and the dual-process model of behaviour change [28] have also been applied. A number of studies employed multiple behaviour change theories. For instance, King et al. applied social cognitive theory and self-regulatory principles of behaviour change, social influence theory, operant conditioning principles, and emotional transference within a technology platform [16]. Hergenroeder et al. applied both social cognitive theory and the theory of planned behaviour to change sedentary behaviour [18]. Many behaviour change techniques were used including self-monitoring [29, 32], health coaching [30], action panning [19, 30], goal setting [19, 30], in addition to targeting behaviour change processes including motivation, and social influences [30]. With the increased use of technology as a mode of intervention delivery, theories specific to the dynamic nature of technology are appropriate. Compernolle et al. employed the behavioural intervention technology theory (BIT) to guide their technology-supported intervention [29, 32]. Changing sedentary behaviour presents a unique challenge when it comes to theories to guide behaviour change compared to changing physical activity, in that the primary goal is to reduce or take away a "bad" behaviour versus adding in a "good" behaviour as with physical activity. Because the number of factors that shape behaviour and interplay of these factors is so complex, determining the best theory or theories to change sedentary behaviour is still a work in progress [31].

19.2.4 Characteristics of Sedentary Behavioural Interventions

In addition to similarities and differences in methodology and theories employed, there are also similarities and differences in the intervention characteristics. In 2011, Owen and his colleagues outlined a conceptual model to understand the determinants of sedentary behaviour and proposed factors to consider when developing interventions to reduce sedentary behaviour based on the ecological model of sedentary behaviour [34]. This model proposes five domains that influence sedentary behaviour: intrapersonal, perceived environment, sedentary behaviour domains, behaviour settings: access and characteristics, and policy environment. Of the five domains outlined, published interventions to reduce sedentary behaviour among the elderly target four of the five domains: (1) intrapersonal, (2) perceived environment, (3) sedentary behaviour domains, and (4) access and characteristics of behavioural settings. As is typical in physical activity interventions, these interventions largely, but not exclusively, focused on individual level attributes and aspects that are in our consciousness that determine behaviour. Few focused on autonomic behaviours and environmental factors.

The majority of interventions (84%) aimed at reducing sedentary behaviour targeted individual level attributes including awareness of time spent sedentary, goal setting, planning, identifying barriers to reducing sedentary behaviours, self-monitoring, and feedback [12, 14, 15, 17–25, 28–32]. Further, these studies included educational materials to increase participants' knowledge of the benefits of reducing sedentary time [9, 14, 17–23, 26, 28–30, 32, 35, 36]. These interventions varied in length from 1 week to 1 year with seven lasting 12 weeks or longer and nine lasting 8 weeks or less. Twelve weeks was the most common length of intervention ($n = 5$).

Forty-two per cent of the interventions targeted relevant contextual factors that may influence sedentary time such as environmental or social factors. Four of the five interventions included real-time feedback to participants in addition to self-monitoring of sedentary time [18, 26, 29, 32]. Three studies targeted an environmental factor to change sedentary behaviour [15, 23, 27] and one used an external prompt/sign to promote behaviour change [30]. Five studies targeted social factors that may influence sedentary behaviour such as incorporating peer discussions, including family into the intervention delivery, and targeting social influences within the intervention design [17, 19, 20, 28, 30]. All of these studies focused on both individual level factors and environmental or social, with the exception of Lerma et al. which only focused on an environmental intervention [27]. These interventions varied in length from 2 weeks to 12 weeks, with five interventions lasting 12 weeks.

Only one study that focused on reducing sedentary behaviours in older adults targeted a specific domain of sedentary behaviour. Lerma and his colleagues conducted a one-week feasibility trial in which they intervened during leisure time television viewing by placing a pedal device in their home that would turn sedentary television viewing into an active behaviour [27]. All other studies focused on total daily sedentary behaviour. Four of these studies focused only on breaking up prolonged sedentary time [18, 26, 29, 32], while nine focused on reducing total sedentary time [12, 14, 17, 19–23, 28] and three studies focused on reducing sedentary time and breaking up prolonged bouts of sedentary behaviour [15, 30, 31].

Most studies had in-person interaction; some included follow-up phone calls either to check in or to provide a coaching session [17–24, 26–29, 32]. No interventions were delivered in a virtual format.

Of note, in addition to evaluating changes in sedentary behaviour, a number of studies examined the impact of changing sedentary behaviour on health-related outcomes. A few studies evaluated the effects of changes in sedentary behaviours on physical function [19, 23, 25], health-related quality of life [19, 23], pain [19], psychological parameters [12], and muscle attributes [24]. Most studies show improvement in physical function and health-related quality of life. These improvements were seen in some studies even without a significant decrease in sedentary time, but with greater frequency of breaks in sedentary time, suggesting that the act of the sit-to-stand and stand-to-sit transitions may be beneficial for function and quality of life, particularly in those individuals who are deconditioned.

Overall, the majority of studies that focus on reducing sedentary behaviour intervene on the individual and either environmental or social influences on behaviour. Studies tended to focus on changing total daily sedentary behaviour, rather than focusing on just one domain of sedentary behaviour. There was large variation in intervention structure, length of the intervention, and goals for reducing sedentary behaviour. In-person participant contact either with other participants or study staff was the preferred mode of delivery instead of virtual or remote delivery.

19.2.5 Effectiveness of Interventions to Reduce Sedentary Behaviour

Despite the variations in study methodology, length of the intervention, theory employed, and interventional structure and tools, results show promise that sedentary behaviour can be reduced in this population sub-group. On average, it appears that reductions in sedentary behaviour vary ranging from no change in total time spent in sedentary behaviour [18, 26, 29, 32] to reductions in sedentary behaviour of about 30–65 min or approximately 3–6% of the waking day. Of course the data is variable, but these results are seen after short-term and longer duration interventions and using subjective and device-based methods of assessing sedentary behaviour. Interventions lasting one to 8 weeks showed reductions in objectively measured sedentary behaviour ranging from 24 to 68 min per day [14, 15, 17, 19, 24, 25, 31]. Fitzsimons [14] demonstrated a significant decrease in activPal-assessed sitting or lying time by 24 min/d or 2.2% of the waking day after a 7-day intervention. Similarly, Rosenberg et al. [15] showed a decrease in activPAL-assessed sedentary behaviour by 27 min/day (−3% of waking day) after an 8 week intervention. Gardiner et al. [13] showed a decrease in accelerometer measured sedentary behaviour by 3.7% of the waking day which equated to a reduction in sedentary behaviour by approximately 40 min. Koltyn et al. and Crombie et al. showed a decrease in accelerometer measured sedentary behaviour of 65–68 min per day as well as decreases in prolonged sitting [17, 19]. Interventions lasting 12 weeks or longer showed decreases in sedentary time ranging from 30 min [22], 48 min [20], and 78 min [30] to 2.2% of the day (~21 min if awake for 16 h) [21]. In addition to total daily sedentary time, a few studies also assessed changes to bouts of prolonged sedentary behaviour, showing a reduction in time spent in prolonged sedentary bouts [18, 26]. However, not all studies successfully changed the number of breaks during prolonged sedentary behaviour [22].

Sedentary behaviour changes measured by questionnaire varied substantially, with King et al. reporting a decrease in television viewing (assessed by MOST) of 29 min per day after an 8-week intervention [16]. Chang et al. reported a much larger decrease in IPAQ sitting time of 76 min/day after an 8-week intervention [12]. Finally, Maher et al. reported reductions in self-reported sedentary behaviour of 838 min per week or about 2 h per day [28]. This larger decrease in sedentary time could be due to the tool used to assess sedentary behaviour, the focus of the intervention, or the behaviour change theory applied.

Because waking hours are filled either with either sedentary pursuits or active behaviours, when sedentary behaviour is decreased, it must be replaced with activity of some kind. As a result of the reductions in sedentary behaviour, some studies show increases primarily in light-intensity physical activity [15, 19], moderate-to-vigorous-intensity physical activity only [12, 25, 31], or both light-and moderate-to-vigorous-intensity physical activity, stepping [20, 21], or stepping and standing [14, 16, 30]. Not all changes in sedentary behaviour were met with changes in activity, possibly due to the measurement tool used, and some studies did not measure or report physical activity [22, 23, 26, 28]. While the focus of these interventions was on strategies and tools to assist participants to reduce sedentary behaviour, these substituted behaviours were a positive by-product of changing sedentary behaviour. It should be noted, however, that the intervention applied by Lerma et al. provided each participant with directions on how much sedentary time to replace with seated pedalling (15, 30, 45 or 60 min) [27]. Participants adhered to the intervention and exceeded their goals for pedalling.

Taken together, it appears that changes in sedentary time in the order of 30–60 min can be expected from interventions that aim to reduce sedentary behaviour among the elderly. Whether this change in sedentary time is sufficient to impact health, function, and quality of life in this population, and whether this change in sedentary behaviour can be sustained long-term, remains to be determined.

19.3 Interventions that Focus on Changing Physical Activity Level, but also Reduce Sedentary Behaviour

19.3.1 Design of Studies to Change Physical Activity Level that also Impacts Sedentary Behaviour

In addition to studies that aim to change sedentary behaviour, there are a handful of studies that aim to change physical activity behaviours by (1) increasing physical activity behaviour [35, 37–42], (2) changing both physical activity and sedentary behaviour [43], (3) examining the feasibility of a physical activity intervention [36, 44], (4) changing both physical activity and nutrition behaviours [45], or (5) improving cardiometabolic risk [46]. In addition to assessing their primary aim, these studies also measure the interventional impact on sedentary behaviour. The majority of these studies have used a randomised control trial study design to assess their primary question [35, 37, 39, 40, 42–46], while some applied randomised comparison trials [36, 38, 41]. The intervention length varied, ranging from 8 weeks [38], 12 weeks [36, 37, 40, 44], 16 weeks [41, 42] 24 weeks [43], and 6 months [35, 45, 46] to 1 year [39]. Most studies included participants with a mean age in the 60 s [36, 37, 40, 41, 43, 45, 46] or 70 s [38, 42, 44] and one with the mean age in the 80 s [35]. Two studies included overweight or obese elderly adults with type 2 diabetes [37, 43], and one included elderly individuals living in a nursing home or care facility [35]. Most studies screened for activity level, only including those who are inactive [36, 38–42, 44–46].

19.3.2 Methodologies Utilised to Assess Sedentary Behaviour Intervention Response in Physical Activity Studies

Similar to the interventions specifically designed to alter sedentary behaviour, interventions in this area have also employed a wide variety of assessment tools. Objective tools used to measure both physical activity and sedentary behaviour simultaneously included the ActiGraph accelerometer [37, 39, 43], the activPAL inclinometer/accelerometer [44], both the ActiGraph accelerometer and acitvPAL inclinometer/accelerometer [42], an ActiGraph accelerometer and a Fitbit Zip [38], the SenseWear Armband [36, 41], or the PAM AM 300 [40]. Subjective assessment tools used to provide measures of sedentary behaviour include the IPAQ [45, 46], the Longitudinal Aging study Amsterdam questionnaire [35], and the Cardia Sedentary Behavior Questionnaire [36]. Therefore, due to the variety of both objective and subjective tools employed, direct comparisons of changes in sedentary behaviour become more difficult.

19.3.3 Theories Employed in Physical Activity Interventions that also Impact Sedentary Behaviour

The interventions employed a variety of theories to change physical activity behaviour or physical activity and sedentary behaviours, employing some of the same theories used in those studies with the primary aim of changing sedentary behaviour. Theories included the cognitive behavioural theory [37, 43], social cognitive theory [42, 44, 45], and the behaviour change wheel [40]. Four studies also included motivational interviewing [36, 37, 43, 46] as part of their intervention package to change physical activity behaviour. Other behaviour change techniques used included addressing issues around problem solving and goal setting [36]. Four studies did not explicitly state the theory applied [35, 38, 39, 41]. Overall, despite the fact that changing sedentary behaviour requires elimination of a negative behaviour and changing physical activity behaviour requires adding a positive behaviour, these results suggest that theories applied to change physical activity behaviours may be transferable to change sedentary behaviour. There remains a paucity of research to explore the effect of making environmental changes to change active and sedentary behaviours in the elderly. Finally, when considering behavioural intervention designed to change multiple behaviours, it is important to explore the impact of simultaneous changes of multiple behaviours or enlist a sequential approach to target each behaviour individually [47].

19.3.4 Characteristics of Interventions

All the interventions that focused on physical activity or exercise targeted individual level attributes such as self-efficacy, goal setting, feedback, and exercise [16, 35–46]. Further, six of 13 studies provided a specific exercise prescription to the participants within the study [35, 38, 39, 41, 45, 46]. These interventions varied in length from 8 weeks to 12 months, with 6 months being the most common length of intervention ($n = 4$).

Three interventions targeted relevant contextual factors that may influence behaviour change including social support and social influence in addition to targeting individual level factors [16, 37, 43]. These studies ranged in length from eight to 24 weeks. No studies targeted environmental factors to change behaviour. Two interventions targeted proximal social factors to change behaviour including walking groups or dance lessons in addition to targeting the individual level factors [42, 44]. These studies ranged in length from 12 to 16 weeks.

Most studies had in-person interaction, with some interventions focused on one-on-one individual level contact [36, 38, 40, 43–46] and some included group sessions [37, 42, 46]. Only one intervention included follow-up phone calls or emails either to check in or to provide a coaching session [45]. There was one intervention which was delivered remotely through a Smartphone App [16].

In addition to a focus on changing physical activity behaviour, a number of studies examined how these interventions would impact not only sedentary behaviour but also health-related outcomes. Studies evaluated the effects of physical activity interventions on cardiometabolic risk factors [37, 38, 40, 46], physical function [38], cardiorespiratory fitness [42], or constipation [35]. Positive effects on cardiorespiratory fitness [42], body composition, and cardiometabolic risk factors [38, 46] were seen in the intervention groups. However, due to changes in both physical activity and sedentary behaviour, the effect of sedentary behaviour alone on these health-related variables cannot be determined.

Overall, the studies that focused on increasing physical activity or exercise behaviours primarily intervened on the individual level, while few introduced additional components to intervene on other relevant contextual or proximal social factors. Similar to the sedentary-focused interventions, studies assessed the change in total daily sedentary behaviour and did not focus on any one domain of sedentary behaviour and only a few studies reported giving explicit instructions to change sedentary behaviour. Finally, most of these studies included frequent contact between the participant and study staff and included some form of goal setting.

19.3.5 *Effectiveness of Physical Activity Interventions to Reduce Sedentary Behaviour*

Overall, there was a large range in the magnitude of change in sedentary behaviour, extending from no significant change in sedentary behaviour to a decrease of 1 h and 15 min. Of those studies that showed a significant change in sedentary behaviour, decreases ranged from a reduction in ActiGraph-measured sedentary behaviour of 23 min per day after a 24 week intervention [43], 21–29 min per day after a 12 month intervention, and 39 min per day after a 16-week intervention to a 72 min per day decrease sedentary behaviour after a 12 week intervention [37]. Mutrie et al. showed a significant decrease in activPAL-measured sedentary behaviour by 48 min over 12 weeks [44]. Finally, Burke et al. showed a 50.7 min per day decrease in IPAQ-assessed sedentary behaviour after a 6-month intervention [45]. Four studies did not show a change in sedentary behaviour as a result of the intervention [35, 36, 38, 40]. These interventions focused on changing habitual physical activity through education [40] or through engaging in strength and/or functional training two times per week [35], or focused on exercise or physical activity behaviour [36, 38]. These interventions ranged from 8 weeks with a 20-week follow-up [38], 12 weeks [36], and 6 months [40] to 1 year [35]. Additionally, although Kallings et al. showed a significant within-group decrease in IPAQ-reported sedentary behaviour of 2 h per day, the change was not significantly different than the control group who decreased by 1 h per day [46]. Therefore, it appears that interventions that aim to change physical activity or both physical activity and sedentary behaviour through an increase in aerobic-style physical activity are not as effective in reducing sedentary behaviour as those interventions that focus on changing only sedentary behaviour, as was suggested by [48].

A number of studies reported both objectively measured physical activity and sedentary behaviour data, allowing an examination of how these behaviours change in accordance with one another. According to accelerometer data, many of the changes in physical activity behaviour were also accompanied by positive changes in sedentary behaviour [37, 39, 41, 43]. Self-report data also support similar outcomes with increases in aerobic and resistance activity being accompanied by positive changes in sedentary behaviour [45, 46].

Therefore, similar to interventions that primarily aim to change sedentary behaviours, these interventions that focus on physical activity show that there is variation in the activity behaviour and intensity that replaces sedentary behaviour and this replacement behaviour is likely dependent on the physical activity intervention applied.

19.3.6 Sustainability of Changes in Sedentary Behaviour in Response to Physical Activity Interventions

It is important to be able to change behaviour, but arguably maintaining that behaviour change is the ultimate goal because it will have a longer and more enduring effect on health. A few studies followed up on whether the behaviour change that resulted from the intervention was sustained after the intervention finished. Mutrie et al. showed a 41-min reduction in sedentary behaviour after a 12-week intervention. After a 12-week follow-up period, sedentary behaviour only increased by 7 min from the end of the intervention to the end of the follow-up period [44]. DeGreef and colleagues showed a significant decrease in sedentary behaviour (−23 min per day) after a 24-week intervention focusing on physical activity and sedentary behaviour [43]. The reduction in sedentary behaviour was still significantly lower (−12 min per day) than baseline after 1 year, albeit an attenuated effect. Alternatively, results from DeGreef et al. and McNeil et al. were not as favourable [37, 39]. Despite showing a significant reduction in sedentary time (−72 min) in the intervention group compared with controls after the 12-week intervention, 1-year after completion of the intervention sedentary behaviour levels of both the intervention (−6 min from baseline) and control (−15 min from baseline) groups returned to baseline levels [37]. Similarly, McNeil et al. showed significant reductions in sedentary time of 21–29 min after the 12 month intervention [39]. However, after a 12-month follow-up period, sedentary time increased back to levels seen at baseline [39]. Roberts et al. and Westland et al. did not show a decrease in sedentary behaviour during the intervention or during follow-up [38, 40]. In fact, sedentary behaviour was higher after the intervention compared with baseline, and did not decrease in the 12-week follow-up period [38]. Therefore, based on the results from these studies, the sustainability of changes in sedentary behaviour as a result of physical activity interventions remains inconclusive and provides evidence that designing interventions among the elderly population to promote long-term change in sitting behaviours is warranted.

19.4 Summary

As has been stated by many scholars in many different ways, changing behaviour is complicated. There is not a one-size-fits-all intervention to change sedentary behaviour in the elderly population. The current literature reports a variety of different behavioural theories, interventional techniques and characteristics, study designs, and measurement tools being used to change sedentary behaviour. As this body of information grows, identifying effective characteristics can help us to be more successful in changing and maintaining changes in sedentary behaviour. It is important to note that despite the variation in methodology and study design, studies have shown that sedentary behaviour can change. With the increase in the number of studies and the improvement in strength of study design over the last few years, there has been an arguably significant increase in effectiveness of sedentary behaviour interventions reported in the literature. In the previous version of this chapter, we reported that sedentary behaviour interventions resulted in decreases in sedentary behaviour of about 30-min per day. With the addition of more high-quality studies, research has shown that ~30–60 min reductions in sedentary time can be expected with interventions aimed at reducing sedentary behaviour. The changes can happen rapidly, but it is not fully understood whether these changes in sedentary behaviour can be sustained.

There are many questions that remain to be answered. Probably the most important, but difficult to answer, *what is the optimal amount of daily sedentary behaviour that an elderly person should engage in?* Some sitting is healthy and restorative for mental, emotional, or physical well-being. Some sitting is necessary and done for a purpose. But research suggests there is a point where one sits too much and for too long a duration. Secondly, *can changing sedentary behaviour have an impact on the health and quality of life of an elderly individual?* We should not strive to change a behaviour for the sake of changing that behaviour. There needs to be a physical, cognitive, emotional, or social benefit to the change in behaviour. Third, *what are the characteristics of interventions that will produce the largest and most sustainable change in sedentary behaviour?* The studies reviewed in this chapter have relied heavily on behaviourally based and individual focused interventions; fewer have focused on altering social or environmental factors that influence sedentary behaviour. Changing the cues to be sedentary may have a substantial impact on daily sedentary behaviour; however, we have yet to experimentally determine this. This has been shown to be effective with worksite interventions (sit-stand workstations). Therefore, future interventions should focus on altering social and environmental aspects to reduce sedentary behaviour. Further, with our lives becoming increasingly dependent on technology, future interventions could explore the efficacy and effectiveness of in-person interventions compared to remotely delivered interventions in changing sedentary behaviours. Finally, *which behavioural change theories will be most successful in changing sedentary behaviour?* We do not know the most effective behaviour change theories, techniques, or intervention components to reduce sedentary behaviour, although recommendations have been made for adults [31]. Interventions within the elderly have largely relied on social cognitive theory, with some studies not mentioning the theory(ies) employed. Recent exploration of the dual-process model that focuses on habits and intentions/reflections holds promise given the habitual nature of sedentary pursuits. Additionally, with the increasing reliance of technology to support intervention delivery, focus on dynamic and rapid changing behavioural theories will become increasingly important to employ. Finally, moving beyond the individual to explore the interpersonal, community, organisation, and policy influences on sedentary behaviour for older adults may provide interesting bases for intervention. Therefore, future research should focus on determining those theories, techniques, and intervention components that have the largest impact on sedentary behaviour.

The human body is designed to move and there are negative consequences of inactivity as is evidenced by the growing epidemic of chronic disease in our population. Additionally, our environment and modern-day lifestyles are designed for us to move as little as possible. Therefore, given that elderly are one of the most sedentary segments of the population, and they have the highest rates of chronic acquired disease and disability, there is an immediate and urgent need to understand how to change these behaviours.

References

1. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, et al. Amount of time spent in sedentary behaviors in the United States, 2003-2004. Am J Epidemiol. 2008;167(7):875–81.
2. Harvey JA, Chastin SF, Skelton DA. Prevalence of sedentary behavior in older adults: a systematic review. Int J Environ Res Public Health. 2013;10(12):6645–61.
3. Shiroma EJ, Freedson PS, Trost SG, Lee IM. Patterns of accelerometer-assessed sedentary behavior in older women. JAMA. 2013;310(23):2562–3.
4. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996-2011. Am J Prev Med. 2011;41(2):207–15.
5. Stamatakis E, Hamer M, Tilling K, Lawlor DA. Sedentary time in relation to cardio-metabolic risk factors: differential associations for self-report vs accelerometry in working age adults. Int J Epidemiol. 2012;41(5):1328–37.
6. Dogra S, Stathokostas L. Sedentary behavior and physical activity are independent predictors of successful aging in middle-aged and older adults. J Aging Res. 2012;2012:190654.
7. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ, et al. Breaks in sedentary time: beneficial associations with metabolic risk. Diabetes Care. 2008;31(4):661–6.
8. Henson J, Yates T, Biddle SJ, Edwardson CL, Khunti K, Wilmot EG, et al. Associations of objectively measured sedentary behaviour and physical activity with markers of cardiometabolic health. Diabetologia. 2013;56(5):1012–20.
9. Chomistek AK, Manson JE, Stefanick ML, Lu B, Sands-Lincoln M, Going SB, et al. Relationship of sedentary behavior and physical activity to incident cardiovascular disease: results from the Women's Health Initiative. J Am Coll Cardiol. 2013;61(23):2346–54.
10. Koster A, Caserotti P, Patel KV, Matthews CE, Berrigan D, Van Domelen DR, et al. Association of sedentary time with mortality independent of moderate to vigorous physical activity. PloS One. 2012;7(6):e37696.
11. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009;41(5):998–1005.
12. Chang AK, Fritschi C, Kim MJ. Sedentary behavior, physical activity, and psychological health of Korean older adults with hypertension: effect of an empowerment intervention. Res Gerontol Nurs. 2013;6(2):81–8.
13. Gardiner PA, Eakin EG, Healy GN, Owen N. Feasibility of reducing older adults' sedentary time. Am J Prev Med. 2011;41(2):174–7.
14. Fitzsimons CF, Kirk A, Baker G, Michie F, Kane C, Mutrie N. Using an individualised consultation and activPAL feedback to reduce sedentary time in older Scottish adults: results of a feasibility and pilot study. Prev Med. 2013;57(5):718–20.
15. Rosenberg DE, Gell NM, Jones SM, Renz A, Kerr J, Gardiner PA, et al. The feasibility of reducing sitting time in overweight and obese older adults. Health Educ Behav. 2015;42(5):669–76.

16. King AC, Hekler EB, Grieco LA, Winter SJ, Sheats JL, Buman MP, et al. Harnessing different motivational frames via mobile phones to promote daily physical activity and reduce sedentary behavior in aging adults. PloS One. 2013;8(4):e62613.
17. Koltyn KF, Crombie KM, Brellenthin AG, Leitzelar B, Ellingson LD, Renken J, et al. Intervening to reduce sedentary behavior in older adults—pilot results. Health Promot Perspect. 2019;9(1):71–6.
18. Hergenroeder AL, Gibbs BB, Kotlarczyk MP, Perera S, Quinn T, Shuman V, et al. Sit less for successful aging pilot study: feasibility of an intervention to reduce sedentary time in older adults in independent living communities. Cardiopulm Phys Ther J. 2020;31(4):142–51.
19. Crombie KM, Leitzelar BN, Almassi NE, Mahoney JE, Koltyn KF. Translating a “Stand Up and Move More” intervention by state aging units to older adults in underserved communities: protocol for a randomized controlled trial. Medicine (Baltimore). 2019;98(27):e16272.
20. Gine-Garriga M, Dall PM, Sandlund M, Jerez-Roig J, Chastin SFM, Skelton DA. A pilot randomised clinical trial of a novel approach to reduce sedentary behaviour in care home residents: feasibility and preliminary effects of the GET READY study. Int J Environ Res Public Health. 2020;17(8)
21. Owari Y, Suzuki H, Miyatake N. “Active Guide” brochure reduces sedentary behavior of elderly people: a randomized controlled trial. Acta Med Okayama. 2019;73(5):427–32.
22. Tosi FC, Lin SM, Gomes GC, Aprahamian I, Nakagawa NK, Viveiro L, et al. A multidimensional program including standing exercises, health education, and telephone support to reduce sedentary behavior in frail older adults: randomized clinical trial. Exp Gerontol. 2021;153:111472.
23. Matson TE, Anderson ML, Renz AD, Greenwood-Hickman MA, McClure JB, Rosenberg DE. Changes in self-reported health and psychosocial outcomes in older adults enrolled in sedentary behavior intervention study. Am J Health Promot. 2019;33(7):1053–7.
24. Grant D, Tomlinson D, Tsintzas K, Kolic P, Onambele-Pearson G. Minimizing sedentary behavior (without increasing medium-to-vigorous exercise) associated functional improvement in older women is somewhat dependent on a measurable increase in muscle size. Aging (Albany NY). 2020;12(23):24081–100.
25. Grant D, Tomlinson D, Tsintzas K, Kolic P, Onambele-Pearson GL. The effects of displacing sedentary behavior with two distinct patterns of light activity on health outcomes in older adults (implications for COVID-19 quarantine). Front Physiol. 2020;11:574595.
26. Harvey JA, Chastin SFM, Skelton DA. Breaking sedentary behaviour has the potential to increase/maintain function in frail older adults. J Frailty Sarcopenia Falls. 2018;3(1):26–31.
27. Lerma NL, Cho CC, Swartz AM, Maeda H, Cho Y, Strath SJ. Acceptance and feasibility of seated elliptical pedaling to replace sedentary behavior in older adults. J Aging Phys Act. 2020;1-10
28. Maher JP, Sliwinski MJ, Conroy DE. Feasibility and preliminary efficacy of an intervention to reduce older adults' sedentary behavior. Transl Behav Med. 2017;7(1):52–61.
29. Compernolle S, Cardon G, van der Ploeg HP, Van Nassau F, De Bourdeaudhuij I, Jelsma JJ, et al. Engagement, acceptability, usability, and preliminary efficacy of a self-monitoring mobile health intervention to reduce sedentary behavior in Belgian older adults: mixed methods study. JMIR Mhealth Uhealth. 2020;8(10):e18653.
30. Thralls Butte K, Levy SS. Stand up now: a sedentary behavior intervention in older adults of moderate to low physical function. J Aging Phys Act. 2020;29(3):516–28.
31. Gardner B, Smith L, Lorencatto F, Hamer M, Biddle SJ. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. Health Psychol Rev. 2016;10(1):89–112.
32. Compernolle S, Van Dyck D, Cardon G, Brondeel R. Exploring breaks in sedentary behavior of older adults immediately after receiving personalized haptic feedback: intervention study. JMIR Mhealth Uhealth. 2021;9(5):e26387.

33. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary Behavior Research Network (SBRN)—terminology consensus project process and outcome. Int J Behav Nutr Phys Act. 2017;14(1):75.
34. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. Am J Prev Med. 2011;41(2):189–96.
35. Chin APMJ, van Poppel MN, van Mechelen W. Effects of resistance and functional-skills training on habitual activity and constipation among older adults living in long-term care facilities: a randomized controlled trial. BMC Geriatr. 2006;6:9.
36. Barone Gibbs B, Brach JS, Byard T, Creasy S, Davis KK, McCoy S, et al. Reducing sedentary behavior versus increasing moderate-to-vigorous intensity physical activity in older adults. J Aging Health. 2017;29(2):247–67.
37. De Greef K, Deforche B, Tudor-Locke C, De Bourdeaudhuij I. A cognitive-behavioural pedometer-based group intervention on physical activity and sedentary behaviour in individuals with type 2 diabetes. Health Educ Res. 2010;25(5):724–36.
38. Roberts LM, Jaeger BC, Baptista LC, Harper SA, Gardner AK, Jackson EA, et al. Wearable technology to reduce sedentary behavior and CVD risk in older adults: a pilot randomized clinical trial. Clin Interv Aging. 2019;14:1817–28.
39. McNeil J, Farris MS, Ruan Y, Merry H, Lynch BM, Matthews CE, et al. Effects of prescribed aerobic exercise volume on physical activity and sedentary time in postmenopausal women: a randomized controlled trial. Int J Behav Nutr Phys Act. 2018;15(1):27.
40. Westland H, Schuurmans MJ, Bos-Touwen ID, de Bruin-van Leersum MA, Monninkhof EM, Schroder CD, et al. Effectiveness of the nurse-led activate intervention in patients at risk of cardiovascular disease in primary care: a cluster-randomised controlled trial. Eur J Cardiovasc Nurs. 2020;19(8):721–31.
41. Wang X, Breneman CB, Sparks JR, Blair SN. Sedentary time and physical activity in older women undergoing exercise training. Med Sci Sports Exerc. 2020;52(12):2590–8.
42. Aguinaga S, Marquez DX. Impact of Latin dance on physical activity, cardiorespiratory fitness, and sedentary behavior among Latinos attending an adult day center. J Aging Health. 2019;31(3):397–414.
43. De Greef KP, Deforche BI, Ruige JB, Bouckaert JJ, Tudor-Locke CE, Kaufman JM, et al. The effects of a pedometer-based behavioral modification program with telephone support on physical activity and sedentary behavior in type 2 diabetes patients. Patient Educ Couns. 2011;84(2):275–9.
44. Mutrie N, Doolin O, Fitzsimons CF, Grant PM, Granat M, Grealy M, et al. Increasing older adults' walking through primary care: results of a pilot randomized controlled trial. Fam Pract. 2012;29(6):633–42.
45. Burke L, Lee AH, Jancey J, Xiang L, Kerr DA, Howat PA, et al. Physical activity and nutrition behavioural outcomes of a home-based intervention program for seniors: a randomized controlled trial. Int J Behav Nutr Phys Act. 2013;10:14.
46. Kallings LV, Sierra Johnson J, Fisher RM, Faire U, Stahle A, Hemmingsson E, et al. Beneficial effects of individualized physical activity on prescription on body composition and cardiometabolic risk factors: results from a randomized controlled trial. Eur J Cardiovasc Prev Rehabil. 2009;16(1):80–4.
47. Prochaska JJ, Spring B, Nigg CR. Multiple health behavior change research: an introduction and overview. Prev Med. 2008;46(3):181–8.
48. Martin A, Fitzsimons C, Jepson R, Saunders DH, van der Ploeg HP, Teixeira PJ, et al. Interventions with potential to reduce sedentary time in adults: systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1056–63.

Chapter 20
Interventions Directed at Reducing Sedentary Behaviour in Persons with Pre-Existing Disease or Disability

Stephanie A. Prince

Abstract This chapter reviews evidence from intervention studies targeting the reduction of sedentary behaviours among persons with pre-existing disease or disability. It briefly reviews the evidence for the need for such interventions and provides a summary of interventions that have been completed to date. It also briefly reviews interventions that are on the horizon and provides considerations for the design of future interventions. Finally, this chapter discusses areas of future research and methodological issues associated with this research.

What Is New?

- A systematic review that investigated whether smartphone applications are effective at changing physical activity and sedentary behaviour in people with cardiovascular disease found only a small number of studies on sedentary behaviour, with mixed results [1].
- A systematic review that summarized interventions to reduce sedentary behaviour in people with stroke showed that there is insufficient evidence to guide practice on how best to reduce sedentary behaviour in that specific target group [2].
- Systematic review evidence identified that multi-component lifestyle sedentary behaviour interventions including a combination of motivational counselling, technologies (e.g., wearables, smartphones), monitoring, and social interaction among clinical populations (e.g., obesity, type 2 diabetes, cardiovascular disease, neurological/cognitive diseases, musculoskeletal diseases) resulted in greater reductions in sedentary behaviour on the order of 89 minutes per day. In addition to reducing sedentary behaviour,

(continued)

S. A. Prince (✉)
Division of Prevention and Rehabilitation, University of Ottawa Heart Institute, Ottawa, Canada

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_20

these interventions also resulted in improvements to cardiometabolic markers of risk [3].
- More research using high-quality randomized controlled trials is needed to investigate the effectiveness of interventions aimed at reducing sedentary behaviour in persons with pre-existing disease and disability.

20.1 Introduction

Interventions targeting the reduction of sedentary behaviours have only begun to emerge. The majority to date have predominantly focused on seemingly healthy populations in the general public and have been largely carried out in workplace settings [4, 5]. Very few have involved populations with pre-existing disease and/or disability. This is important given that non-communicable chronic disease and disability are both highly prevalent, with an estimated 15% of the world's population living with some form of disability and non-communicable diseases accounting for 38 million deaths a year [6, 7]. Secondary prevention of further illness and disability is an important strategy to not only improve health-related quality of life but also reduce associated healthcare expenditures.

Sedentary behaviours have been shown to be high among specific disease and disability groups and in many cases higher than those found in the general population [8–17]. Figure 20.1 shows the average daily objectively measured sedentary time derived from publications using the National Health and Examination Surveys (NHANES) in the United States [10–17]. While greater amounts of sedentary time have been shown to be associated with an increased likelihood of developing many of these diseases [18, 19], it may further increase after the onset of the disease as a result of symptoms. Rehabilitation and management programmes for several diseases exist (e.g. cardiac rehabilitation, diabetes management, multiple sclerosis activity guidelines) but largely target medical management of the disease and other lifestyle factors including diet, smoking, and physical activity [20–22]. Unfortunately, research has shown that interventions that focus on physical activity, but not sedentary behaviours, are not likely to yield meaningful reductions in sedentary time [4]. It is possible that individuals who participate in these physical activity-oriented interventions compensate for their bouts of physical activity by sitting for longer periods of time during the remainder of the day [23]. A recent study looking at sedentary time among cardiac rehabilitation graduates showed that even among a group of patients who are likely more active than those who had not undergone such an intervention, sedentary time was high and associated with poorer functional capacity [8]. Replacing sedentary time with light or higher intensities of movement can likely improve health risk and physical functioning [24–26], especially among individuals already at greater risk.

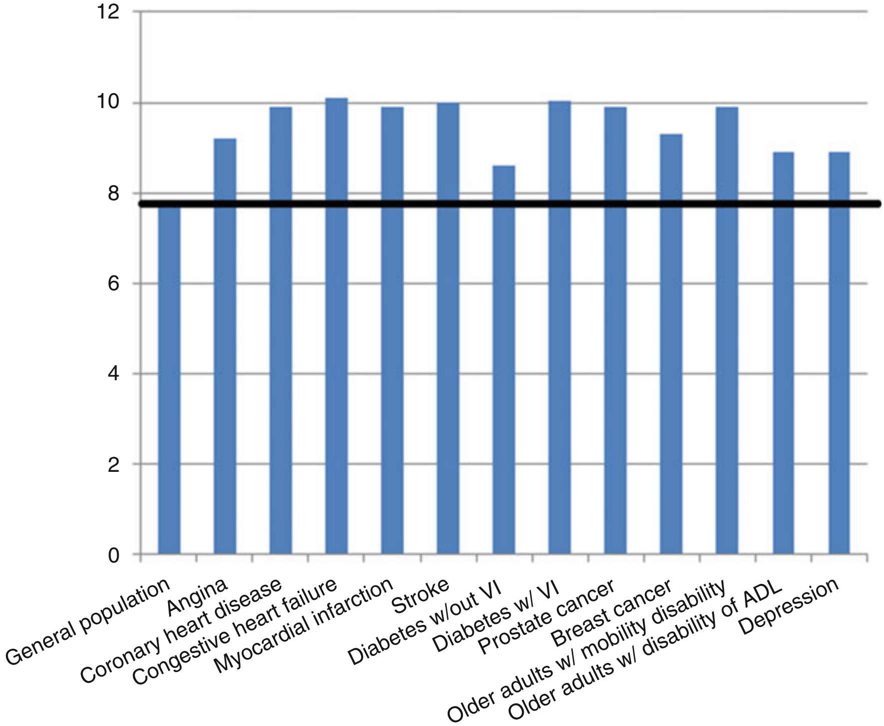

Fig. 20.1 Objectively measured sedentary time (hours/day) across select disease and disability groups. Data come from various publications reporting on sedentary time from the National Health and Examination Survey (NHANES) [7–14]. *ADL* activities of daily living, *VI* visual impairment

20.2 Current Interventions in Persons with Disease and Disability

A review of the published literature by the author was only able to identify evaluations of nine interventions delivered exclusively to individuals with pre-existing disease or disability, including a component targeting sedentary behaviours. The diseases and conditions included type 2 diabetes, hypertension, stroke, cancer, rheumatoid arthritis, multiple sclerosis, and psychotic disorders. Table 20.1 provides a description of all nine interventions and their outcomes. Most of the interventions showed promise in reducing sedentary behaviours. Although the interventions spanned several diseases/conditions, none addressed specific disabilities or conditions in children. Unfortunately, health promotion and prevention efforts also largely overlook people with disabilities [6]. Most of the interventions included multiple components; many used pedometers [27, 28, 33] along with face-to-face [28, 30, 32, 35], group coaching [27, 35, 36], and/or telephone support [28, 30, 36]. One of the interventions used one-on-one video coaching sessions in individuals with multiple

Table 20.1 Characteristics of interventions directed at reducing sedentary behaviour in persons with pre-existing disease or disability

Author, year	Focus	Intervention components	Design and sample size	Duration	SB outcome	SB findings	Other findings
Type 2 diabetes							
De Greef, 2010 [27]	PA + SB	• Five group sessions guided by health coach: Motivational interviewing, self-monitoring, social support, lifestyle plan, feedback. • Booster session at week 23. • Pedometer + diary.	RCT I = 20 C = 21	12 weeks	Accelerometer sedentary time	• Sedentary time significantly ↓ in the intervention group between baseline and the 13 week follow-up, but not between baseline and 1 year. • No significant changes in the control group.	• Significant between-group effect for PA, intervention group significantly ↑ PA over the intervention period, but was not maintained at 1 year. • No significant effect on BMI, weight, BP, cholesterol, HbA1c.
De Greef, 2011 [28]	PA + SB	• One face-to-face (motivational interviewing). • Pedometer. • Seven telephone calls (goal-setting, self-efficacy, self-monitoring, social support, benefits, decisional balance, problem-solving strategies, relapse prevention).	RCT I = 60 C = 32	24 weeks	Accelerometer sedentary time IPAQ sitting time	• Intervention group significantly ↓ objectively measured sedentary time between baseline and 24 weeks and between baseline and 1 year, while the control group increased. • Self-reported sitting time was only significantly lower between baseline and 1 year.	• Significant between-group differences in objectively measured steps/day, total activity and light activity between baseline and 24 weeks and 1 year.
Pellegrini, 2015 [29]	SB	• Smartphone app (*NEAT!*) + intervention accelerometer. • Noise or vibration	Pre-post pilot N = 7	1 month	Accelerometer sedentary time (% wear time), breaks in sedentary time, intensity	• ↓ sedentary time ($8.1 \pm 4.5\%$, $p = 0.003$) • ↓ breaks in sedentary	• High acceptability of the technology. • App allowed participants to be more

		prompts upon 20 consecutive minutes of sedentary time.			of breaks, duration of breaks	time (15.8 ± 8.8 breaks, $p = 0.003$) • ↑ break duration (1.0 ± 0.5 minutes)	conscious of sitting time. • Majority would use the app in the future.
Stroke							
English, 2015 [30]	PA + SB	• Four counselling sessions: Sit less, move more, break up sitting time with short bursts (motivational interviewing).	RCT with attention matched controls $I = 19$ $C = 14$	7 weeks	*activ*PAL™3 time spent sitting, standing and stepping	• Sitting time ↓ by 30 ± 50.6 min/day in the intervention group and by 40.4 ± 92.5 in the control group; intervention not superior. • Both groups ↓ their time in prolonged sitting and ↑ time spent standing and stepping.	• Pain, spasticity and fatigue did not changes in either group. • No between-group difference in MVPA.
Cancer							
Lynch, 2014 [31]	PA, diet quality, weight management, alcohol, tobacco, SB	• Telephone-delivered, multiple behaviour change. • Eleven sessions with health coach. • Handbook. • Regular motivational postcard prompts. • Pedometer. • Study quarterly newsletter.	RCT I = 205 C = 205	6 months	Self-reported screen time and total sedentary time	• Intervention group had a significant ↓ in sedentary hours at 6 months (−0.65; 95% CI: −1.14, −0.15) and at 12 months (−1.21; 95% CI: −1.71, −0.70). • Intervention also had a significant ↓ in screen time and TV time at 6 and 12 months.	• None reported.

(continued)

Table 20.1 (continued)

Author, year	Focus	Intervention components	Design and sample size	Duration	SB outcome	SB findings	Other findings
						• Control group had a significant ↓ in sedentary hours at 12 months only (−0.55; 95% CI: −1.06, −0.05). • No between-group differences in screen time, TV time or total sedentary time at 6 or 12 months.	
Rheumatoid arthritis							
Thomsen, 2014 [32]	SB	• Three motivational counselling sessions of 60–90 minutes with a health professional. • Individual SMS-reminders aiming to reduce sedentary time.	RCT I = 10 C = 9	4 months	*activ*PAL™ time spent sitting	• Intervention group saw average daily sitting time decreased by 0.30 hours/day, while the control group increased by an average of 0.15 hours/day. • Between-group difference was −0.45 hours/day.	• None reported.
Multiple sclerosis							
Klaren, 2014 [33, 34]	PA + SB	• Study website. • Pedometer. • Log book. • One-on-one video coaching sessions.	Pilot RCT I = 33 C = 37	6 months	IPAQ sitting time	• Significant intervention effect, with the intervention group self-reporting a reduction of ~1.65 hours/	• Significant and positive effect of intervention on fatigue severity, depression, anxiety, and self-

						day of sitting time compared to control.	reported PA. • No significant effect on pain, sleep quality or physical health-related quality of life.
Hypertension							
Chang, 2013 [35]	SB, PA, psychological health	• Empowerment intervention. • Healthy lifestyle education (with ways to ↓ SBs). • Health goals. • Social support via group discussion. • Exercise training (to reduce SBs).	Quasi-experimental I = 27 C = 21	8 weeks	IPAQ sitting time	• Intervention group ↓ weekly sitting time by 543.33 ± 494.79 minutes and was significantly greater than the control group ($t = -3.03$, p = 0.004). • Control group ↓ weekly sitting time by 60.45 ± 630.29 minutes.	• No between-group differences in change in depression. • Intervention group showed greater gains in self-efficacy for PA, perceived health and total PA.
Psychotic disorders							
Baker, 2014 [36]	Diet, PA, SB	• Eight manual-guided telephone sessions. • Feedback and goal setting (using motivational interviewing). • Goal ≤2 hours of screen time/day. • Participants received $20 for each completed session. • Resource booklet with diary.	Pre-post N = 17	?	Marshall questionnaire: Leisure screen time Overall sitting time	• Leisure screen time decreased significantly by an average of 135 minutes/day. • Total weekday sitting time decreased significantly by an average of 143 minutes/day.	• Significant improvement in fruit consumption, diet quality and global functioning. • Trend for improvement in vegetable consumption, quality of life, time spent walking and a reduction in the number of cigarettes smoked.

(continued)

Table 20.1 (continued)

Author, year	Focus	Intervention components	Design and sample size	Duration	SB outcome	SB findings	Other findings
							• No improvement in depression scores. • Overall high program satisfaction.

C control group, *RCT* randomized controlled trial, *BMI* body mass index, *BP* blood pressure, *I* intervention group, *IPAQ* International Physical Activity Questionnaire, *PA* physical activity, *SB* sedentary behaviour.

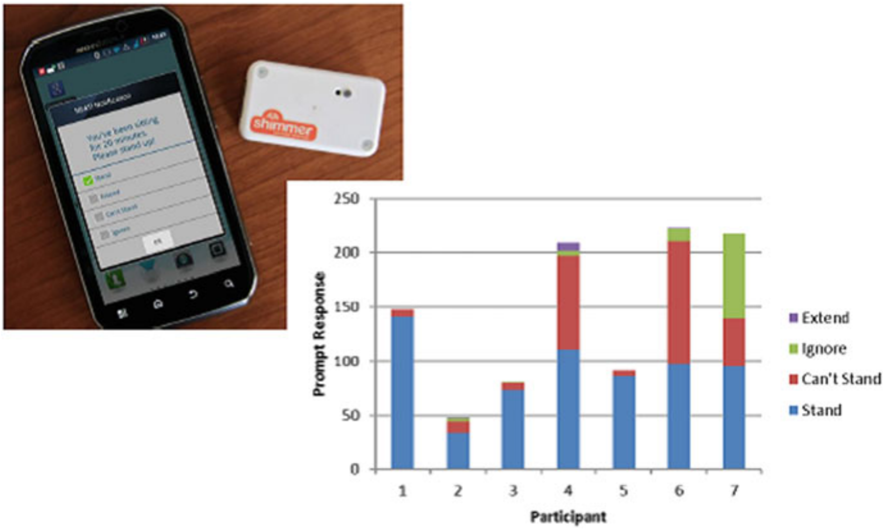

Fig. 20.2 *NEAT!* app and accelerometer and participant responses to reminders [29]

sclerosis [33]. The interventions ranged from 1 to 6 months in duration, and most (five out of nine studies) evaluated sedentary time using an objective measure (accelerometer or activPAL™). Dosing of the interventions ranged from a single visit (to explain the use of a device) [29] to an intervention that included a total of 11 telephone sessions with a health coach [31]. In addition, two interventions also included reminders via text messages [32] and postcard prompts [31]. Other components of interventions included a website [33], study newsletter [31], participant handbook [31, 36], and/or diary [27, 28, 33, 35, 36].

Only two of the interventions exclusively targeted sedentary behaviours [29, 32]. Both interventions incorporated a technological component that provided a form of reminder to participants to reduce sedentary time. The use of wearable technology was applied in one feasibility study involving individuals with type 2 diabetes. The study tested a smartphone app (NEAT!) combined with an accelerometer. The NEAT! app provided real-time reminders using noise or vibration to prompt participants to stand up after 20 consecutive minutes of sedentary time [29]. Figure 20.2 shows both the app and accelerometer used in the study, as well as individual participant responses to the reminders. Although the study was small and did not include a control group, it showed promising reductions in overall sedentary time. Interestingly, the reductions in sedentary time were likely attributed to greater break length rather than the increased number of breaks. The study also reported a high acceptability of the technology by participants [29]. The other intervention to exclusively target sedentary behaviours used a combination of three counselling sessions and individual short message service (SMS) reminders aimed at reducing sedentary time [32]. This intervention, although underpowered, showed promising results for reducing sedentary time and good feasibility [32].

The two interventions with the most promising reductions in sedentary time (versus control) were based on behavioural theories that involved goal setting and discussion of barriers and facilitators of behaviour change, targeted both physical activity and sedentary behaviours, and used a combination of one-on-one sessions and a pedometer [28, 33]. Once again, the use of real-time feedback (i.e. pedometers) on behaviours appears to be an important component to helping reduce sedentary time among clinical populations. Evidence suggests that feedback and self-monitoring are promising sedentary behaviour change strategies [37]. The intervention in individuals with type 2 diabetes showed significant reductions in sedentary time at 1 year compared to baseline measures [28]. The other, in multiple sclerosis patients, reported significant reductions in highly prevalent symptomatic outcomes including fatigue, depression, and anxiety [33]. Promising results were also found from an 8-week empowerment theory-based intervention targeting sedentary behaviours, physical activity, and psychological health among older hypertensive patients [35]. The intervention provided examples for reducing sedentary behaviours, used goal setting, social support through group discussion sessions, and exercise training sessions. A significant between-group difference was observed for self-reported weekly sitting time, with the reductions in the intervention group significantly larger than those observed in the control group [35]. While the study design was weakened by allowing participants to self-select their group (intervention versus control), it does represent a more "real-world" scenario where patients may opt into programmes that may work best for them.

20.3 Interventions on the Horizon

Sedentary behaviours are beginning to gain a great deal of attention as possible intervention targets for people living with chronic conditions. More and more promising research will continue to emerge. A glance at various trial registration sites revealed a number of trials set to examine the effects of interventions targeting the reduction of sedentary behaviours among chronically ill populations. Further, several protocols for interventions have also been recently published in the peer-reviewed literature, with findings to come [38–44]. The feasibility of using wearable technologies such as the Fitbit® (www.fitbit.com) [40, 41] and the Polar V800 (Polar Inc., Denmark) [43], and the use of SMS or text messaging to smartphones [38], is being tested.

The Physical Activity Support Kit Initiative (PASKI) is also currently being developed to provide a toolkit of resources to help individuals living with chronic diseases to "move more and sit less" [45]. The toolkit will provide screening and assessment tools, guidance for the prescription of activities, strategies to monitor individuals and address barriers, information regarding equipment, and information about available community resources. Most promising is that working groups have been created to target a variety of chronic conditions with specialists from each condition [45].

20.4 Considerations for the Design of Interventions

When designing interventions for special populations, it is important to consider factors related to their disease(s) and/or disability and how these might impact an individual's ability to reduce and break up sedentary time. Some groups will have specific barriers and limitations to allocating greater time to higher movement intensities. It is essential for intervention designs to consider safety; some groups may be at great risk of falls or injury associated with an increase in time spent standing or moving. For example, an older frail individual with chronic obstructive pulmonary disease (COPD) may be limited not only by symptoms of the disease itself but also by their level of frailty, which could lead to musculoskeletal injury. This is where it becomes particularly important to assess the appropriateness of the intervention goals and establish what amount of reduction is feasible while still being meaningful for improving function. In addition, it is necessary to recognize that concomitant treatments/factors may be occurring (e.g. cancer treatment, ongoing physiotherapy, medication side effects), and interventions should consider the relevance of these treatments to the feasibility of not only participating in the intervention but also the capacity to meaningfully reduce sedentary behaviours.

Additionally, interventions need to consider the feasibility of intervention delivery. It may not always be possible to use wearable technologies, face-to-face coaching, or group settings. In some cases, in-person interventions may be the most suitable, but in others, individuals may feel overly burdened by multiple care appointments, and a remotely delivered intervention is more appropriate. The location of the intervention is also important, as there may be issues with accessibility to facilities stemming from various limitations: financial (e.g. access fees, parking fees), geographic (transportation), or physical access (e.g. availability of ramps and elevators, accommodations for physical disabilities). It is also likely more beneficial to embed interventions into pre-existing programmes of care in order to overcome issues of access and finances.

20.5 Future Directions

The development of interventions targeting the reduction of sedentary behaviours in persons with pre-existing disease or disability is in its infancy. There remain numerous diseases, conditions, and disabilities (e.g. type 1 diabetes, cerebral palsy, cardiovascular diseases, cancers, COPD, thyroid disorders, osteoporosis, mobility disabilities, etc. [not an exhaustive list]) that lack research entirely, and child populations have been left unstudied. A recent systematic review of physical activity and sedentary behaviour intervention studies in children with type 1 diabetes was unable to identify any interventions specifically targeting sedentary behaviours [46]. Studies are needed to further demonstrate the feasibility of implementation within pre-existing clinical care programmes (e.g. cancer care, cardiac rehabilitation or physical therapy).

The efficacy of technology-based interventions on reduced sedentary behaviours has been shown in general population groups [47–50]. Technologies such as wearable devices (e.g. Fitbit, Jawbone UP, Polar activity trackers, activPAL3™ VT) and smartphone and computer applications have the potential for patients to access real-time information on their behavioural habits, providing instant and readily available feedback and a mechanism for sharing information with members in the circle of care. These devices use behaviour change techniques and can assist in goal setting and self-monitoring while providing environmental cues to encourage breaking up sedentary time, as well as increase activity [51]. The use of text messaging can provide a quick, inexpensive, and effective tool for behaviour change [52].

Step counters as part of an intervention have been shown to reduce sedentary time among adults [53]. Some devices (e.g. Jawbone UP, activPAL3™ VT, Apple Watch, Garmin v'ıvosmart® HR) have the capacity to provide prompts or cues when prolonged periods of sedentary time occur. Some can also provide further information about exercise levels, heart rate, and sleep time. Work is needed to compare the different mechanisms of prompting from both a technical and user perspective. Future interventions would also benefit from comparing the efficacy of and user preference for different types of prompts (e.g. on screen prompts from a smartphone versus vibration from a wearable device).

While there is evidence to show that breaking up prolonged bouts of sedentary time is beneficial for cardiometabolic health and physical functioning [54–56], it is important to establish safe and feasible recommendations for persons with pre-existing disease and disability. To date, standing and moving every 20–30 min have been recommended based on available research [54, 57, 58], but it is possible that these targets are not manageable for all groups. Many conditions may offer further challenges to reducing sedentary time from a symptom or mobility perspective and should be factored into recommendations around frequency of breaks, overall sedentary time reduction goals as well as replacement behaviours. Moving from sedentary to light-intensity activity rather than higher intensities may be a more feasible approach for some groups and still offer many benefits [59]. Future interventions would benefit from looking to establish the safety, feasibility, and efficacy of sedentary behaviour guidelines with respect to total sedentary time and frequency of breaks from sedentary time.

Many of the interventions tested to date have used smaller, proof-of-concept feasibility studies that lack the evaluation components necessary to assess intervention efficacy (i.e. randomization, blinding, control group). As the field moves forward, there will be opportunities to learn from the successes of these smaller feasibility studies and from the few larger efficacy randomized controlled trials to develop solid interventions and improve upon previous methodologies. Researchers and practitioners will also need to move forward with effectiveness research to establish whether these interventions can be integrated into clinical care practice in "real-life" scenarios.

Finally, as technology for measuring sedentary time and patterns of sedentary time improves, studies will benefit from more accurate and objective measures. To date, many studies have evaluated the effectiveness of interventions in persons with pre-existing disease and disability using self-reported sitting time, mostly using the International Physical Activity Questionnaire (IPAQ). Where feasible, interventions would benefit from the use of objective measures of sedentary time and activity (e.g. accelerometers, activPAL™) to provide more accurate measures of continuous movement patterns that include not just total sedentary time, but breaks and bouts, as well as time spent in various postures (e.g. sitting, standing, lying). These devices also help reduce the possibility of response bias. It is, however, important to recognize that there may be challenges and limitations to wearing these in certain persons with pre-existing disease and disability. The area of sedentary behaviour intervention research in persons with pre-existing disease and disability is very much in its infancy. Future work is needed to identify the safety and efficacy recommendations for reducing sedentary behaviours in clinical populations. Interventions should consider the challenges to reducing sedentary behaviours in some individuals due to factors such as safety, symptoms, and parallel interventions and care, and consider integration into pre-existing clinical care programmes.

References

1. Patterson K, Davey R, Keegan R, Freene N. Smartphone applications for physical activity and sedentary behaviour change in people with cardiovascular disease: a systematic review and meta-analysis. PLoS One. 2021;16(10):e0258460.
2. Saunders DH, Mead GE, Fitzsimons C, Kelly P, van Wijck F, Verschuren O, et al. Interventions for reducing sedentary behaviour in people with stroke. Cochrane Database Syst Rev. 2021;6: CD012996.
3. Nieste I, Franssen WMA, Spaas J, Bruckers L, Savelberg H, Eijnde BO. Lifestyle interventions to reduce sedentary behaviour in clinical populations: a systematic review and meta-analysis of different strategies and effects on cardiometabolic health. Prev Med. 2021;148:106593.
4. Prince SA, Saunders TJ, Gresty K, Reid RD. A comparison of the effectiveness of physical activity and sedentary behaviour interventions in reducing sedentary time in adults: a systematic review and meta-analysis of controlled trials. Obes Rev. 2014;15(11):905–19.
5. Martin A, Fitzsimons C, Jepson R, Saunders DH, van der Ploeg HP, Teixeira PJ, et al. Interventions with potential to reduce sedentary time in adults: systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1056–63.
6. World Health Organization. Disability and Health 2015. Available from: http://www.who.int/mediacentre/factsheets/fs352/en/.
7. World Health Organization. Noncommunicable diseases 2015 cited 2016. Available from: http://www.who.int/mediacentre/factsheets/fs355/en/.
8. Prince SA, Blanchard CM, Grace SL, Reid RD. Objectively-measured sedentary time and its association with markers of cardiometabolic health and fitness among cardiac rehabilitation graduates. Eur J Prev Cardiol. 2016;23(8):818–25.
9. Hubbard EA, Motl RW, Manns PJ. The descriptive epidemiology of daily sitting time as a sedentary behavior in multiple sclerosis. Disabil Health J. 2015;8(4):594–601.

10. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. Am J Epidemiol. 2008;167 (7):875–81.
11. Evenson KR, Butler EN, Rosamond WD. Prevalence of physical activity and sedentary behavior among adults with cardiovascular disease in the United States. J Cardiopulm Rehabil Prev. 2014;34(6):406–19.
12. Butler EN, Evenson KR. Prevalence of physical activity and sedentary behavior among stroke survivors in the United States. Top Stroke Rehabil. 2014;21(3):246–55.
13. Lynch BM, Dunstan DW, Winkler E, Healy GN, Eakin E, Owen N. Objectively assessed physical activity, sedentary time and waist circumference among prostate cancer survivors: findings from the National Health and nutrition examination survey (2003–2006). Eur J Cancer Care. 2011;20(4):514–9.
14. Lynch BM, Dunstan DW, Healy GN, Winkler E, Eakin E, Owen N. Objectively measured physical activity and sedentary time of breast cancer survivors, and associations with adiposity: findings from NHANES (2003–2006). Cancer Causes Control: CCC. 2010;21(2):283–8.
15. Manns P, Ezeugwu V, Armijo-Olivo S, Vallance J, Healy GN. Accelerometer-derived pattern of sedentary and physical activity time in persons with mobility disability: National Health and nutrition examination survey 2003 to 2006. J Am Geriatr Soc. 2015;63(7):1314–23.
16. Dunlop DD, Song J, Arntson EK, Semanik PA, Lee J, Chang RW, et al. Sedentary time in U.S. older adults associated with disability in activities of daily living independent of physical activity. J Phys Act Health. 2015;12(1):93–101.
17. Vallance JK, Winkler EAH, Gardiner PA, Healy GN, Lynch BM, Owen N. Associations of objectively-assessed physical activity and sedentary time with depression: NHANES (2005–2006). Prev Med. 2011;53(4–5):284–8.
18. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32.
19. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012;55:2895–905.
20. Ades PA. Cardiac rehabilitation and secondary prevention of coronary heart disease. New Engl J Med. 2001;345(12):892–902.
21. Sigal RJ, Kenny GP, Wasserman DH, Castaneda-Sceppa C, White RD. Physical activity/ exercise and type 2 diabetes a consensus statement from the American Diabetes Association. Diabetes Care. 2006;29(6):1433–8.
22. Latimer-Cheung AE, Ginis KAM, Hicks AL, Motl RW, Pilutti LA, Duggan M, et al. Development of evidence-informed physical activity guidelines for adults with multiple sclerosis. Arch Phys Med Rehabil. 2013;94(9):1829-36.e7.
23. Craft LL, Zderic TW, Gapstur SM, VanIterson EH, Thomas DM, Siddique J, et al. Evidence that women meeting physical activity guidelines do not sit less: an observational inclinometry study. Int J Behav Nutr Phys Act. 2012;9(1):122.
24. Buman MP, Winkler EAH, Kurka JM, Hekler EB, Baldwin CM, Owen N, et al. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. Am J Epidemiol. 2014;179(3):323–34.
25. Hamer M, Stamatakis E, Steptoe A. Effects of substituting sedentary time with physical activity on metabolic risk. Med Sci Sports Exerc. 2014;46(10):1946–50.
26. Healy GN, Winkler EA, Owen N, Anuradha S, Dunstan DW. Replacing sitting time with standing or stepping: associations with cardio-metabolic risk biomarkers. Eur Heart J. 2015;36 (39):2643–9.
27. De Greef K, Deforche B, Tudor-Locke C, De Bourdeaudhuij I. A cognitive-behavioural pedometer-based group intervention on physical activity and sedentary behaviour in individuals with type 2 diabetes. Health Educ Res. 2010;25(5):724–36.

28. De Greef KP, Deforche BI, Ruige JB, Bouckaert JJ, Tudor-Locke CE, Kaufman JM, et al. The effects of a pedometer-based behavioral modification program with telephone support on physical activity and sedentary behavior in type 2 diabetes patients. Patient Educ Couns. 2011;84(2):275–9.
29. Pellegrini CA, Hoffman SA, Daly ER, Murillo M, Iakovlev G, Spring B. Acceptability of smartphone technology to interrupt sedentary time in adults with diabetes. Transl Behav Med. 2015;5(3):307–14.
30. English C, Healy GN, Olds T, Parfitt G, Borkoles E, Coates A, et al. Reducing sitting time after stroke: a phase II safety and feasibility randomized controlled trial. Arch Phys Med Rehabil. 2016;97(2):273–80.
31. Lynch BM, Courneya KS, Sethi P, Patrao TA, Hawkes AL. A randomized controlled trial of a multiple health behavior change intervention delivered to colorectal cancer survivors: effects on sedentary behavior. Cancer. 2014;120(17):2665–72.
32. Thomsen T, Aadahl M, Hetland ML, Beyer N, Loeppenthin K, Esbensen BA. Reduction of sedentary behaviour in patients with rheumatoid arthritis. A randomized feasibility study. Conference: Annual European congress of rheumatology of the European league against rheumatism. EULAR Ann Rheum Dis. 2014;2014:1210.
33. Klaren RE, Hubbard EA, Motl RW. Efficacy of a behavioral intervention for reducing sedentary behavior in persons with multiple sclerosis: a pilot examination. Am J Epidemiol. 2014;47(5): 613–6.
34. Pilutti LA, Dlugonski D, Sandroff BM, Klaren R, Motl RW. Randomized controlled trial of a behavioral intervention targeting symptoms and physical activity in multiple sclerosis. Multiple sclerosis (Houndmills, Basingstoke, England). 2014;20(5):594–601.
35. Chang AK, Fritschi C, Kim MJ. Sedentary behavior, physical activity, and psychological health of Korean older adults with hypertension: effect of an empowerment intervention. Res Gerontol Nurs. 2013;6(2):81–8.
36. Baker AL, Turner A, Kelly PJ, Spring B, Callister R, Collins CE, et al. 'Better health Choices' by telephone: a feasibility trial of improving diet and physical activity in people diagnosed with psychotic disorders. Psychiatry Res. 2014;220(1–2):63–70.
37. Gardner B, Smith L, Lorencatto F, Hamer M, Biddle SJ. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. Health Psychol Rev. 2016;10(1):89–112.
38. Esbensen BA, Thomsen T, Hetland ML, Beyer N, Midtgaard J, Loppenthin K, et al. The efficacy of motivational counseling and SMS-reminders on daily sitting time in patients with rheumatoid arthritis: Protocol for a randomized controlled trial. Trials. 2015;16(1):23.
39. Eakin EG, Reeves MM, Marshall AL, Dunstan DW, Graves N, Healy GN, et al. Living well with diabetes: a randomized controlled trial of a telephone-delivered intervention for maintenance of weight loss, physical activity and glycaemic control in adults with type 2 diabetes. BMC Public Health. 2010;10:452.
40. Clayton C, Feehan L, Goldsmith CH, Miller WC, Grewal N, Ye J, et al. Feasibility and preliminary efficacy of a physical activity counseling intervention using Fitbit in people with knee osteoarthritis: the TRACK-OA study protocol. Pilot Feasibility Stud. 2015;1(1):1–10.
41. Amorim AB, Pappas E, Simic M, Ferreira ML, Tiedemann A, Jennings M, et al. Integrating Mobile health and physical activity to reduce the burden of chronic low back pain trial (IMPACT): a pilot trial protocol. BMC Musculoskelet Disord. 2016;17(1):1–8.
42. Harris L, Melville C, Jones N, Pert C, Boyle S, Murray H, et al. A single-blind, pilot randomised trial of a weight management intervention for adults with intellectual disabilities and obesity: study protocol. Pilot Feasibility Stud. 2015;1(1):1.
43. Ried-Larsen M, Christensen R, Hansen KB, Johansen MY, Pedersen M, Zacho M, et al. Head-to-head comparison of intensive lifestyle intervention (U-TURN) versus conventional multi-factorial care in patients with type 2 diabetes: protocol and rationale for an assessor-blinded, parallel group and randomised trial. BMJ Open. 2015;5(12):e009764.

44. Eakin EG, Hayes SC, Haas MR, Reeves MM, Vardy JL, Boyle F, et al. Healthy living after cancer: a dissemination and implementation study evaluating a telephone-delivered healthy lifestyle program for cancer survivors. BMC Cancer. 2015;15(1):1.
45. The University of British Columbia. Physical Activity Support Kit Initiative (PASKI): Move more. Sit Less 2015. Available from: http://physicaltherapy.med.ubc.ca/physical-therapy-knowledge-broker/physical-activity-support-kit-initiative-paski-move-more-sit-less/.
46. Macmillan F, Kirk A, Mutrie N, Matthews L, Robertson K, Saunders DH. A systematic review of physical activity and sedentary behavior intervention studies in youth with type 1 diabetes: study characteristics, intervention design, and efficacy. Pediatr Diabetes. 2014;15(3):175–89.
47. King AC, Hekler EB, Grieco LA, Winter SJ, Sheats JL, Buman MP, et al. Harnessing different motivational frames via mobile phones to promote daily physical activity and reduce sedentary behavior in aging adults. PLoS One. 2013;8(4):e62613.
48. Bond DS, Thomas JG, Raynor HA, Moon J, Sieling J, Trautvetter J, et al. B-MOBILE-A smartphone-based intervention to reduce sedentary time in overweight/obese individuals: a within-subjects experimental trial. PLoS One. 2014;9(6):e100821.
49. Kendzor DE, Shuval K, Gabriel KP, Businelle MS, Ma P, High RR, et al. Impact of a Mobile phone intervention to reduce sedentary behavior in a community sample of adults: a quasi-experimental evaluation. J Med Internet Res. 2016;18(1):e19.
50. Barwais FA, Cuddihy TF. Empowering sedentary adults to reduce sedentary behavior and increase physical activity levels and energy expenditure: a pilot study. Int J Environ Res Public Health. 2015;12(1):414–27.
51. Lyons EJ, Lewis ZH, Mayrsohn BG, Rowland JL. Behavior change techniques implemented in electronic lifestyle activity monitors: a systematic content analysis. J Med Internet Res. 2014;16(8):e192.
52. Cole-Lewis H, Kershaw T. Text messaging as a tool for behavior change in disease prevention and management. Epidemiol Rev. 2010;32:56–69.
53. Qiu S, Cai X, Ju C, Sun Z, Yin H, Zügel M, et al. Step counter use and sedentary time in adults: a meta-analysis. Medicine. 2015;94(35):e1412.
54. Dunstan DW, Kingwell BA, Larsen R, Healy GN, Cerin E, Hamilton MT, et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes Care. 2012;35(5):976–83.
55. Carson V, Wong SL, Winkler E, Healy GN, Colley RC, Tremblay MS. Patterns of sedentary time and cardiometabolic risk among Canadian adults. Prev Med. 2014;65:23–7.
56. Sardinha LB, Santos DA, Silva AM, Baptista F, Owen N. Breaking-up sedentary time is associated with physical function in older adults. J Gerontol A Biol Sci Med Sci. 2015;70(1):119–24.
57. Bailey DP, Locke CD. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. J Sci Med Sport/Sports Med Australia. 2015;18(3):294–8.
58. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. Am J Clin Nutr. 2013;98(2):358–66.
59. Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ, et al. Objectively measured sedentary time, physical activity, and metabolic risk: the Australian diabetes, obesity and lifestyle study (AusDiab). Diabetes Care. 2008;31(2):369–71.

Chapter 21
Specific Approaches to Reduce Sedentary Behaviour in Persons with Overweight/Obesity

Katherine E. DeVivo, Dori Rosenberg, Sara H. Marchese, and Christine A. Pellegrini

Abstract Sedentary behaviour reduction could be a health-promoting strategy for individuals with a higher weight who may have substantial barriers to engaging in moderate-to-vigorous-intensity physical activity. There has been an increase in interventions that explicitly target the reduction of sedentary behaviour in adults with overweight/obesity. Based on the current literature, the majority of interventions have small sample sizes and are short term. However, a few trials have included larger sample sizes (>150 participants) and suggest that sedentary behaviour reduction interventions with strong scientific designs can be effective at reducing sedentary time and improving health in adults with higher weight. Interventions that were found to be effective at reducing sedentary behaviour varied in duration, study design, and the intervention mechanisms to target behaviour. Components found to be effective at reducing sedentary behaviour include self-monitoring, both active and passive, goal setting, and receiving feedback. Additionally, some studies were found to have a promising influence on weight-related outcomes (body mass index, waist circumference, body weight) and other health-related outcomes. Although promising, adequately powered randomised controlled trials, longer interventions, and long-term follow-ups are needed to better understand the effects of sedentary behaviour reduction interventions in adults with a higher weight.

K. E. DeVivo · C. A. Pellegrini (✉)
Arnold School of Public Health, Department of Exercise Science, The University of South Carolina, Columbia, USA
e-mail: kdevivo@email.sc.edu; cpellegrini@sc.edu

D. Rosenberg
Kaiser Permanente Washington Health Research Institute, Seattle, WA, USA
e-mail: Dori.E.Rosenberg@kp.org

S. H. Marchese
Rush University Medical Center, Chicago, IL, USA
e-mail: sara_a_hoffmanmarchese@rush.edu

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_21

What Is New?

- The chapter has been expanded to include sedentary reduction approaches for populations with overweight/obesity published within the last five years.
- Approaches to reduce sedentary time are reviewed and discussed based on sample size, effectiveness, and intervention duration.
- Limitations and future directions based on the updated literature on sedentary behaviour reduction approaches are discussed.

21.1 Introduction

Throughout this chapter, we use the terms “overweight” and “higher weight” to identify populations with any body mass index (BMI) over 25 kg/m^2. We recognise that there is no term or phrase that is preferred by all populations [1]. We also opted not to use the term “obese”, unless a study specifically used the term, because this term is known to be stigmatising and not preferred among many people with overweight or obesity [1]. Furthermore, we are aware that there is no ideal terminology at this point in the field. Because people with a higher BMI have higher sitting time on average than populations with a lower BMI, in this chapter, we focus on interventions that have targeted individuals with a BMI that indicates overweight or obesity.

Estimates suggest that U.S. adults with higher weight spend up to 9.5 hours per day in sedentary behaviour, with the majority of this time accumulated at work and in leisure time [2]. Likewise, adults reporting sitting time of ≥8 hours/day are more likely to have a BMI >25 kg/m^2 as compared to those reporting <4 hours/day of sitting [3]. We recognise that little is understood about why populations with higher BMI have higher sitting time, and there are likely social and ecologic barriers, including systemic racism and weight stigma, that could be impacting such associations. However, given that over 70% of adults in the United States have a BMI ≥ 25 kg/m^2 and that high sedentary time has been associated with morbidity and mortality in epidemiologic studies [4, 5], it is important to investigate whether sedentary behaviour reduction is a feasible behaviour change target for populations with barriers to engaging in moderate-to-vigorous physical activity (MVPA) [6, 7].

Sedentary reduction programs may also be appealing for those with a higher weight, as they may stand to gain the largest health improvements from replacing sedentary time with standing, light, moderate, and/or vigorous-intensity physical activity. The barriers to MVPA are higher among individuals with a higher weight [8]; thus, alternatives that may be more feasible compared to traditional physical activity interventions are being examined. Specifically, a growing body of research has sought to determine the feasibility, acceptability, and effectiveness of interventions designed to reduce sedentary behaviour either specifically targeting or including individuals with a higher weight.

The benefits of physical activity are well established; however, the amount of adults meeting the recommended guidelines is low [9]. Common barriers to regular participation in physical activity include lack of time, motivation, and cost [10]. Additional barriers specific to populations with a higher weight include anticipated stigma around exercising in public places (e.g., at the gym), mobility-limiting comorbidities, displeasure with activity, fear of injury, fatigue, and joint pain due to excess weight [8, 11, 12]. These additional barriers may contribute to the lower levels of activity observed in adults with a BMI $\geq$ 25 kg/m^2 [3].

For those who are unable to meet physical activity recommendations, the 2018 Physical Activity Guidelines underscore the need for adults to avoid inactivity and reduce time spent sedentary [13]. While interventions should continue to promote MVPA, targeting a reduction of sedentary behaviour may be an additional strategy to help increase overall activity levels and energy expenditure among adults with a higher weight. Consistent evidence indicates an inverse relationship between sedentary time and light-intensity physical activity [14, 15]; thus, targeting a reduction in sedentary time and interrupting prolonged bouts of sitting with short bouts of movement may be a helpful starting point for long-term behaviour change related to physical activity. A stepwise approach to physical activity counselling that starts with targeting sedentary behaviour may be a feasible, first-step recommendation for those struggling to meet general activity guidelines [16]. However, it is not clear whether targeting sitting reduction is an effective health promotion strategy on its own? Targeting a reduction in sedentary time may not only help to lower the risk of chronic diseases but may also have implications for weight loss and the prevention of additional weight gain. For instance, Levine and colleagues [17] have suggested that adults with a higher weight could increase their daily energy expenditure by approximately 350 kcal by replacing 2 hours of sedentary time with light-intensity physical activities such as standing and light ambulation. Although this substitution does not produce a substantial increase in energy expenditure, over the course of a week, the additional energy expended may aid with weight management. Therefore, it is important to examine interventions that target sedentary behaviour in adults with a higher weight and explore intervention components that may be critical for effectively reducing sedentary behaviour in this population.

21.2 Effects of Interventions to Reduce Sedentary Time

Interventions that target sedentary behaviour in adults with a higher weight were reviewed, and 27 studies are included and described in Tables 21.1, 21.2, and 21.3. The studies included are discussed collectively based on their sample size, effectiveness at reducing sedentary time, and study duration.

Table 21.1 Sedentary reduction interventions with sample sizes >150 participants

Author, Year	Sedentary reduction intervention	Design (D), Sample size (SS), BMI	Duration	Sedentary outcome and measure	Sedentary results	Additional health-related results
Biddle et al. 2015 [18]	– 3-hour educational workshop, use of a self-monitoring tool, and follow-up motivational phone call	– D: Randomised controlled trial – SS: $n = 187$ – BMI (total): 34.6 ± 4.9 kg/m^2	12 months	– O: Sedentary behaviour (defined as <100 counts per minute) and self-reported; time spent sitting/lying, standing, stepping and number of sitting/lying to upright transitions – M: Actigraph GT3X accelerometer; activPAL3 – IPAQ for self-reported sitting	– Small reduction in daily sedentary time (intervention group reduced by 17.4 minutes/day and the control by 13.8 minutes/day; $p = 0.52$) – Reduction in self-reported average sitting time (hours) per weekday and weekend day	– No change in weight/BMI or other health markers
Danquah et al. 2016 [19]	– Appointment of local ambassadors, management support, environmental changes (e.g., high-standing tables, sit-stand desks), a lecture and a workshop	– D: Cluster randomised controlled trial – SS: $n = 317$ – BMI (control): 27 ± 4.8 kg/m^2 – BMI (intervention): 26 ± 5.0 kg/m^2	1 month	– O: Total time spent sitting at work, number of prolonged sitting periods at work, number of sit-to-stand transitions, sitting outcomes at 3 months – M: ActiGraph GT3X accelerometer	– 71 minutes less sitting time per 8-h workday at 1 month and 48 minutes less at 3 months – Number of prolonged sitting periods was lower (−0.79/8-h workday) at 1 month – Sit-to-stand transitions were higher (+14%/sitting hour) at 1 month	– At 3 months, body fat percentage was 0.61% points lower – No change in waist circumference – Change in weight/BMI not reported
Thomsen et al. 2017 [20] and 2020 [21]	– 3 individual motivational counselling sessions to discuss individually set behavioural goals – Sent 0–5 tailored text	– D: Single-center, 2-arm observer-blinded RCT – SS: $n = 150$	16 weeks	– O: Change in daily sitting time, self-reported daily sitting time, number of breaks in sitting time	End of intervention – Reduction in daily sitting time was − 1.61 hours/day in intervention versus	End of intervention – No change in weight/BMI – Change in cholesterol in favour of intervention

	messages per week to reduce sedentary behaviour through increasing light-intensity physical activity	– RA patients – BMI (total): 26.4 ± 5.4 kg/m^2		– M: activPAL 3TM monitor	0.59 hours/day increase in control (between-group differences −2.20 hours/day [95% CI -2.72, −1.69], $p < 0.01$) – Differences in self-reported daily sitting time in favour of the intervention group 18-month post-intervention: – Reduction in daily sitting time was −1.10 hours/day in intervention versus 1.32 increase in control (between-group differences −2.43 hours/day [95% CI −2.99, −1.86]) – Differences in self-reported daily sitting time in favour of the intervention group	(reduction of −0.24 in intervention compared to +0.13 in control) – No changes in weight, WC, WHR, BP, AIC, triglycerides – Pain improved in intervention group 18-month post-intervention – Changes in total cholesterol, triglycerides, and eAG in favour of intervention group (−0.86, −0.26, and − 1.15 mmoles/liter, respectively) – Pain improved still Glucose sig reduced favouring intervention – No changes in weight, waist circumference, or waist/hip ratio

Table 21.2 Sedentary reduction interventions with significant reductions in sedentary time

Author, Year	Sedentary reduction intervention	Design (D), Sample Size (SS), BMI	Duration	Sedentary outcome and measure	Sedentary results	Additional health-related results
Adams et al. 2013 [22]	– Combination of face-to-face groups and email messages to reinforce goal-progress with individualised feedback and peers modeled less SB – Received workbook with weekly SB logs and accelerometer-determined percentages of SB along with pedometer data to develop goals	– D: Quasi-experimental, group × time design (intervention or waitlist control) – SS: $n = 64$ – BMI (total): 36.4 ± 7.7 kg/m^2	6 weeks	– O: Time spent in sedentary behaviour and self-reported SB – M: ActiGraph GT3X+	– Reduction in time reported sitting from 57.9 ± 29.7 h/week to 45.9 ± 28.91 h/week for intervention ppts with no change in waitlist – No change in accelerometer measures	– Change in waist circumference decreased from 108.5 ± 15.9 cm to 106.24 ± 15.8 cm – No change in BMI
Bond et al. 2014 [23]	– Combined a smartphone with an onboard accelerometer and a smartphone app – Real-time monitoring of sedentary behaviour – Sedentary behaviour goal-setting, prompting, and feedback – Presented with 3 smartphone-based PA break conditions in counterbalanced order, each for 7 days (3-min after 30 consecutive	– D: Within subjects design – SS: $n = 30$ – BMI (total): 36.2 ± 7.5 kg/m^2	4 weeks	O: Time spent in sedentary behaviour M: SenseWear mini armband monitor	– Time spent in sedentary behaviour decreased from 72.2% at baseline to 66.3% (3-min), 66.6% (6-min), and 69.0% (12-min) – Greater reductions in percent time spent sedentary in the 3-min PA break condition (−5.9%) compared to the 12-min PA break condition (−3.3%)	– Change in weight/BMI not reported

	sedentary, 6-min after 60 continuous sedentary, or 12-min after 120 continuous sedentary)					
Carr et al. 2013 [24]	– Access to a portable pedal machine at worksite – Access to a motivational website to receive tips and reminders focused on reducing sedentary behaviours throughout the day – Pedometer to use in conjunction with the website	– D: Randomised controlled trial – SS: $n = 49$ – BMI (control): 31.7 ± 4.9 kg/m^2 – BMI (intervention): 33.2 ± 4.5 kg/m^2	12 weeks	– O: Daily sedentary time – M: StepWatch physical activity monitor	– Intervention group reduced daily sedentary time (mean change (95% CI): −58.7 min/day (–118.4 to 0.99; $p < 0.01$))	– Intervention effect was observed for waist circumference ($p = 0.03$; −1 cm for intervention and + 1 cm for control) – Within group decrease in SBP for the intervention group (–4.3 mm hg)
Ezeugwu et al. 2018 [25]	– Intervention administered at home by a physical therapist – Goals to (1) increase awareness about health risks of prolonged SB and (2) reduce prolonged SB by encouraging frequent standing/stepping during waking hours – Wore a MisFit flash monitor to act as a self-monitor and motivational tool	– D: Single group longitudinal intervention study – SS: $n = 34$ – BM (total)I: 27.2 ± 0.8 kg/m^2	8 weeks	– O: Time sedentary, standing, stepping and upright and number of steps, sit-to-stand transitions – M: activPAL	– SB decreased by 54.2 ± 13.8 minutes/ day at post-intervention, week 9, but not at week 16 – The percentage of waking time spent sedentary decreased and standing time increased ($p < 0.01$) post-intervention but not at follow-up	– Increase in BMI from baseline to follow-up of 0.6 ± 0.2 – Improvements in systolic BP

(continued)

Table 21.2 (continued)

Author, Year	Sedentary reduction intervention	Design (D), Sample Size (SS), BMI	Duration	Sedentary outcome and measure	Sedentary results	Additional health-related results
Kozey-Keadle et al. 2014 [26]	– Assigned to 1 of 4 groups (exercise (EX), sedentary time reduction (rST), combined EX + rST, and control) – (EX) supervised aerobic exercise training 5 d/week – (rST)weekly meetings with trained research assistant to strategize SB reduction and overcome barriers; given daily step goal and pedometer – EX-rST: Combination of EX and rST	– D: Quasi-experimental – SS: $n = 57$ – BMI (total): 35.1 ± 4.6 kg/m^2	12 weeks	– O: Percent sedentary (time sitting or lying divided by total wear time), percent standing, and percent stepping – M: activPAL	– EX-rST and rST decreased sedentary time (rST - 4.8, (0.8–7.9)%; EX-rST −5.1, (−2.2, 7.9)% compared to control at all time points – At 6 and 12 weeks there were no differences between EX and control, while EX-rST was lower than EX	– Change in weight/ BMI not reported
Laslovich et al. 2020 [27]	– Bimonthly online video series (same as attention control group) – Online sedentary reduction program which includes self-monitoring, goal setting, real-time feedback, problem-solving and planning – GRUVE activity tracker provides prompts after 50 min, feedback, and online goal progression	– D: Randomised control trial – SS: $n = 38$ – BMI (control): 28.8 ± 5.2 kg/m^2 – BMI (intervention): 29.5 ± 4.1 kg/m^2	12 weeks	– O: Time spent sitting/ lying, standing, stepping; sit-to-stand transitions; steps – M: activPAL monitor	– Intervention decreased sit/lie hours(−0.80 ± 0.87 vs 0.18 ± 0.77), increased sit-to-stand transitions (7.1 ± 10.5 vs −1.4 ± 5.71) and increased steps (2814 ± 1753 vs 742 ± 1321) compared to control	– Increase of 0.46 in peripheral arterial tone-reactive hyperemia index

Lewis et al. 2016 [28]	– One hour face-to-face intervention session and guided through a review of their sitting time, normative feedback on sitting time and setting goals to reduce sitting time and bouts of prolonged sitting. – Set weekly goals and received weekly phone calls	– D: Pre-experimental (pre-post) – SS: $n = 27$ – BMI: 27.9 ± 4.1 kg/m^2	6 weeks	– O: Sitting time and bouts of prolonged sitting (≥30 minutes) – M: activPAL	– Reduction in total daily sitting time by 51.5 min/day ($p = 0.006$) – Number of bouts of prolonged sitting reduced by 0.8 per day ($p = 0.002$) – Self-reported sitting reduced by 96 min/day ($p < 0.001$) – Reported watching TV by 32 min/day less ($p = 0.005$) – Percentage of waking time spent sitting reduced by 5.3% ($p = 0.004$)	– Change in weight/BMI not reported
MacEwan et al. 2017 [29]	– Provided with height adjustable desk	– D: Randomised controlled trial – SS: $n = 25$ – BMI (control): 34.6 ± 7 kg/m^2 – BMI (intervention): 36.5 ± 9 kg/m^2	12 weeks	– O: Time spent sitting/supine, standing, and steps/day – M: activPAL monitor	– Reductions in workday (344 ± 107 to 186 ± 101 min/day) and total sitting time (645 ± 140 to 528 ± 91 min/day) as compared to control – Increases in workday standing time in intervention vs control (154 ± 108 to 301 ± 101 min/day)	– No changes in weight/BMI or other cardiometabolic risk factors
Mailey et al. 2016 [30]	– 30-minute session with research assistant, identified strategies for SB	– D: Parallel group randomised trial – SS: $n = 49$	8 weeks	– O: Time spent in sedentary behaviour	– SB decreased by 35.57 min/day in the	– No changes in body weight or waist circumference

(continued)

Table 21.2 (continued)

Author, Year	Sedentary reduction intervention	Design (D), Sample Size (SS), BMI	Duration	Sedentary outcome and measure	Sedentary results	Additional health-related results
	breaks and use of computer/mobile applications to prompt activity breaks – Use of daily activity logs to track SB breaks – Goal accumulate 30 minutes/day of activity/non-sitting time – Randomly assigned to [1] short—stand/move for 1–2 min every 30 minutes, or [2] long—two 15-min breaks from sitting/workday	– BMI (total): 32.4 ± 9.6 kg/m^2		– M: Actigraph GT3X accelerometer	short break group but not in the long break group	– Total cholesterol decreased in both groups
Pellegrini et al. 2015 [31]	– Us of the *NEAT!* App and provided with activity monitor (shimmer) – When sedentary for 20 consecutive minutes *NEAT!*, initiated a noise or vibration to encourage participant to stand up	– D: Feasibility pilot study – SS: $n = 9$ – BMI (total): 37.4 ± 9.9 kg/m^2	4 weeks	O: The percentage of wear time each day spent in sedentary behaviour – M: ActiGraph	– Daily percent sedentary time decreased by 8.1 ± 4.5% between baseline and 1 month – Daily percent of time spent in light-intensity PA increased by 7.9 ± 5.5%	– Change in weight/BMI not reported
Rosenberg et al. 2015 [32]	– 5 phone calls from a health coach – Set goals 1) decrease total sitting time by 2 hr./day through more	– D: One-arm pre--test post-test study – SS: $n = 25$ – BMI (total): 34 kg/m^2	8 weeks	– O: Change in total sitting time, sit-to-stand transitions; self-reported sitting time and sedentary behaviour	– Improvements in sitting time (−27 mins/day, $p < 0.05$), standing time (+25 mins/day, $p < 0.05$), percent of the	– Gait speed improved (0.42 secs, $p = 0.01$) – BMI reduced by 0.53 points ($p = 0.02$)

	standing and moving and 2) additional 15 breaks from sitting throughout the day – Mailed graphical weekly feedback charts, a study workbook and self-monitoring logs			– M: activPAL monitor; international physical activity questionnaire and sedentary behaviour questionnaire	day spent standing (+3%, $p = 0.01$), and a decrease in the per cent of the day spent sitting (−3%, $p = 0.01$) – Reduced self-reported weekday sitting by 1.81 hours/day, $p = 0.01$) and weekend reduced by 0.96 hours/day $p = 0.02$)	Weight reduced by 1.27 lbs. ($p = 0.07$)
Rosenberg et al. 2020 [33]; Matson et al. 2019 [34]	– 6 health coaching contacts, a study workbook, a jawbone UP band to remind participants to take breaks from sitting behaviours (generated from objectively measured SB)	– D: Single-blind, randomised two-arm controlled trial-SS: $n = 60$ – BMI (total): 35.4 ± 4.9 kg/m^2	12 weeks	– O: Daily sitting time, standing and stepping time, sit-to-stand transitions, steps, bouts of sitting longer than 30 minutes – M: activPAL monitor	– Greater reduction in sitting time between groups favouring the intervention group (−58 min/day, $p = 0.007$) – Prolonged sitting bouts reduced by 1.4 favouring the intervention group, $p = 0.003$ – Standing time increased by 41.1 mins/day favouring intervention group, $p = 0.014$ – Greater increases in standing time and decreases in prolonged sitting bouts	– SBP reduced by −3.93 mm HG favouring intervention group ($p = 0.24$) – DBP reduced by 2.97 mmHg favouring intervention group ($p = 0.14$) – Weight reduced 1.8 lbs. favouring intervention ($p = 0.16$) – WC reduced by 0.52 inches favouring intervention group ($p = 0.2$) – BMI reduced 0.31 points favouring intervention ($p = 0.19$) – No changes in functional outcomes or glucose or cholesterol

Table 21.3 Sedentary Reduction Interventions with Non-Significant Effects or Interventions Less Than 1 Month

Author, Year	Sedentary Reduction Intervention	Design (D), Sample Size (SS), BMI	Duration	Sedentary Outcome & Measure	Sedentary Results	Additional Health-Related Results
Barone Gibbs et al. 2017 [35]	– Participants assigned to 1) *sit less* group (goal to reduce sedentary time by 1 hr./day) or 2) *get active* group (goal to reach 150 min/week MVPA) – Both groups received in-person and phone consultations with an exercise physiologist and wore BodyMedia SenseWearPro armband (SWA) with Bluetooth connection to their smartphone	– D: Randomised controlled trial – SS: $n = 38$ – BMI (sit less): 28.3 ± 6.3 kg/m^2 – BMI (get active): 28.9 ± 4.8 kg/m^2	12 weeks	– O: Total sedentary time (sum of "awake" minutes with ≤1.5 METs), and self-reported sedentary behaviour – M: SenseWearPro armband (ASWA)	– No change in objectively measured or self-reported sedentary time in either group	– Weight decreased in *get active* group compared to *sit less* group – Objectively measured MVPA increased in the get active group – Self-reported MVPA increased in both groups – Improved short physical performance battery score in the sit less group
Carr et al. 2016 [36]	– Randomised either: [1] 30 minute face-to-face ergonomic consultation, encouraged to take sitting breaks every 30–45 minutes, and 3 weekly emails; [2] same intervention as above, plus seated elliptical machine and iPod touch to monitor and receive feedback on daily pedalling. They	– D: Two-arm randomised controlled trial – SS: $n = 60$ – BMI (control): 33.0 ± 5.6 kg/m^2 – BMI (intervention):34.5 $\pm$ 6.8 kg/m^2	16 weeks	– O: Percentage of occupational time spent sedentary – M: GENEActiv ankle accelerometer	– No changes in per cent of occupational time spent sedentary – Increase in occupational physical activity (total counts)	– No changes in weight or cardiometabolic biomarkers

	also received pedalling goals (30–80 min/day)					
English et al. 2016 [37]	– Series of 4 counselling sessions with the main message being to sit less and move more, with encouragement to regularly break up sitting time with short bursts of light-intensity activity (standing, walking), feedback on sitting time Control: Calcium (attention matched)	– D: Randomised control trial – SS: $n = 33$ – BMI (control): 27.5 ± 3.0 kg/m^2 – BMI (intervention): 29.3 ± 5.8 kg/m^2	7 weeks	– O: Time spent sitting, standing, and stepping, and periods of prolonged, uninterrupted sitting of ≥30 minutes duration – M: activPAL3 monitor	– Daily sitting time reduced on average 30.0 ± 50.6 min/day for intervention and 40.4 min for controls – Prolonged sitting time reduced on average 36.1 ± 65 min/day for intervention and 44.2 mins/day for controls – Both groups exceeded the target of reducing sitting time by at least 30 min/day	– Change in weight/BMI not reported
Júdice et al. 2015 [38]	– Goal to reduce sitting time by 3 hours/week (30–60 minutes/day) – Software program with hourly alerts to break-up sitting-time at work – Provided with pedometer, texts, and phone calls to maintain current activity levels	– D: Crossover randomised controlled pilot – SS: $n = 10$ – BMI (total): 32.6 ± 5.5 kg/m^2	1 week	– O: Hours spent sitting, standing, stepping; sit/stand transitions; number of steps. – M: activPAL monitor	– Less time sitting (1.85 hours/day) – More time standing (0.77 hours/day) – More stepping (1.09 hours/day) – No differences in sit/stand transitions – More steps (6363 steps/day)	– Change in weight/BMI not reported
Kozey-Keadle et al. 2012 [39]	– Provided with information about potential health risks associated with SB and benefits of increases light-intensity PA	– D: Quasi-experimental – SS: $n = 20$ – BMI (total): 33.7 ± 5.6 kg/m^2	1 week	– O: % of wear time that was sedentary and % stepping, standing, and sit-to-stand transitions; self-reported usual time sitting in total number of	– Reduced sitting time from 67.0% to 62.7% of wear time – Stepping time increased from 9.8% to 11.7% of wear time	– Change in weight/BMI not reported

(continued)

Table 21.3 (continued)

Author, Year	Sedentary Reduction Intervention	Design (D), Sample Size (SS), BMI	Duration	Sedentary Outcome & Measure	Sedentary Results	Additional Health-Related Results
	– Packet containing list of strategies to reduce SB and checklist to monitor SB for 7 days – Pedometer and goal of 7500 steps/day			hours and minutes/day – M: activPAL and ActiGraph accelerometers and the Total sitting questionnaire (T-SQ) and domain-specific questionnaire	– Steps increased from 6417 ± 3366 to 8167 ± 3600 steps per day	
Lyons et al. 2017 [40]	– Received jawbone Up24 monitor and a tablet – Brief weekly telephone counselling – Set daily and weekly goals (activity and sedentary behaviour), self-monitored, and received prompts after 1 hour of sedentary time	– D: Parallel randomised controlled pilot trial – SS: $n = 40$ – BMI (total): 30.3 ± 3.5 kg/m^2	12 weeks	– O: Mean minutes spent sitting per day – M: activPAL monitor	– Sitting time per day in intervention (baseline 1132 [127.19] minutes to 12 weeks 1088.92 [175.56]) 95% CI: −0.21 (−0.54 to 0.12)	– Weight changes in intervention (baseline 82.58 [11.96 kgs] to 12 weeks 81.72 [11.71 kgs]) 95% CI: −0.33 [−0.67 to 0.00)
Maher et al. 2017 [41]	– Three 1.5 hour meetings with content designed to reduce sedentary behaviour – Included group discussion and videos on sedentary behaviour awareness, normative estimates, outcome expectancies, action	– D: Cluster randomised controlled trial – SS: $n = 42$ – BMI: 29.7 ± 7.1 kg/m^2	2 weeks	– O: Self-reported time spent sitting or lying down during weekdays and weekends – M: Nine item domain specific measure of behaviour	– Group x time interactions for total and weekday SB – Intervention decreased total SB time by 837.8 min/week – Decreased watching TV (−44.0 min/weekday) and reading (−31.0 min/weekday)	– Change in weight/BMI not reported

	planning and behavioural goals					
Otten et al. 2009 [42]	– Phase 1: 3-week observation-only phase – Phase 2: 3-week TV reduction (intervention) OR 3-week observation (control) Phase 2 intervention: Reduced TV viewing by 50% from objectively measured phase 1 – When reached TV limit, TV would turn off and remain off until the following week and time limit was refreshed	– D: Randomised controlled trial – SS: $n = 36$ – BMI (control): 32.3 ± 5.9 kg/m^2 – BMI (intervention): 31.8 ± 5.3 kg/m^2	3 weeks	– O: Sedentary energy expenditure as measured by TV viewing time – M: SenseWear pro 3 armband	– Those in the intervention group decreased time spent in sedentary activities by 3.8% compared to the 1.1% decrease in the control group – TV viewing was different between intervention and control in phase 1 to 2.	– No change in weight/BMI, but BMI decreased between phases 1 and 2 in the intervention group
Prince et al. 2018 [43]	– Participants given VTAP monitor that provided real-time feedback via alerts (gentle vibrotactile or "buzzing" feedback) once the wearer was sedentary for 30 consecutive minutes and required 2 minutes of standing/movement to reset	– D: Two-arm randomised controlled pilot trial – SS: $n = 40$ – BMI (control): 30.5 kg/m^2 – BMI (intervention): 28.7 kg/m^2	8 weeks	– O: Change in daily sitting/lying time; time spent in prolonged periods of sitting >30 and > 60 minutes; number of sit/stand transitions; time spent sitting, lying, standing, and stepping – M: activPAL3 monitor	– No change in daily sitting time	– No change in weight/BMI
Ryan et al. 2020 [44]	– 4 face-to-face sessions (30–45 minutes) with a physiotherapist – Yamax SW-200 Digi-	– D: Randomised control trial – SS: $n = 60$ – BMI (control):	3 months	– O: Sedentary (sitting and lying), standing, and stepping time – M: activPAL3	– There was no difference in sedentary time or step-counts – Stepping time differed	– Change in weight/BMI not reported

(continued)

Table 21.3 (continued)

Author, Year	Sedentary Reduction Intervention	Design (D), Sample Size (SS), BMI	Duration	Sedentary Outcome & Measure	Sedentary Results	Additional Health-Related Results
	Walker pedometer to monitor and record PA, SB, and step-count behaviours – Discussed behaviour-change techniques guided by a handbook containing pre-reading and reflection	26.3 ± 5.9 kg/m^2 – BMI (intervention): 25.9 ± 5.3 kg/m^2			between groups at 3 and 9 months in favour of the intervention group	
Urda et al. 2016 [45]	– Week 1—both groups maintain current activity levels – Week 2—control continue to maintain and intervention received an alert every hour during the workday to disrupt occupational sedentary time by engaging in light physical activity, and were provided handout with light physical activity options and written educational materials	– D: Experimental design with random assignment – SS: $n = 44$ – BMI total): 30.5 ± 8.2 kg/m^2	2 weeks	– O: Hours/week spent sitting, standing, and stepping while at work – M: activPAL3 monitor	– No difference in sedentary time – Less average sit time during the intervention for the intervention group (5.42 compared to 6.05 hours/workday)	– Change in weight/BMI not reported
Zhu et al. 2018 [46]	– Sit–stand workstation provided, emails from supervisors encouraging use of workstation, promotional flyers, and	– D: Two-arm, natural experiment – SS: $n = 36$ – BMI (comparison) I:	18 months	– O: Time spent sitting, standing, sit-to-stand transitions, and time accrued in prolonged	– Work sitting reduced by 56.7 ± 89.1 min per 8 h workday at 4 months and 52.6 ± 68.3 min per 8 h workday at 18 months	– No changes in BMI or other cardiometabolic factors

	e-newsletters for 4 months	25.4 ± 3.5 kg/m^2 – BMI (intervention): 26.0 ± 5.4 kg/m^2		sitting – M: activPAL3c	– Standing time increased (37.4 ± 69.2 min/8 h workday) at 4 months and (17.7 ± 54.8 min/8 h workday) and 18 months	

21.2.1 Sedentary Reduction Interventions with Sample Sizes >150 Participants

Three efficacy trials that included larger sample studies and longer-term follow-up are reviewed in more detail here and in Table 21.1. Biddle et al. [18] conducted a randomised controlled trial including 187 participants (mean age = 32.8 ± 5.6 years, 68.5% female, 19.8% Black or minority ethnic group, mean BMI = 34.6 ± 4.9 kg/m^2) who were followed for 12 months. The intervention group received one 3-hour workshop, a self-monitoring tool (Gruve device, MUVE, Inc., USA), and one follow-up phone call. Sedentary time was measured with both the ActiGraph GT3X and the activPAL. There were no between-group differences in either measure of sedentary time or self-reported sitting time, and there were no changes in health outcomes (glucose, insulin, HbA1c, cholesterol). While this study was well-designed, the results suggest that sedentary behaviour is a complex behaviour change and that simple, brief interventions or tools are insufficient for sitting time reduction.

Danquah et al. [19] conducted a cluster randomised controlled trial involving 317 office workers across 4 workplaces (mean age 46 ± 10 years, 66% female, mean BMI 26 ± 4.9 kg/m^2). The intervention aimed to enhance social support for reducing workplace sitting by appointing an ambassador at each site, the agreement of management to serve as role models, environmental changes (high tables in conference rooms and offices and routes for walking meetings), a workshop, and optional emails and text messages. The workshop included using sit–stand desks (which the participants already had), breaking up prolonged sitting bouts, standing and walking meetings, and common goals as well as a health lecture. Sitting time was measured with a thigh-worn ActiGraph accelerometer. At 1 month, there was a − 71 minute/day difference in workday (8-hour) sitting time favouring the intervention group and a − 48 min/day difference at 3 months). Prolonged sitting periods, standing time, steps, body fat percentage, and fat-free mass also significantly improved favouring the intervention group. There were no significant differences for sit-to-stand transitions, waist circumference, leisure sitting time, MVPA, or fat mass. This study demonstrates the importance of tailoring interventions to the places people spend the majority of their time, such as at work. Interestingly, it does not seem that the effects of setting specific interventions on reducing sitting time generalise to other settings for leisure time sitting.

A randomised controlled trial including 150 participants with rheumatoid arthritis was conducted by Thomsen et al. [20, 21] (mean age 59.6 ± 11.7 years, 81% female, mean BMI 26.4 ± 5.4 kg/m^2). The intervention included three one-on-one motivational counselling sessions and text messages (set at participants' preferred frequency and timing with a maximum of one message/weekday) over 16 weeks. The main targets of the intervention were to reduce TV viewing, substitute sitting with standing at work and home, breaking up prolonged sitting bouts, and limiting sitting bouts to less than 30 minutes [47]. Primary outcomes were measured by activPAL. Sitting time reduced by −2.2 hours/day favouring the intervention group

($p < 0.0001$) at 16 weeks. Standing time increased by 1.5 hours/day favouring the intervention group, while stepping time increased about a half-hour per day. Fatigue, pain, self-efficacy, and quality of life all improved favouring the intervention group at 16 weeks. There were no significant effects on blood pressure, weight, waist circumference, BMI, HDL, LDL, triglycerides, or HbA1c at 16 weeks. The researchers also examined the maintenance of behavioural and health changes at the 18-month post-intervention follow-up. Daily sitting maintained its reduction (−2.43 hours/day favouring the intervention group). Standing, stepping, fatigue, pain, self-efficacy, and quality of life continued to be improved favouring the intervention condition. C-reactive protein, swollen and tender joints, HDL, LDL, blood pressure, weight, and waist circumference were not significantly different. Glucose, total cholesterol, and triglycerides reduced for intervention group participants. Overall, the intervention group was able to retain their reductions in sitting time at the 18-month post-intervention follow-up. Furthermore, it took longer than the primary endpoint to see improvements in health markers suggesting that longer studies of sitting reduction may be needed to see the full realisation of health effects. The intervention targeted people with rheumatoid arthritis, which could indicate sitting reduction interventions could be particularly beneficial for people with rheumatological conditions.

These three high-quality trials suggest that sedentary behaviour reduction interventions with robust intervention designs can reduce sedentary time and improve health in adults with higher weight. Mobile health tools and environmental strategies appeared helpful. On the contrary, very brief interventions may not be as efficacious as indicated by the results of Biddle et al. [18]. Furthermore, having access to a sit–stand workstation is helpful, but workers often require extra information and support to ensure they have a plan for putting the workstation into its standing mode in order to displace sitting time. Further trials are needed to confirm these findings in samples that include diverse participants, those with higher body weight, and people with chronic health conditions.

21.2.2 Sedentary Reduction Interventions Leading to Significant Reductions in Sedentary Behaviour

Not including the studies already discussed, there were twelve studies that reported significant reductions in sedentary behaviour that included adults with a higher weight (Table 21.2). The duration of the studies ranged from 4 to 12 weeks (4 weeks $n = 2$, 6 weeks $n = 2$, 8 weeks $n = 3$, and 12 weeks $n = 5$). Five of these studies were randomised controlled trials, whereas other study designs include quasi-experimental, single-group longitudinal, and feasibility pilot studies.

Intervention mechanisms to target sedentary behaviour that were found to be effective include components grounded in behaviour change theory. Self-monitoring, goal setting, and receiving feedback on sedentary time were common approaches used among these interventions, and a wide range of tools and devices were used. Some studies used self-reported activity logs to track sedentary behaviour breaks and sedentary time [22, 30, 32]. Objective measures such as pedometers or activity trackers were also commonly used to help monitor sedentary time and provide feedback on their progress towards sedentary reduction goals. For example, in a study by Ezeugwu et al. [25], participants were provided with a wrist-worn activity monitor to use as a self-monitoring and motivational tool throughout the intervention. The monitor provided real-time feedback on daily progress and had customizable goal-setting capability. Technology was commonly provided to participants and used as part of the interventions for not only self-monitoring purposes but also to prompt or interrupt sedentary time. Some forms of technology or prompting tools included websites [24, 27, 30], smartphone applications [23, 30, 31], and wearable devices [23–27, 30, 31, 33]. Additional tools designed to help reduce sedentary time included a pedal machine [24] and height adjustable desk [29].

The majority of the interventions used goal setting as a primary intervention component to reduce sedentary behaviour. Program goals ranged from reducing total sedentary time to increasing sedentary breaks. Some specific examples of sedentary reduction goals included: accumulating 30 minutes of activity/non-sitting time by standing/moving for 1–2 minutes every 30 minutes or two 15-minute breaks [30]; decreasing total sitting time by 2 hour/day through standing/moving and have an additional 15 breaks from sitting through the day [32]; setting regular/weekly individual sedentary reduction goals with a coach or online program [22, 23, 27, 28, 32, 33].

Objectively measured time spent in sedentary behaviour and daily sitting, standing, and stepping time as well as sit-to-stand transitions were the most reported outcomes. The activPAL accelerometer was the most commonly used tool [25–29, 32, 33] to assess sedentary behaviour; other instruments included the ActiGraph accelerometer [22, 30, 31], the StepWatch physical activity monitor [24], the SenseWear Armband [23], and self-reported questionnaires. Findings for each study are reported in Table 21.2. Reductions in sedentary behaviour are reported in total time per day, total time per week, percentage of time spent in sedentary behaviour, etc. The most common report of reductions in sedentary behaviour was in minutes per day and ranged from −27 minutes/day [32] to 58 minutes/day [24, 33]. Another common outcome measure was the percentage of time spent in sedentary behaviour with the largest reduction being 8.1% [31] and others being around 5% [23, 26, 28]. Additionally, two studies reported a reduction in the number of bouts of prolonged sitting [28, 33].

21.2.3 Influence of Effective Sedentary Behaviour Reduction Interventions on Health Outcomes

Of the fifteen studies that resulted in significant changes in sedentary behaviour, including those with sample sizes >150 participants, nine found promising results also influencing additional health outcomes. Considering the population of interest for this chapter, it is noteworthy that some of the interventions found significant changes in waist circumference [22, 24, 33], total body weight [32, 33], BMI [32, 33], and body fat percentage [19]. Rosenberg and colleagues found that in an 8-week trial [32], BMI reduced by 0.53 points and weight reduced by 1.27 pounds. These investigators also found promising results in a 12-week trial [33] with participants in the intervention group reducing BMI by 0.31 points and reducing weight by 1.8 pounds. Other outcomes that were improved included blood pressure [24, 25, 33], both systolic and diastolic, total cholesterol [20, 21], fasting blood glucose [21], and peripheral arterial tone-reactive hyperemia [27]. Self-reported health, such as fatigue, pain, and quality of life, have shown improvement as well [20, 21].

21.2.4 Sedentary Reduction Interventions with Non-Significant Reductions in Sedentary Behaviour

Many approaches attempted to-date to reduce sedentary time have not led to significant reductions in sedentary time; however, as compared to physical activity, sedentary behaviour is a relatively new behaviour of interest. As a result, much of the sedentary reduction literature has focused on establishing the feasibility, acceptability, and safety of new approaches and programs designed to reduce sedentary time. Therefore, many of the previously published studies were not powered to detect behavioural outcomes. Specifically, 7 studies are included in Table 21.3 with intervention durations greater than 1 month, but with non-significant effects on sedentary time. The sample sizes of these studies were small, ranging from 33 to 60 participants. Additionally, many of these new approaches are being tested among populations with high prevalence or at high risk of overweight/obesity, including adults with stroke [37], multiple sclerosis [44], coronary artery disease [43], and older adults [35, 40]. Although not necessarily resulting in significant reductions in sedentary time, the majority of these sedentary programs appear to be safe, even among the clinical and high-risk populations tested [37, 44]. Further, several studies have established preliminary feasibility and acceptability of measuring sedentary time using activPALs in various populations [37, 43] or of the use of different behavioural approaches to reduce sedentary time, including wearable monitors [40], telephone counselling [40], use of prompts [43], and physiotherapist led in-person sessions [44].

21.2.5 Sedentary Reduction Interventions with Interventions Durations Less than 1 Month

Five studies specifically targeted reductions in sedentary behaviour, but with shorter intervention windows than the studies described above with either significant or non-significant effects on sedentary time. Specifically, studies with intervention durations less than 1 month are included in Table 21.3 [38, 39, 41, 42, 45]. Tools used included education information [39, 41, 45], pedometers [38, 39], computer/text/phone reminders [38, 45], group discussions [41], goal setting [38, 39, 41], and television (TV) lockout devices [42]. These studies suggest that in the short term, participants were able to reduce sitting, increase steps, and reduce TV time.

21.3 Limitations

Although there has been an increase in the number of studies over the last decade examining sedentary reduction interventions among adults with a BMI ≥ 25 kg/m^2, the majority of the published literature to date includes many research methodological limitations which hinder the ability to draw definitive conclusions. One majority limitation to date is the sample size. Only three studies included over 100 participants [18–21] (range 150–317). The sample size in all other studies reviewed ranged from 10 to 60 participants. Many of the studies with smaller sample sizes were pilot studies focused on establishing feasibility and acceptability of the intervention. As a result, these studies may not have been adequately powered to detect significant changes in either sedentary time or other health-related outcomes such as body weight.

A second overarching limitation of the studies reviewed is that few studies examined changes in sitting time over one year [18, 21]; all other studies were short-term and ranged from one week to 16 weeks. Some of the lack of changes in sedentary behaviour or health-related outcomes including weight and BMI could be due to the short duration of the studies. Related, as compared to many physical activity interventions, many of the studies examined included low-intensity interventions. For physical activity interventions, increased contact frequency is associated with increased physical activity levels [48]. Among the sedentary reduction interventions reviewed here, many studies did not have regular contact with study participants throughout the intervention. Some studies, for example, only included the use of reminding or prompting technology to interrupt sedentary time. Conceptually, sedentary behaviour and physical activity differ, which means different behaviour change techniques may be necessary to modify sedentary behaviour as compared to those shown to be effective at changing physical activity. However, the lack of changes in sedentary time could also be a result of the lower intensity of the interventions.

Another limitation of the studies reviewed is that the majority of the sedentary reduction interventions were not designed specifically for adults with a higher weight; however, given the increasing prevalence of adults with a BMI $\geq$ 25 kg/m^2, the average BMI of participants for most of the studies was above 25 kg/m^2. Many of the studies did not measure or report changes in body weight or BMI after the intervention. Of the studies that did report weight or BMI, there were only a few that saw reductions or trends for reductions in either weight or BMI following the intervention [32, 33]. Similarly, other health outcomes that showed promising effects include blood pressure [24, 25, 33], total cholesterol [20, 21], fasting blood glucose [21], and peripheral arterial tone-reactive hyperemia [27]; however, many studies did not measure or report these outcomes.

21.4 Future Directions

Although the number of sedentary reduction interventions continues to increase, the effects of sedentary reduction approaches on sedentary time and longer-term metabolic and cardiovascular health among adults with a higher weight remains unclear. Future studies are needed with larger sample sizes, longer interventions, and follow-up durations. The majority of studies to date focus on establishing the feasibility and acceptability of sedentary reduction approaches; as more research suggests these approaches are in fact feasible and acceptable, researchers should consider designing studies with adequate power to detect reductions in sedentary time. Additionally, many of the interventions only included a few behaviour change techniques and little to no interventionist/coach contact. Future studies are needed to determine the most effective behaviour change techniques for sedentary behaviour as well as the optimal frequency of contact to ensure sustained changes in behaviour long-term. The multiphase optimisation strategy (MOST) is a framework that can be used to evaluate and optimise a behaviour intervention based on set criteria such as effectiveness, affordability, scalability, and efficiency [49]. Factorial experiments conducted within the optimisation phase of MOST could help to disentangle components or levels of components that are more effective in influencing sedentary behaviour reduction, and then these components could be tested together in an optimised treatment package within a traditional randomised controlled trial design [49].

21.5 Summary

There has been an increase in interventions to target the reduction of sedentary behaviour in adults with overweight/obesity. Based on the current review, there have not been many studies that have included a larger sample size (>150 participants); however, these high-quality trials with large sample sizes do suggest that sedentary behaviour reduction interventions with strong designs can be effective at reducing sedentary time and improving health in adults with higher weight. Interventions that were found to be effective at reducing sedentary behaviour varied in duration, study design, and the intervention mechanisms to target behaviour. However, components such as self-monitoring, both self-reported and objectively measured, goal setting, and receiving feedback seemed to be common approaches found in effective interventions. In addition to reducing sedentary time, some studies were found to have a promising impact on weight-related outcomes (BMI, waist circumference, total body weight) and other health-related outcomes. However, much work is still needed and randomised controlled trials with larger sample sized, longer durations, and follow-up durations are needed to examine the effects of sedentary behaviour reduction interventions on adults with higher weight.

References

1. Puhl RM. What words should we use to talk about weight? A systematic review of quantitative and qualitative studies examining preferences for weight-related terminology. Obes Rev. 2020;21(6):e13008.
2. Matthews CE, Carlson SA, Saint-Maurice PF, Patel S, Salerno EA, Loftfield E, et al. Sedentary behavior in U.S. adults: fall 2019. Med Sci Sports Exerc. 2021 Dec;53(12):2512–9.
3. Paz-Krumdiek M, Rodriguez-Vélez SG, Mayta-Tristán P, Bernabe-Ortiz A. Association between sitting time and obesity: a population-based study in Peru. Nutr Diet. 2020;77 (2):189–95.
4. Ekelund U, Tarp J, Fagerland MW, Johannessen JS, Hansen BH, Jefferis BJ, et al. Joint associations of accelerometer-measured physical activity and sedentary time with all-cause mortality: a harmonised meta-analysis in more than 44 000 middle-aged and older individuals. Br J Sports Med. 2020 Dec 1;54(24):1499–506.
5. Patterson R, McNamara E, Tainio M, de Sá TH, Smith AD, Sharp SJ, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. Eur J Epidemiol. 2018 Sep 1;33(9):811–29.
6. Hales CM. Prevalence of obesity and severe obesity among adults: United States, 2017–2018. NCHS Data Brief 2020;(360):1–8.
7. Wang Y, Beydoun MA, Min J, Xue H, Kaminsky LA, Cheskin LJ. Has the prevalence of overweight, obesity and central obesity levelled off in the United States? Trends, patterns, disparities, and future projections for the obesity epidemic. Int J Epidemiol. 2020 Jun 1;49 (3):810–23.
8. Der Ananian C, Wilcox S, Saunders R, Watkins K, Evans A. Factors that influence exercise among adults with arthritis in three activity levels. Prev Chronic Dis. 2006;3(3):1–16.
9. Bennie JA, De Cocker K, Teychenne MJ, Brown WJ, Biddle SJH. The epidemiology of aerobic physical activity and muscle-strengthening activity guideline adherence among 383,928 U.S. adults. Int J Behav Nutr Phys Act. 2019 Apr 18;16:34.
10. Lee C, Ory MG, Yoon J, Forjuoh SN. Neighborhood walking among overweight and obese adults: age variations in barriers and motivators. J Community Health. 2013 Feb;38(1):12–22.
11. Schvey NA, Sbrocco T, Bakalar JL, Ress R, Barmine M, Gorlick J, et al. The experience of weight stigma among gym members with overweight and obesity. Stigma Health. 2017 Nov;2 (4):292–306.
12. Ekkekakis P, Lind E. Exercise does not feel the same when you are overweight: the impact of self-selected and imposed intensity on affect and exertion. Int J Obes. 2006 Apr;30(4):652–60.

13. US Department of Health and Human Services. Physical Activity Guidelines for Americans [Internet]. 2nd Edition. Washington, DC; 2018. Available from: https://health.gov/our-work/physical-activity/current-guidelines
14. Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ, et al. Objectively measured sedentary time, physical activity, and metabolic risk. Diabetes Care. 2008 Feb;31(2):369–71.
15. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. Eur Heart J. 2011 Mar;32(5):590–7.
16. Dogra S, Copeland JL, Altenburg TM, Heyland DK, Owen N, Dunstan DW. Start with reducing sedentary behavior: a stepwise approach to physical activity counseling in clinical practice. Patient Educ Couns [Internet]. 2021 Sep 13 [cited 2021 Oct 14]; Available from: https://www.sciencedirect.com/science/article/pii/S0738399121006285
17. Levine JA, Lanningham-Foster LM, McCrady SK, Krizan AC, Olson LR, Kane PH, et al. Interindividual variation in posture allocation: possible role in human obesity. Science. 2005 Jan 28;307(5709):584–6.
18. Biddle SJH, Edwardson CL, Wilmot EG, Yates T, Gorely T, Bodicoat DH, et al. A Randomised controlled trial to reduce sedentary time in young adults at risk of type 2 diabetes mellitus: project STAND (Sedentary Time ANd Diabetes). PLoS ONE [Internet]. 2015 Dec 1 [cited 2021 Jun 12];10(12). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4666612/
19. Danquah I, Kloster S, Holtermann A, Aadahl M, Bauman A, Ersbøll A, et al. Take a stand!–a multi-component intervention aimed at reducing sitting time among office workers–a cluster randomized trial. Int J Epidemiol. 2017 Feb 1;46(1):128–40.
20. Thomsen T, Aadahl M, Beyer N, Hetland ML, Løppenthin K, Midtgaard J, et al. The efficacy of motivational counselling and SMS reminders on daily sitting time in patients with rheumatoid arthritis: a randomised controlled trial. Ann Rheum Dis. 2017 Sep;76(9):1603–6.
21. Thomsen T, Aadahl M, Beyer N, Hetland ML, Løppenthin KB, Midtgaard J, et al. Sustained long-term efficacy of motivational counseling and text message reminders on daily sitting time in patients with rheumatoid arthritis: long-term follow-up of a randomized, Parallel-Group. Trial Arthritis Care Res. 2020;72(11):1560–70.
22. Adams M, Davis P, Gill D. A hybrid online intervention for reducing sedentary behavior in obese women. Front Public Health. 2013;1:45.
23. Bond DS, Thomas JG, Raynor HA, Moon J, Sieling J, Trautvetter J, et al. B-MOBILE - a smartphone-based intervention to reduce sedentary time in overweight/obese individuals: a within-subjects experimental trial. PLoS One. 2014 Jun 25;9(6):e100821.
24. Carr LJ, Karvinen K, Peavler M, Smith R, Cangelosi K. Multicomponent intervention to reduce daily sedentary time: a randomised controlled trial. BMJ Open. 2013 Oct;1:3(10).
25. Ezeugwu VE, Manns PJ. The feasibility and longitudinal effects of a home-based sedentary behavior change intervention after stroke. Arch Phys Med Rehabil. 2018 Dec 1;99(12):2540–7.
26. Kozey-Keadle S, Staudenmayer J, Libertine A, Mavilia M, Lyden K, Braun B, et al. Changes in sedentary time and physical activity in response to an exercise training and/or lifestyle intervention. J Phys Act Health. 2014 Sep 1;11(7):1324–33.
27. Laslovich S, Alvar BA, Allison M, Rauh MJ. Effects of lifestyle physical activity on vascular function in asymptomatic peripheral arterial disease. Med Sci Sports Exerc. 2020 Jan;52(1):8–15.
28. Lewis LK, Rowlands AV, Gardiner PA, Standage M, English C, Olds T. Small steps: preliminary effectiveness and feasibility of an incremental goal-setting intervention to reduce sitting time in older adults. Maturitas. 2016 Mar;85:64–70.
29. MacEwen BT, Saunders TJ, MacDonald DJ, Burr JF. Sit-stand desks to reduce workplace sitting time in office workers with abdominal obesity: a randomized controlled trial. J Phys Act Health. 2017 Sep 1;14(9):710–5.
30. Mailey EL, Rosenkranz SK, Casey K, Swank A. Comparing the effects of two different break strategies on occupational sedentary behavior in a real world setting: a randomized trial. Prev Med Rep. 2016 Aug 9;4:423–8.

31. Pellegrini CA, Hoffman SA, Daly ER, Murillo M, Iakovlev G, Spring B. Acceptability of smartphone technology to interrupt sedentary time in adults with diabetes. Transl Behav Med. 2015 Sep;5(3):307–14.
32. Rosenberg DE, Gell NM, Jones SMW, Renz A, Kerr J, Gardiner PA, et al. The feasibility of reducing sitting time in overweight and obese older adults. Health Educ Behav Off Publ Soc Public Health Educ. 2015 Oct;42(5):669–76.
33. Rosenberg DE, Anderson ML, Renz A, Matson TE, Lee AK, Greenwood-Hickman MA, et al. Reducing sitting time in obese older adults: the I-STAND randomized controlled trial. J Aging Phys Act. 2020 Jun 4;28(6):864–74.
34. Matson TE, Anderson ML, Renz AD, Greenwood-Hickman MA, McClure JB, Rosenberg DE. Changes in self-reported health and psychosocial outcomes in older adults enrolled in sedentary behavior intervention study. Am J Health Promot. 2019;33(7):1053–7. https://doi.org/10.1177/0890117119841405.
35. Barone Gibbs B, Brach JS, Byard T, Creasy S, Davis KK, McCoy S, et al. Reducing sedentary behavior versus increasing moderate-to-vigorous intensity physical activity in older adults: a 12-week randomized, Clinical Trial. J Aging Health. 2017 Mar 1;29(2):247–67.
36. Carr LJ, Leonhard C, Tucker S, Fethke N, Benzo R, Gerr F. Total worker health intervention increases activity of sedentary workers. Am J Prev Med. 2016;50(1):9–17. https://doi.org/10.1016/j.amepre.2015.06.022.
37. English C, Healy GN, Olds T, Parfitt G, Borkoles E, Coates A, et al. Reducing sitting time after stroke: a phase II safety and feasibility randomized controlled trial. Arch Phys Med Rehabil. 2016 Feb 1;97(2):273–80.
38. Júdice PB, Hamilton MT, Sardinha LB, Silva AM. Randomized controlled pilot of an intervention to reduce and break-up overweight/obese adults' overall sitting-time. Trials. 2015 Nov 2;16:490.
39. Kozey-Keadle S, Libertine A, Staudenmayer J, Freedson P. The feasibility of reducing and measuring sedentary time among overweight, non-exercising office workers. J Obes. 2012;2012:282303.
40. Lyons EJ, Swartz MC, Lewis ZH, Martinez E, Jennings K. Feasibility and acceptability of a wearable technology physical activity intervention with telephone counseling for mid-aged and older adults: a randomized controlled pilot trial. JMIR MHealth UHealth [Internet]. 2017 Mar 6 [cited 2021 Jun 12];5(3):e28. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5359416/
41. Maher JP, Sliwinski MJ, Conroy DE. Feasibility and preliminary efficacy of an intervention to reduce older adults' sedentary behavior. Transl Behav Med. 2017 Mar;7(1):52–61.
42. Otten JJ, Jones KE, Littenberg B, Harvey-Berino J. Effects of television viewing reduction on energy intake and expenditure in overweight and obese adults: a randomized controlled trial. Arch Intern Med. 2009 Dec 14;169(22):2109–15.
43. Prince SA, Reed JL, Cotie LM, Harris J, Pipe AL, Reid RD. Results of the sedentary intervention trial in cardiac rehabilitation (SIT-CR study): a pilot randomized controlled trial. Int J Cardiol. 2018 Oct 15;269:317–24.
44. Ryan JM, Fortune J, Stennett A, Kilbride C, Lavelle G, Hendrie W, et al. Safety, feasibility, acceptability and effects of a behaviour-change intervention to change physical activity behaviour among people with multiple sclerosis: results from the iStep-MS randomised controlled trial. Mult Scler J. 2020 Dec 1;26(14):1907–18.
45. Urda JL, Lynn JS, Gorman A, Larouere B. Effects of a minimal workplace intervention to reduce sedentary behaviors and improve perceived wellness in middle-aged women office workers. J Phys Act Health. 2016 Aug 1;13(8):838–44.
46. Zhu W, Gutierrez M, Toledo MJ, et al. Long-term effects of sit-stand workstations on workplace sitting: a natural experiment. J Sci Med Sport. 2018;21(8):811–6. https://doi.org/10.1016/j.jsams.2017.12.005.
47. Thomsen T, Aadahl M, Beyer N, Hetland ML, Løppenthin K, Midtgaard J, et al. Motivational counselling and SMS-reminders for reduction of daily sitting time in patients with rheumatoid

arthritis: a descriptive randomised controlled feasibility study. BMC Musculoskelet Disord. 2016 Oct 18;17(1):434.
48. Greaves CJ, Sheppard KE, Abraham C, Hardeman W, Roden M, Evans PH, et al. Systematic review of reviews of intervention components associated with increased effectiveness in dietary and physical activity interventions. BMC Public Health. 2011 Feb 18;11:119.
49. Collins LM, Kugler K, editors. Optimization of behavioral, biobehavioral, and biomedical interventions [Internet]. Springer International Publishing; 2018 [cited 2020 Jun 29]. (Statistics for Social and Behavioral Sciences). Available from: https://www.springer.com/gp/book/9783319917757

Chapter 22
Programmes Targeting Sedentary Behaviour Among Ethnic Minorities and Immigrants

Melicia C. Whitt-Glover, Amanda A. Price, and Breana Odum

Abstract Sedentary behaviour has been associated with increased morbidity and mortality, and successful strategies for addressing it could have major public health implications. National objectively monitored and self-report data show higher rates of sedentary behaviour among racial/ethnic minority groups compared to whites and increasing rates among immigrants the longer they live in the United States. This chapter describes the prevalence of sedentary behaviour and factors associated with it in racial/ethnic minority groups, including personal characteristics, built and sociocultural environments, knowledge/attitudes/beliefs, and historical context. This chapter also summarizes findings from interventions focused on decreasing screen time/sedentary behaviour among racial/ethnic minority children and adolescents and adults. Given the lack of definitive conclusions about successful strategies for addressing sedentary behaviour in racial/ethnic minority groups, the chapter concludes with suggestions for the next steps for reducing sedentary behaviour using the African American Collaborative Obesity Research Network paradigm as an exemplar model for creating culturally appropriate interventions.

What Is New?

- A systematic review reported that among immigrant children, the average sedentary time ranges from one to 3 h per day [1].
- A systematic mapping review showed that among ethnic minority groups in Europe, sedentary behaviour is influenced by a wide variety of social and cultural factors [2].
- Research on sedentary behaviour among ethnic minorities, immigrants, and individuals living in low- and middle-income countries is still sparse.

M. C. Whitt-Glover (✉) · A. A. Price · B. Odum
Gramercy Research Group, Winston Salem, NC, USA
e-mail: mwhittglover@gramercyresearch.com

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_22

22.1 Introduction

Sedentary behaviour has been defined by the Sedentary Behaviour Research Network as "…any waking activity characterized by an energy expenditure ≤1.5 metabolic equivalents *and* a sitting or reclining posture [3]". In recent years, sedentary behaviour has become an area of concern in health-related research because of its independent linkages with mortality, even when controlling for other health-related behaviours, including weight, diet, and physical activity [4–7]. Sedentary behaviour has also been associated with an increased prevalence of poor health-related behaviours, such as increased food intake, which can lead to poor health outcomes, including obesity, hypertension, type 2 diabetes mellitus, cardiovascular disease, certain cancers, and frailty [7–9]. The American Academy of Pediatrics currently recommends avoiding using television and other entertainment media before the age of 2, limiting television time to <2 h daily after age 2, and removing television sets from children's bedrooms [10]. Historically, the push to achieve national recommendations for daily physical activity among adults has not included recommendations for reducing sedentary behaviour. Although there are still no specific national recommendations for screen time and sedentary behaviour for adults, the 2008 Physical Activity Guidelines for Americans suggest that adults should "avoid inactivity" [11, 12].

22.1.1 Sedentary Behaviour Prevalence

The National Health and Nutrition Examination Survey (NHANES) is the only national surveillance system that provides objectively monitored measures of physical activity and sedentary behaviour. NHANES has been used to assess health and nutrition among children and adults in the United States through a combination of interviews and physical examinations since the 1960s. In 2003, NHANES began using accelerometers in a subsample of respondents to collect population-level estimates of physical activity. Data from NHANES 2003–2004 showed that children aged 6–11 years spent 5.9–6.1 h per day in sedentary behaviour [13]. Adolescents aged 12–15 years spent 7.4–7.6 daily hours in sedentary behaviour, and young adults aged 16–19 years engaged in 7.6–8.2 daily hours of sedentary behaviour. Data from 3725 adults who participated in NHANES 2005–2006 showed that of the~14 h of daily wear time, adults spent ~478.9 min per day (~8 h per day) engaged in sedentary behaviour, which did not include sleeping [14]. Among older adults, data from NHANES 2003–2006 showed that adults >60 years of age were sedentary for ~516.7 min per day (~8.6 h per day) [15]. In all cases, sedentary behaviour was higher among racial/ethnic minority groups compared to whites. Studies assessing sedentary behaviour via self-report have also identified higher prevalence of sedentary behaviour in racial/ethnic minority groups compared to whites, though all groups tend to underestimate sedentary behaviour and overestimate physical activity when self-report measures are used [16, 17]. For more details on the prevalence of sedentary behaviour among children and adults, please refer to Chap. 2. Data on sedentary behaviour among immigrants in the United States show patterns that are similar to racial/ethnic minority groups living in the United States. A small study of Latina immigrants residing in Alabama showed a positive association between the number of years living in the United States and sedentary behaviour [18]. A study of ~2000 Chinese men and women living in New York City evaluated the impact of immigration on obesity and related risk factors [19]. Physical activity at work, during travel, and during recreational activities was assessed using a questionnaire. When the leisure-time physical activity was considered, Chinese immigrants living in the United States for >15 years had higher odds of being physically active than those living in the United States for <15 years. Interestingly, newer Chinese immigrants (those residing in the United States <5 years) had higher odds of engaging in work- or travel-related physical activity than Chinese immigrants living in the United States >6 years, suggesting that acculturation may reduce incidental daily physical activities that are associated with sedentary behaviour even while increasing purposeful leisure-time activities associated with exercise or physical fitness. Similar linkages between acculturation and increased sedentary behaviour have also been observed among youth [20].

22.2 Strategies to Address Sedentary Behaviour Among Racial/Ethnic Minorities

Because the concept of addressing sedentary behaviour is fairly new, there have been limited interventions focused on reducing sedentary behaviour. Most studies have focused on reducing television, video games, and computer use (i.e. screen time) in children and adolescents through school, after-school, or summer camps and family-based, or clinical settings. Few studies have included large samples of racial/ethnic minority or immigrant populations. A 2012 systematic review of interventions to reduce screen time in children <12 years of age identified 47 studies, 29 of which "...achieved significant reductions in TV viewing or screen-media use" [21]. Of the 47 studies identified, only 14 included racial/ethnic minority children. Studies that included racial/ethnic minority children in school-based settings primarily focused on educating children on strategies for decreasing sedentary behaviour, and most showed little or no impact on sedentary behaviour or television viewing/screen time. Studies in home and community-based settings intervened through family counselling and education or alternative activities (e.g. a soccer programme) and showed no or modest changes in media use/screen time or small reductions in household television viewing, meals eaten while watching television, and having the television on while no one was watching. Videotape and videogame usage did not appear to be impacted by intervention strategies. Clinic-based studies primarily focused on education and counselling by clinic staff, and most showed increases in the percentage of parents who self-reported that children watched <2 h of television daily and did not watch television during meals. There was no apparent impact on screen time in the one clinical study where an electronic monitor was used [22]. Other reviews of the literature on reducing screen time in children have drawn similar conclusions—findings from intervention studies have been inconsistent, none have demonstrated long-term impact, and additional research is needed [23–25]. The review by Schmidt and colleagues is the only one that provided information about and focused assessment of the inclusion of racial/ethnic minority groups in study samples included in their review [21].

Very few intervention studies have specifically focused on reducing sedentary behaviour among adults. Several studies have evaluated strategies for reducing sedentary time in workplace settings (see Chap. 18 for more details), including sit/stand and treadmill workstations, changing workplace layouts to require more walking (e.g. locating printers further away from workstations), organizational policies to promote physical activity (e.g. exercise breaks, walking meetings), and education and reminders (e.g. stair prompts) to encourage reductions in sitting [26–28]. A recent Cochrane review identified 20 qualitative and 6 quantitative studies focused on reducing sedentary time in workplace settings in adults [28]. Unfortunately, the studies identified did not include sufficient numbers to assess the impact of such interventions among racial/ethnic minority populations. Previous reviews of the literature have described findings from studies focused on increasing physical activity levels among sedentary/low-active adults from racial/ethnic minority communities, presumably by increasing physical activity and reducing sedentary behaviour [29]. Most of these studies have focused on women, citing men as a hard-to-reach population, and the majority of studies have focused on African American and Hispanic communities. Intervention strategies have included individual- and group-based interventions performing supervised and unsupervised physical activity across a variety of settings [29–34]. In general, studies show mixed results, with some describing modest increases in post-intervention physical activity levels and others showing little or no impact. None of the studies focused on racial/ethnic minority adults have identified strategies for long-term and sustainable increases in physical activity.

22.3 Factors Associated with Sedentary Behaviour in Racial/Ethnic Minority Groups

Sedentary behaviour has been associated with a variety of personal and environmental (built and sociocultural) characteristics. Female gender has been associated with sedentary behaviour in some racial/ethnic minority groups, primarily because of competing responsibilities of childcare and household duties that limit availability for participation in leisure-time physical activity or raise feelings of guilt for engaging in physical activity given more pressing demands [35–38]. The demands of family, caregiving, and household duties may leave some women feeling too exhausted to engage in physical activity and may make rest/sedentary behaviour necessary to continue fulfilling daily duties. Concerns of safety for girls engaging in outdoor physical activity or active transportation [39], feelings among girls of being incompetent or embarrassed during physical activity and preferring to engage in sedentary behaviour rather than participate in physical activity [40], concerns about personal appearance and preference for sedentary behaviour to preserve hairstyles [41], feelings among girls that physical activity is "babyish" and better suited for boys [40], and preference for a larger body type that is more supportive of sedentary behaviour than engaging in physical activity [41] also influence sedentary behaviour. Age is another personal characteristic that can influence sedentary behaviour, particularly in the presence of chronic diseases associated with increasing age, which can influence both willingness and ability to engage in physical activity due to complications from disease and/or fear of further injury or death, leading to increased sedentary behaviour [42–44]. Several factors in the built environment have been shown to influence sedentary behaviour, including living in neighbourhoods that are older and/or suburban without walkable destinations [45, 46].

Sociocultural preferences can also impact choices to engage in sedentary behaviour in racial/ethnic minority communities. Data suggests that seeing others exercising in one's neighbourhood can influence physical activity levels, though the influence can be either negatively or positively correlated, depending on the population subgroup [47–50]. It stands to reason that not seeing others in one's neighbourhood exercising can deter participation in physical activity, possibly due, again, to concerns about safety, appearance, or embarrassment. Cultural preference for sedentary behaviour particularly when gathering with friends and family members (e.g. eating, sitting, and visiting) and the importance placed on engaging with friends and family members could influence sedentary behaviour in racial/ethnic minority groups. Culturally specific knowledge, attitudes, and beliefs about the importance of rest relative to physical activity/exercise can also influence sedentary behaviour. A qualitative study by Airhihenbuwa and colleagues reported on ten focus groups with African American men and women [51]. The identified themes indicated that participants felt that rest was more important than physical activity for good health and that most African Americans obtained sufficient physical activity through daily lifestyle because of a perceived higher prevalence of occupations requiring manual labour and physically demanding household activities. At least one physical activity intervention study among African American women noted that women who successfully met the national recommendation for daily physical activity (>30 min) rewarded themselves by resting more, indicating the additional rest was necessary to maintain levels of increased physical activity (Whitt-Glover, unpublished data from references [52 and 53]). Although not focused specifically on racial/ethnic minority groups, a study of obese adolescents identified a similar pattern; when obese youth engaged in high-intensity exercise in morning exercise sessions, they compensated by reducing physical activity energy expenditure in the afternoon [54].

Concerns about safety may be an additional cultural factor that can influence sedentary behaviour. As mentioned previously, concern for the safety of girls and women exercising outside or engaging in active transportation can influence sedentary behaviour. Additional safety concerns related to racial profiling have contributed to sedentary behaviour and reluctance to engage in outdoor physical activities, like jogging, among African American men [55]. Other racial/ethnic subgroups, particularly undocumented immigrants, may face similar fears with regards to exercising in public places, thus leading to increased sedentary behaviour. Sedentary behaviour, particularly television viewing, may be used as a coping behaviour for daily stressors. In a study of ~3200 adults involved in the Coronary Artery Risk Development in Young Adults Study, discriminatory experiences were associated with increased screen time among African American men [56]. Stressors associated with lower income/high poverty, unemployment or underemployment, and systemic racism might be positively associated with sedentary behaviour in other population subgroups as well, though additional studies are needed to confirm this hypothesis.

22.4 Suggested Next Steps for Addressing Sedentary Behaviour in Racial/Ethnic Minority Groups

Given the limited number of studies focused on sedentary behaviour among racial/ethnic minority groups and immigrants, and the increasing interest in addressing sedentary behaviour because of the negative health impact, strategies that can successfully address and decrease sedentary behaviour are needed. Most of the published systematic reviews and meta-analyses on the impact of interventions to reduce sedentary behaviour identified small numbers of racial/ethnic minorities as a limitation. A review of parenting and childhood obesity research noted that underrepresentation of individuals from specific demographic groups hinders generalizability of study findings and suggests that input from a diverse set of individuals and groups is necessary to ensure that study findings are applicable to a wide range of population subgroups [57].

The African American Collaborative Obesity Research Network (AACORN) has developed an exemplar paradigm for use in addressing weight and related behaviours in African American communities [58]. The paradigm suggests that a broad approach that is informed by knowledge of life in African American communities is needed to create holistic approaches that embrace and reflect social and cultural perspectives of the community (Fig. 22.1). The AACORN paradigm suggests that consideration of a variety of "lenses" or perspectives—including those of researchers who are outside the research communities (e.g. researches whose race/ethnic backgrounds do not reflect the communities on which interventions are focused), researchers who are part of the research communities based on race/ethnic background, and the community members who are the focus of interventions is critical for creating strategies that appropriately reflect the communities of

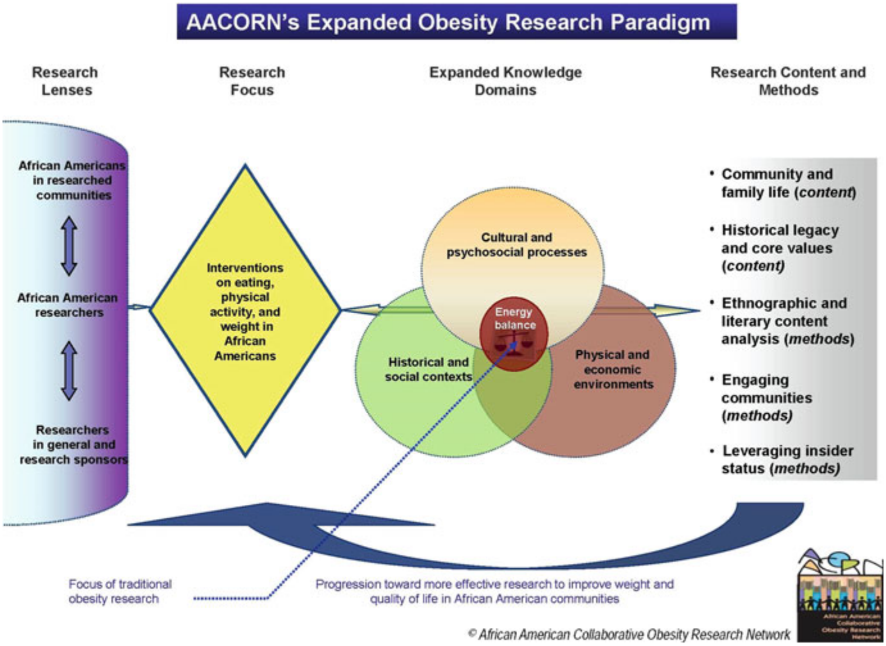

Fig. 22.1 The expanded obesity research paradigm of the African American Collaborative Obesity Research Network (AACORN)

intervention focus. The AACORN paradigm also suggests that intervention strategies should take into account cultural and psychosocial processes, historical and social contexts, and physical and economic environments, all of which influence how and why individuals in communities choose to engage in behaviours. Other racial/ethnic minority groups (e.g. Hispanics) are beginning to adapt the AACORN paradigm to design culturally relevant interventions (personal communication with David Marquez).

The AACORN paradigm is an example of how the factors, mentioned above, that influence sedentary behaviour can be incorporated into strategies to address sedentary behaviour in racial/ethnic minority groups. For example, in addition to providing education in adults, a successful strategy for addressing sedentary behaviour might incorporate the importance of family/friends, caregiving duties, and safety by suggesting family-based physical activities and emphasizing the importance of engaging in physical activity in addition to existing daily activities. Interventions could specifically target the sedentary times during the day and influence those rather than suggesting participants identify additional time to engage in leisure or exercise-related activities. Identifying strategies to address sedentary behaviour that are free or low cost could alleviate any socioeconomic concerns. Soliciting input from members of the communities in which interventions would be implemented would be helpful for incorporating additional feedback.

The AACORN paradigm is one example of addressing sedentary behaviour in racial/ethnic minority communities. Even if the AACORN paradigm is not used, what is evident is that sedentary behaviour is high in racial/ethnic minority communities; morbidity and mortality associated with sedentary behaviour are also high in racial/ethnic minority communities. Identifying successful paradigms and strategies to address sedentary behaviour in high-risk communities is a critical need.

22.5 Summary

Although intervention strategies have addressed sedentary behaviour in children, few studies have included a sufficient number of racial/ethnic minority children. Studies have shown mixed short-term and no long-term success. Almost no interventions have addressed sedentary behaviour in adults outside workplace settings, and participation of racial/ethnic minority groups in studies of adults is sparse. This chapter provided insight into the prevalence of sedentary behaviour in racial/ethnic minority groups, a review of strategies to address sedentary behaviour in racial/ethnic minority groups, and suggestions for how to improve interventions to address sedentary behaviour in the future. As sedentary behaviour has been deemed "the new smoking" because of its direct contribution to morbidity and mortality, identifying successful strategies to address sedentary behaviour in high-risk communities have the potential for a major public health impact.

References

1. Ahmed S, Uddin R, Ziviani J, Khan A. Global prevalence of physical activity, sedentary behaviour, and sleep of immigrant children: a systematic review. J Racial Ethn Health Disparities. 2021;8(6):1364–76.
2. Langoien LJ, Terragni L, Rugseth G, Nicolaou M, Holdsworth M, Stronks K, et al. Systematic mapping review of the factors influencing physical activity and sedentary behaviour in ethnic minority groups in Europe: a DEDIPAC study. Int J Behav Nutr Phys Act. 2017;14(1):99.
3. Sedentary Behaviour Research Network. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metab. 2012;37(3):540–2.
4. Owen N, Healy GN, Howard B, Dunstan DW. Too much sitting: health risks of sedentary behaviour and opportunities for change. Rockville, MD; 2012. Contract No.: 3.
5. Bassett DR Jr, Freedson P, Kozey S. Medical hazards of prolonged sitting. Exerc Sport Sci Rev. 2010;38(3):101–2.
6. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009;41(5):998–1005.
7. Stewart RA, Benatar J, Maddison R. Living longer by sitting less and moving more. Curr Opin Cardiol. 2015;30(5):551–7.
8. Chaput JP, Visby T, Nyby S, Klingenberg L, Gregersen NT, Tremblay A, et al. Video game playing increases food intake in adolescents: a randomized crossover study. Am J Clin Nutr. 2011;93(6):1196–203.

9. Bouchard C, Blair SN, Katzmarzyk PT. Less sitting, more physical activity, or higher fitness? Mayo Clin Proc. 2015;90(11):1533–40.
10. American Academy of Pediatrics. Children, adolescents, and television. Pediatrics. 2001;107 (2):423–6.
11. Physical Activity Guidelines Advisory Committee. Physical activity guidelines advisory committee report, 2008. Washington, DC: US Department of Health and Human Services; 2008.
12. U. S. Department of Health and Human Services. 2008 Physical Activity Guidelines for Americans 2008.
13. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, et al. Amount of time spent in sedentary behaviors in the United States, 2003-2004. Am J Epidemiol. 2008;167 (7):875–81.
14. Schuna JM Jr, Johnson WD, Tudor-Locke C. Adult self-reported and objectively monitored physical activity and sedentary behavior: NHANES 2005-2006. Int J Behav Nutr Phys Act. 2013;10:126.
15. Evenson KR, Buchner DM, Morland KB. Objective measurement of physical activity and sedentary behavior among US adults aged 60 years or older. Prev Chronic Dis. 2012;9(11): 110109.
16. Kenney MK, Wang J, Iannotti R. Residency and racial/ethnic differences in weight status and lifestyle behaviors among US youth. J Rural Health: Official Journal of the American Rural Health Association and the National Rural Health Care Association. 2014;30(1):89–100.
17. Seguin R, Buchner DM, Liu J, Allison M, Manini T, Wang CY, et al. Sedentary behavior and mortality in older women: the Women's Health Initiative. Am J Prev Med. 2014;46(2):122–35.
18. Sweatt SK, Willig AL, Agne AA, Powell JL, Cherrington AL. Physical activity patterns of Latina immigrants living in Alabama. J Racial Ethn Health Disparities. 2015;2(3):365–72.
19. Afable A, Yeh MC, Trivedi T, Andrews E, Wylie-Rosett J. Duration of US residence and obesity risk in NYC Chinese immigrants. J Immigr Minor Health/Center for Minority Public Health. 2016;18(3):624–35.
20. Almeida J, Duncan DT, Sonneville KR. Obesogenic behaviors among adolescents: the role of generation and time in the United States. Ethn Dis. 2015;25(1):58–64.
21. Schmidt ME, Haines J, O'Brien A, McDonald J, Price S, Sherry B, et al. Systematic review of effective strategies for reducing screen time among young children. Obesity (Silver Spring, Md). 2012;20(7):1338–54.
22. Ford BS, McDonald TE, Owens AS, Robinson TN. Primary care interventions to reduce television viewing in African- American children. Am J Prev Med. 2002;22(2):106–9.
23. Marsh S, Foley LS, Wilks DC, Maddison R. Family-based interventions for reducing sedentary time in youth: a systematic review of randomized controlled trials. Obes Rev. 2014;15(2): 117–33.
24. Wahi G, Parkin PC, Beyene J, Uleryk EM, Birken CS. Effectiveness of interventions aimed at reducing screen time in children: a systematic review and meta-analysis of randomized controlled trials. Arch Pediatr Adolesc Med. 2011;165(11):979–86.
25. Friedrich RR, Polet JP, Schuch I, Wagner MB. Effect of intervention programs in schools to reduce screen time: a meta-analysis. J Pediatr. 2014;90(3):232–41.
26. Bouchard DR, Strachan S, Johnson L, Moola F, Chitkara R, McMillan D, et al. Using shared treadmill workstations to promote less time spent in daily low intensity physical activities: a pilot study. J Phys Act Health. 2016;13(1):111–8.
27. Neuhaus M, Eakin EG, Straker L, Owen N, Dunstan DW, Reid N, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. Obes Rev. 2014;15(10):822–38.
28. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Bhaumik S. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2016;3:CD010912.
29. Conn VS, Coon Sells TG. Effectiveness of interventions to increase physical activity among minority populations: an umbrella review. J Natl Med Assoc. 2016;108(1):54–68.

30. Whitt-Glover MC, Keith NR, Ceaser TG, Virgil K, Ledford L, Hasson RE. A systematic review of physical activity interventions among African American adults: evidence from 2009 to 2013. Obes Rev. 2014;15(Suppl 4):125–45.
31. Whitt-Glover MC, Brand DJ, Turner ME, Ward SA, Jackson EM. Increasing physical activity among African-American women and girls. Curr Sports Med Rep. 2009;8(6):318–24.
32. Whitt-Glover MC, Kumanyika SK. Systematic review of interventions to increase physical activity and physical fitness in African-Americans. Am J Health Promot: AJHP. 2009;23(6): S33–56.
33. Conn V, Phillips L, Ruppar T, Chase J-AD. Physical activity interventions with healthy minority adults: meta-analysis of behavior and health outcomes. J Health Care Poor Underserved. 2012;23(1):59–80.
34. Banks-Wallace J, Conn V. Interventions to promote physical activity among African American women. Public Health Nurs. 2002;19(5):321–35.
35. Henderson KA, Ainsworth BE. Research leisure and physical activity with women of color: issues and emerging questions. Leis Sci. 2001;23:21–34.
36. Henderson KA, Ainsworth BE. A synthesis of perceptions about physical activity among older african american and american Indian women. Am J Public Health. 2003;93(2):313–7.
37. Henderson KA, Ainsworth BE. Enablers and constraints to walking for older African American and American Indian women: the cultural activity participation study. Res Q Exerc Sport. 2000;71(4):313–21.
38. Henderson KA, Ainsworth BE. Sociocultural perspectives on physical activity in the lives of older African American and American Indian women: a cross cultural activity participation study. Women Health. 2000;31(1):1–20.
39. McDonald NC. Critical factors for active transportation to school among low-income and minority students. Evidence from the 2001 National Household Travel Survey. Am J Prev Med. 2008;34(4):341–4.
40. Rees R, Kavanagh J, Harden A, Shepherd J, Brunton G, Oliver S, et al. Young people and physical activity: a systematic review matching their views to effective interventions. Health Educ Res. 2006;21(6):806–25.
41. Boyington JE, Carter-Edwards L, Piehl M, Hutson J, Langdon D, McManus S. Cultural attitudes toward weight, diet, and physical activity among overweight African American girls. Prev Chronic Dis. 2008;5(2):A36.
42. Hsu YW, Belcher BR, Ventura EE, Byrd-Williams CE, Weigensberg MJ, Davis JN, et al. Physical activity, sedentary behavior, and the metabolic syndrome in minority youth. Med Sci Sports Exerc. 2011;43(12):2307–13.
43. Stathi A, Gilbert H, Fox KR, Coulson J, Davis M, Thompson JL. Determinants of neighborhood activity of adults age 70 and over: a mixed-methods study. J Aging Phys Act. 2012;20(2): 148–70.
44. Sander AP, Wilson J, Izzo N, Mountford SA, Hayes KW. Factors that affect decisions about physical activity and exercise in survivors of breast cancer: a qualitative study. Phys Ther. 2012;92(4):525–36.
45. Casagrande SS, Whitt-Glover MC, Lancaster KJ, Odoms-Young AM, Gary TL. Built environment and health behaviors among African Americans: a systematic review. Am J Prev Med. 2009;36(2):174–81.
46. Whitt-Glover MC, Bennett G, Sallis JF. Introduction to the active living research supplement: disparities in environments and policies that support active living. Ann Behav Med. 2013;45 (Suppl 1):S1–5.
47. Ainsworth BE, Wilcox S, Thompson WW, Richter DL, Henderson KA. Personal, social, and physical environmental correlates of physical activity in African-American women in South Carolina. Am J Prev Med. 2003;25(3 Suppl 1):23–9.
48. Sanderson BK, Foushee HR, Bittner V, Cornell CE, Stalker V, Shelton S, et al. Personal, social, and physical environmental correlates of physical activity in rural African-American women in Alabama. Am J Prev Med. 2003;25(3 Suppl 1):30–7.

49. Voorhees CC, Rohm YD. Personal, social, and physical environmental correlates of physical activity levels in urban Latinas. Am J Prev Med. 2003;25(3 Suppl 1):61–8.
50. Wilbur J, Chandler PJ, Dancy B, Lee H. Correlates of physical activity in urban Midwestern African-American women. Am J Prev Med. 2003;25(3 Suppl 1):45–52.
51. Airhihenbuwa CO, Kumanyika S, Agurs TD, Lowe A. Perceptions and beliefs about exercise, rest, and health among African-Americans. Am J Health Promot: AJHP. 1995;9(6):426–9.
52. Whitt-Glover MC, Borden SL, Alexander DS, Kennedy BM, Goldmon MV. Recruiting African American churches to participate in research: the learning and developing individual exercise skills for a better life study. Health Promot Pract. 2016;17(2):297–306.
53. Whitt-Glover MC, Goldmon MV, Karanja N, Heil DP, Gizlice Z. Learning and developing individual exercise skills (L.A.D.I.E.S.) for a better life: a physical activity intervention for black women. Contemp Clin Trials. 2012;33(6):1159–71.
54. Thivel D, Aucouturier J, Metz L, Morio B, Duche P. Is there spontaneous energy expenditure compensation in response to intensive exercise in obese youth? Pediatr Obes. 2014;9(2): 147–54.
55. Noted sociologist says fears keep many African Americans from exercising. The Winston-Salem Chronicle. 2013.
56. Womack VY, Ning H, Lewis CE, Loucks EB, Puterman E, Reis J, et al. Relationship between perceived discrimination and sedentary behavior in adults. Am J Health Behav. 2014;38(5): 641–9.
57. Gicevic S, Aftosmes-Tobio A, Manganello JA, Ganter C, Simon CL, Newlan S, et al. Parenting and childhood obesity research: a quantitative content analysis of published research 2009–2015. Obes Rev. 2016;17(8):724–34.
58. Kumanyika SK, Whitt-Glover MC, Gary TL, Prewitt TE, Odoms-Young AM, Banks-Wallace J, et al. Expanding the obesity research paradigm to reach African American communities. Prev Chronic Dis. 2007;4(4):A112.

Chapter 23
Sedentary Behaviour at the Community Level: Correlates, Theories, and Interventions

Krista S. Leonard, Sarah L. Mullane, Mark A. Pereira, and Matthew P. Buman

Abstract This chapter provides an overview of sedentary behaviour correlates, theories, and interventions in youth communities (schools), adult communities (worksites), and neighbourhoods. Within each community, we identify and discuss (a) observational and experimental studies examining the correlates of sedentary behaviour; (b) demographic, psychosocial, and environmental factors that influence sedentary behaviour (including sedentary behaviour during the COVID-19 global pandemic); and (c) intervention designs and outcomes targeting sedentary behaviour. How technological advances and media influence may impact public awareness and intervention design is discussed. We also highlight the roles and responsibilities of both research and public health organisations to promote healthy behaviours. Finally, we evaluate community-based interventions to provide recommendations and future directions. We conclude that the barriers and challenges faced at the community level for reducing sedentary behaviours may vary per community setting and type. Ultimately, multi-level strategies and collaborative practices, across multiple settings that target sedentary behaviour as an independent risk factor, are needed to improve the efficacy of community-level interventions and increase the potential for future dissemination.

K. S. Leonard (✉) · M. P. Buman
College of Health Solutions, Arizona State University, Phoenix, USA
e-mail: krista.leonard@asu.edu; mbuman@asu.edu

S. L. Mullane
Johnson & Johnson Health and Wellness Solutions, New Brunswick, USA
e-mail: SMullan1@its.jnj.com

M. A. Pereira
School of Public Health, University of Minnesota, Minneapolis, USA
e-mail: perei004@umn.edu

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_23

What Is New?

- The impact of the COVID-19 pandemic on sedentary behaviours in schools, workplaces, and neighbourhoods is discussed.
- Additional evidence of observational studies of the neighbourhood environment and sedentary behaviour is included.
- Further evidence for the evolution of community-based interventions targeting sedentary behaviour is discussed.
- Following advancements in technology, more evidence for the role of technology and media in decreasing sitting time is further discussed.

23.1 Models and Theories of Community-Level Sedentary Behaviour

Community-level settings—schools, worksites, neighbourhoods, and other public spaces—have been shaped to minimise human movement and muscular activity [1, 2]. This minimisation of human movement within these public settings has been exacerbated by the shelter-in-place recommendations and transition to virtual work and school environments due to the COVID-19 pandemic [3, 4]. Ultimately these settings have caused people to move less and sit more. Influences on sedentary behaviour can be considered across five domains: demographic, biological, psychosocial, behavioural, and environmental [5]. We discuss numerous demographic, psychosocial, and environmental factors that influence community-level sedentary behaviour within three main environments—youth communities (schools), adult communities (worksites), and both adult and child communities (neighbourhoods). For biological and behavioural factors at the individual level, see Chaps. 5 and 16. It is important to clearly distinguish sedentary time, the exposure of interest in this chapter, from overall physical activity. This distinction forms the foundation of sedentary behaviour evolution that is prominent at the community level and has shaped measures and interventions in recent years. We posit correlates and determinants of community-based sedentary behaviour across schools, worksites, and neighbourhoods (see Fig. 23.1) play a pivotal role in the design, feasibility, and efficacy of community-level interventions.

23.1.1 Theoretical Overview: What Is Sedentary Behaviour?

In the free-living, full-functioning, healthy population, sedentary behaviour can be defined as spending time in a seated or reclining posture with low levels of energy expenditure, <1.5 metabolic equivalents (METs) [6]. Activities that involve sitting are most often assessed for estimating the quantity of time an individual is sedentary. Most common sedentary activities are sitting while watching television, using a

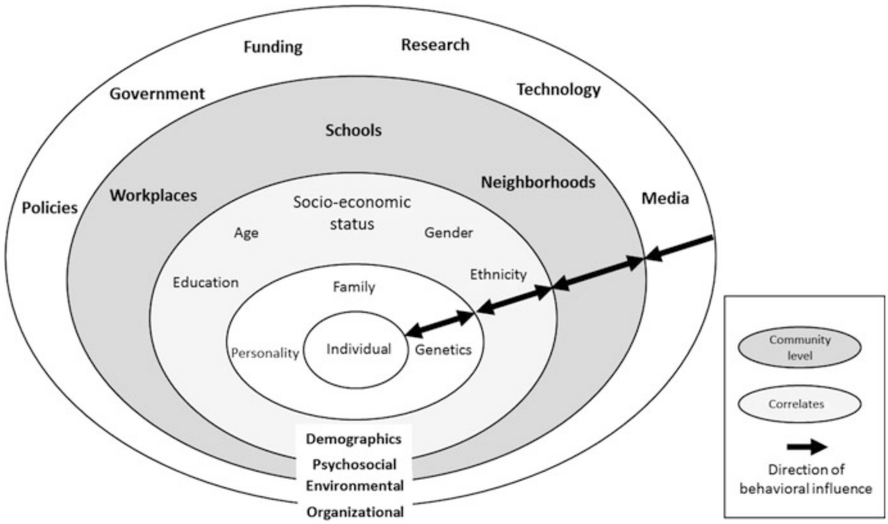

Fig. 23.1 A summary of the community correlates and determinants of sedentary behaviour

computer, playing video games, board games, card games, sewing, talking on the telephone, and reading, working in sedentary occupations that require sitting while doing paperwork, computer work, phone calling, business meetings, etc., and sitting while transporting by car, bus, train, plane, ferry, etc. Due to measurement challenges, it is often difficult to distinguish sedentary time from light physical activity that includes standing, "fidgeting", and "moving about" intermittently. It is suggested that increases in sedentary lifestyles, urbanisation, and changes in modes of transportation each have a contributory effect to the rising rates of sedentary behaviour [6, 7], all of which can be targeted at the community level. It is important to note that evidence regarding how the recent COVID-19 pandemic has influenced sedentary behaviours has begun to emerge. This chapter reflects on the impact of COVID-19 on sedentary behaviours across the community-level settings of schools, workplaces, and the neighbourhood in Sect. 23.1.5.

23.1.2 Schools: Youth Communities

Children are naturally born active [6, 8] but are exposed to opportunities and environments that cause them to be sedentary on a daily basis [9–11]. Sedentary behaviour for children may include sitting in the classroom, sitting during lunchtime, watching TV, playing computer games, completing homework, and passive transport [12–14]. Most commonly, childhood sedentary behaviour is measured in relation to "screen time", however, non-screen time sedentary behaviour accounts for 54% to 60% of overall sedentary time in school-aged children [15, 16]. The education system is influential during the early stages of psychosocial and physical development, as children spend >40% of their waking time in school [17]. American children spend an average length of 6.8 hours per day, or ~ 34 h per week, at school. Two recent studies observed that children and adolescents spend 54% to 77% of their school-time in sedentary behaviours and only 3% to 22% of their school-time in moderate or vigorous physical activity globally [18–20]. Time at school is responsible for the highest proportion (44%) of all non-screen sedentary time in children [18]. Therefore, the school environment presents an opportune community setting for sedentary behaviour reduction strategies [12, 19].

23.1.3 Workplaces: Adult Communities

Sedentary behaviour is still a widely unrecognised risk in many worksites as the design of those environments has evolved to facilitate excessive bouts of prolonged sedentary time. Moderate-to-vigorous physical activity has been engineered out of many workplaces by shifting work toward service economies (away from manufacturing) and associated technological advances (e.g., email, telephones, computer networks). Over the past 50 years, the percentage of jobs in the US involving moderate-to-vigorous physical activity has fallen, with 64% of jobs requiring sedentary behaviours or minimal physical activity [21]. American adults currently spend over 7.7 h/day engaged in sedentary behaviour, most of which occurs at work, where 70% to 90% of their time is spent sitting [6, 22–25]. Further, adults do not appear to compensate for excessive sedentary time during work by increasing light physical activity or moderate-to-vigorous physical activity after work, particularly if workers reported experiencing fatigue following a typical day at work [26]. Thus, the workplace serves as a critical setting for sedentary behaviour reduction strategies in adults.

23.1.4 Neighbourhoods: Adult and Child Communities

The neighbourhood around which the individual resides has many important characteristics that may influence the individual's physical activity. Neighbourhoods, by definition, pertain to a formed community within a town or city and can therefore be used as a platform for community-level sedentary behaviour reduction strategies targeting both adult and youth populations. Recent reviews have emerged on theoretical models of how neighbourhood characteristics impact physical activity and sedentary behaviour [27–30]. A common model discussed is the socioecological model with the individual at the centre and a number of layers of influence extending outward. For more details on the ecological model as applied to sedentary behaviour, see Chap. 15. Theoretically, environmental characteristics that limit opportunities to sit and promote opportunities to stand and move about are key parameters that need to be examined as important environment stimuli towards reducing sitting and increasing light activity, while not necessarily increasing physical activity in the traditional sense as defined above. The design and social and cultural structure, including many aspects of the built environment, natural environment, government policies, crime rates and perceived safety, economic factors, and weather/climate are all examples of neighbourhood and surrounding community characteristics that can influence sedentary time, independent of any influence on physical activity.

Theoretically, if an environmental feature, however specifically or broadly defined, is hypothesised to trigger, whether in subtle or more direct/obvious ways, opportunities to sit or lie down, or opportunities to stand and move, then that feature needs to be given attention when we assess ways that our environment might be importantly impacting sedentary behaviour. We can then move forward to inform the design of possible interventions at the neighbourhood level to influence the sedentary behaviour of the neighbourhood population. We discuss the potential demographic, psychosocial, and environmental factors stemming from schools, workplaces, and neighbourhoods, such as the community climate or culture [31], grade level [32], socioeconomic impacts [33], and more indirect factors such as attitudes towards active transport [34, 35] and climactic barriers [36], that may influence sedentary behaviours at the community level.

23.1.5 COVID-19 and Sedentary Behaviours

On March 11, 2020, the World Health Organisation (WHO) declared the COVID-19 outbreak to be a pandemic. Following this declaration, many countries released social distancing, confinement, and shelter-in-place rules and recommendations. Increases in sedentary behaviours have since been exacerbated by the COVID-19 pandemic globally. Due to elements of the individual (e.g., illness, fear) and environment (e.g., shelter in place, school closures), the COVID-19 pandemic itself has resulted in an increase in sedentary behaviours across all contexts of the community. These behavioural patterns were apparent even early into the pandemic. Dunton et al. [37] found that parents perceived decreases in their children's (ages 5–13) physical activity and increases in their sedentary behaviours from pre-COVID-19 (February 2020) to early-COVID-19 (April–May 2020). Moreover, parents reported that children engaged in 90 minutes of sitting due to remote learning/online school and over 8 hours of leisure-related sitting a day. Similarly, decreases in physical activity and increases in sedentary behaviours were found in Canadian children (5–11 years) and youth (12–17 years) [38]. Xiang et al. [39] conducted a natural experimental longitudinal study in 2426 children and adolescents (6–17 years) in China from January 2020 to March 2020. Time spent in physical activity significantly decreased while total screen time increased during the pandemic by 30 hours per week. This is in line with research showing that screen time, particularly online/video gaming, has exponentially increased throughout the COVID-19 pandemic [40–42]. Sedentary behaviours have also increased among university students globally following the COVID-19 pandemic, particularly due to confinement rules [43–46]. Similarly, a study conducted in Spain found that in a sample of 3800 healthy adults (18–64 years), self-reported physical activity significantly decreased (17% decrease in vigorous physical activity; 58% decrease in walking) while sedentary time increased by 24% during the confinement period due to the pandemic; these changes were more apparent in men than women [47].

Within the work context, sedentary behaviours have increased drastically following the COVID-19 pandemic. Prior to the pandemic, research showed that a flexible work policy (i.e., allowing work from home) resulted in an increase in sitting time [48]. Following the pandemic, approximately 72% of US workers shifted to working entirely from home in May–June 2020, compared to 8% in February 2020, with some organisations making the switch to working from home a permanent one [49, 50]. Unsurprisingly, McDowell et al. [51] found that in 2303 US adults, self-reported sitting time was higher in those who began working from home due to COVID-19 compared to those who remained working in their workplace. In a survey of 3607 employees from eight US companies, 51% of respondents reported an increase in screen time from before to during the pandemic, whereas only 2.7% reported a decrease in screen time [4]. Similarly, Gibbs et al. [49] examined the longitudinal impact of COVID-19 on sedentary behaviours among 112 US desk workers and found over an hour per day increase in total sedentary behaviours from before to during shelter-at-home recommendations (i.e., remote work). Fukushima et al. [52] surveyed 1239 workers in Japan and found that sedentary behaviours during work hours were almost 2 hours higher in those working from home compared to those not working from home.

While the global shelter-in-place recommendations have resulted in an overall increase in sedentary behaviours, this decrease has been more apparent in some environment than others. Mitra et al. [53] sought to examine how changes in physical activity and sedentary behaviours were associated with the built environment in children and youth (5–17 years) in Canada. One month after the announcement of the global pandemic, children and youths' physical activity decreased, whereas sedentary behaviours increased. Further, the investigators found that children and youth living in houses, living further from a major road (e.g., highway), and living in a low-density neighbourhood, were more likely to increase outdoor activity compared to children and youth living in apartments, living close to a major road, and living in high-density neighbourhoods, respectively. These findings highlight the importance of characteristics of neighbourhood environments on physical activity and sedentary behaviours during the COVID-19 pandemic and can be used to inform public health policies to prepare for future pandemics.

In summary, researchers' fear that the lasting effects of the COVID-19 pandemic will be unknown for some time and that decreases in physical activity and increases in sedentary behaviours during the COVID-19 pandemic may long persist even after life begins to "return to normal" [54]. Researchers have suggested that future interventions addressing the immediate and lasting effects of the COVID-19 pandemic on physical activity and sedentary behaviours should take a multi-level approach (e.g., social-ecological model) to address strategies at all levels (e.g., policy, community organisations, educators, healthcare providers, parents, etc.) [55].

23.1.6 Demographic Factors

At the school community level, recent research has identified several demographic associations between sedentary behaviour and the school environment. A study of adolescents ($n = 970$) aged 10–13 years in Finland wore accelerometers for seven consecutive days five times during a two-year follow-up period [56]. The results indicated that adolescents spent 40–43 min/hr. in sedentary time and 2–3 min/hr. in moderate-to-vigorous physical activity during school. Further, sex differences were apparent; girls spent a significantly larger amount of school-time in sedentary activities (42–45 min/hr) than boys (38–41 min/hr), and spent less time in moderate-to-vigorous physical activity (2–3 min/hr. versus 3–4 min/hr). These observations are supported by previous research that identified sex as a main predictor of weekday sedentary behaviour in adolescents; higher levels of objective sedentary behaviour levels were detected in girls compared to boys. A similar relationship was also observed in countries such as Brazil [57, 58] and Canada [59]. Progression into higher education is also associated with increased pressure to study and accompanying prolonged periods of sitting [32]. Conversely, curriculum activities at lower grade levels may change from interactive motor skill learning and development (that may require more movement) to more traditional academic learning at higher grade levels.

In a recent study, desk-based employees reported more than three-quarters of their daily sitting being accrued during occupational pursuits [23], representing a substantial amount of overall sitting being accounted for within this context. Among demographic correlates, age appears to be an important correlate of sedentary behaviour. A review found that some studies have reported older age is associated with higher occupational sedentary behaviour whereas one reported older age is associated with less occupational sedentary behaviour [60]. Furthermore, individuals with higher body mass index (BMI) reported greater occupational sitting [60]. Two recent cross-sectional studies of US adult workers revealed that gender was a strong correlate of occupational sedentary behaviours; women sat longer during the workday, whereas men stood more during the workday [61, 62]. Further, studies have shown that individuals with a higher/advanced education and higher income sit more during work compared to individuals with a lower education and lower income, respectively [60, 61]. A recent study of European adults identified the type of occupation as the strongest predictor of sitting time. Specifically, adults with white-collar jobs were at the highest risk of high sitting time (e.g., >7.5 h/day) [60, 63]. Further, other studies have shown that private sector employees and office workers sat more during work compared to public sector employees and non-office workers, respectively [24, 60, 64]. Full-time employees reported higher levels of occupational sitting than part-time employees. Finally, time during the workday also appears to be associated with sitting and standing time. In a sample of working adults in Japan, temporal associations with device-based sedentary behaviours were examined on both working and non-working days [65]. On both working and non-working days, time spent in sedentary behaviours was lowest during the morning (6:00–11:59) and highest in the evening (18:00–23:59). This temporal pattern is supported by other research as well [66]. The authors suggested these temporal associations may be due to the interaction between physical and psychological conditions (e.g., more energetic in the morning after sleep), basic lifestyles (e.g., engaging in working tasks by daylight), and social structures (e.g., scheduled working).

The resources available to a community (money, time, space, and staffing) may affect sedentary behaviours. It is reported that schools in low-socioeconomic (SES) communities have a distinct lack of social, financial, and instructional resources [67]. Such resource constraints may restrict the time, space, and staffing available to implement innovative teaching and workplace or neighbourhood strategies that aim to reduce sedentary behaviour. A recent study investigating differences in knowledge and behaviours related to active living between schools with contrasting SES and racial characteristics in the US found that adolescents in the low SES school had higher sedentary behaviours and lower physical activity and fitness knowledge compared to adolescents in medium SES schools [33]. Further, adolescents in the low SES school engaged in more TV viewing, video games, and cell phone use compared to adolescents in the medium SES school. In addition to the low physical activity and fitness knowledge in adolescents at the low SES school, the investigators posited that the SES-based disparity in sedentary behaviours may be due to other factors such as lack of resources (e.g., time, financial, etc.). Nevertheless, the school-level SES-based disparities suggest future research is needed to identify how to best close these gaps and also provide important public health implications suggesting policy makers and educational professionals may want to allocate more resources and efforts to help minimise these disparities. Other demographic comparisons are more inconsistent. In a baseline cohort of children and adolescents in Spain, sociodemographic and family circumstances were differently associated with sedentary behaviours based on domain-specific sedentary behaviours and sex [68]. For example, paternal university education level and maternal occupation were associated with higher total sedentary behaviours on weekdays in boys only, whereas maternal university level education was associated with higher education-based sedentary behaviours in girls only.

23.1.7 Psychosocial Factors

Understanding and changing behaviour at the community level is highly dependent on what is considered “acceptable behaviour”. The social norms and policies in a school or workplace environment are highly dependent upon the “school climate” [31] or worksite culture. The school or worksite climate is dictated by the attitudes of all community members. Historically, the school classroom is seen as a place for children to remain seated at their desk, and often children are instructed to engage in "seatwork" [69]. Remaining seated and present at your desk may also be considered a desirable characteristic in the workplace. Conversely, both in the workplace and school environment, leaders or teachers may use standing as a tool to direct attention to a staff member or student. Fewer psychosocial correlates have been identified for occupational sitting. Lafrenz et al. found that higher enjoyment of breaks from sedentary behaviour as well as higher perceived direct supervisor support of active breaks were associated with less sedentary behaviours during the workday [70]. Also, Wilkerson et al. found that employees with higher barrier self-efficacy of standing (i.e., higher confidence to overcome barriers that impede the ability to reduce sitting), higher use of self-regulation strategies (e.g., standing breaks), and positive social norms were associated with higher standing time during work [62]. However, some research has shown that employees sit more during work because they believe it is the norm, whereas standing is counter-normative and may distract colleagues [71]. Other correlates of occupational sitting include perceived behavioural control (i.e., "it is my choice whether I stand up or sit at my desk while I work"), perceived advantages of sitting less, and habit strength. Specifically, increasing perceived behavioural control and increasing perception of the advantages of reduced sitting is associated with less time spent sitting during the workday, whereas a stronger habit of sitting without thinking was associated with increased time spent sitting during work [71, 72].

The learning and working environments are also evolving. Advances in technology have changed the way children, adults, and employees may interact. Many schools are embracing interactive e-learning tools and activities that replace or supplement more traditional teaching methods. However, it is unknown whether a reliance on e-learning may reduce social interaction and opportunity to move in the classroom more than traditional teaching methods. It is also reported that approximately 6.9 million students take at least one online course of any kind [17]. This number has exponentially increased following the COVID-19 pandemic. Following the declaration of the COVID-19 pandemic, schools began to announce closures affecting 666.7 million learners globally, equating to 42% of total enrolled learners [73]. As such, the learning space has become more complex with schools embracing full or hybrid online and virtual learning programs. This change has sparked the conversation of redesigning physical learning spaces with the discussion of permanently adopting remote learning spaces. Although the prevalence of e-learning may reinforce "screen-time", it may also provide an opportunity to incorporate breaks to sitting time. The structure of the class and methods of delivery could be designed to promote breaks to sitting time (i.e., segmented lectures <30 minutes). Additionally, students are less exposed to the social norms of the school climate and may feel more comfortable standing or moving while learning. Further research is needed to investigate these important and plausible interactions.

23.1.8 Environmental Factors

At the environmental level, correlates and determinants of sedentary behaviour are complex and multi-faceted. For example, methods of transport to school and work are influenced by many neighbourhood characteristics. Two recent reviews found that destination-related attributes such as longer distances from workplace to home and access to car parking were positively associated with transport-related sedentary behaviours [74, 75]. Specific to the workplace, changing the environment so that it is conducive to standing and moving more has considerable cost implications. A possible solution that is already being adopted in the adult workplace is the installation of sit–stand desks. The adoption of sit–stand desks may be an important part of the solution at work as employees have reported that building layouts serve as a barrier to standing and moving (e.g., staircase location) and that they feel the workplace is designed for sitting with many factors anchoring them to the desk (e.g., computer, phone, etc.) [71, 75]. Micro-environmental features within the workplace are increasingly being recognised as important factors associated with occupational sitting. Local connectivity (e.g., ability to use different routes to travel through a workplace) and overall connectivity (e.g., travel to and from workstation requires frequent changes in direction) have been positively associated with standing during the workdays, whereas proximity of co-workers (e.g., lots of other workstations/desks in surrounding area) has been negatively associated with standing time [62]. Further, compared to public offices (e.g., cubicle, open space), private offices (e.g., enclosed, not shared) have been shown to have an association with more sitting time, less standing time, and more prolonged sitting throughout the workday [76]. A recent study found that employees spend the majority of their workday alone working at their desk and that the majority of the desk time is spent sitting [66]. This observation supports past research [77] that found the majority of sitting time occurs at the employee's primary desk, with additional sitting occurring at other desks in the workplace. Most sit-to-stand transitions and standing occurred at the employee's primary desk, with additional standing occurring at other desks and in the kitchen/cafeteria areas. The vast majority of stepping behaviours occurred in the corridors of the workplace [66]. Identifying patterns of workplace sitting is critical for understanding how and when to best intervene upon these behaviours as the exposure of the intervention can be adjusted to fit the patterns of the individual (e.g., a sit–stand desk may be more useful for an employee who obtains most of their sitting time at their primary desk). Environmental changes such as sit–stand desks are also extending to the school community [78]. However, funding such large-scale environmental changes is dependent on support from educational and governmental bodies that extends beyond the provision of traditional resources and is a major challenge for environmental community strategies. Acceptance and understanding the value of such changes is reliant upon successful interventions that demonstrate health and educational benefits.

One of the few studies to examine correlates of child sedentary behaviour other than screen time reported that parents' travel to work and parental attitudes and support to their child walking or biking to school were strong correlates of children's active transport [34, 35]. Such factors may indirectly impact the hypothesised innate activity set-point (termed the "activitystat") [79]. This theory suggests that children compensate for reduced sedentary behaviour by increasing it at another time point, with no effect on overall sedentary time. Therefore, transport to school (whether active or passive) may influence sedentary behaviour levels throughout the school day both in the classroom and during recess or outside of the school day. For example, a recent study found that adolescents who used active school commuting for 3 days or more per week had 17% lower odds of reporting high sedentary behaviours after school (not doing homework) [80]. Over the past few decades, active transportation has consistently declined with only 9.6% and 1.1% of children and adolescents aged 5–17 years walking or biking to school, respectively [81]. Many studies have identified that distance to school is the primary barrier to active transportation such that rates of walking/biking to school decrease as the distance to school increases [81–86]. There are numerous neighbourhood-based contributing factors to this barrier such as increasing land costs, school siting standards, school funding formulas, existing land use policies, and lack of coordination between planners and school officials. Correlates of active transport also include other aspects of the built and natural environment such as urbanicity, presence of highways and railroads, steep slopes, intersection density, and tree canopy coverage [87].

Private vehicle use has grown exponentially in the last 50 years. Therefore, the contemporary social norms of habitual personal vehicle use in the United States have made it easier to avoid active transport (i.e., active transport decreases with increases in vehicle ownership) [81, 86]. Child- and parental-perceived neighbourhood crime and real crime as well as parental-perceived concerns of traffic safety were also identified as barriers to active transport [82, 84, 86, 87]. Further, school policies can also be a barrier to active transport. Whether schools allow children to walk or bike to school and the availability of secure bicycle sheds could prevent children from walking or cycling to school. It is important to note that transport to and from school may only be an appending component of overall school-based sedentary behaviour. According to the "activitystat" theory, active transport may in fact increase sedentary behaviour levels during school hours. Alternatively, school policies that encourage active transport may also be more likely to enforce policies that reduce sedentary behaviour throughout the school day. Therefore, the American Heart Association (AHA) recently released a statement encouraging policies that promote increases in active transportation across multiple sectors [88]. For example, the AHA recommends that cities and communities, and school district policies can adopt Safe Routes to School initiatives to facilitate safe active commuting to and from school. More research is needed to fully understand the relationship between community-level policies and behaviour. Research also suggests that climate conditions may influence sedentary behaviour [36, 89–92]. Studies have consistently found that sedentary behaviours in children, adolescents, adults, and older adults are highest during winter months compared to spring or summer months and when there is high rainfall and snow [36, 89–92]. Further, days with higher temperatures and higher relative humidity were associated with greater sedentary time [91]. Higher ambient temperatures may encourage children and adults to substitute indoor leisure behaviours with other less sedentary outdoor activities. Therefore, seasonality and climate may be considered an important factor to consider in sedentary behaviour reduction programs in schools, workplaces, and neighbourhoods. Such influences may differ in climate-extreme countries, within country regions, and across periods of the year, so cross-cultural and cross-geographical comparisons over different seasons are warranted.

A majority of the evidence relating to sedentary behaviour to health at the community level stems from studies of self-reported TV viewing and associations with overweight and obesity [93]. Research is lacking on sedentary behaviour independent of physical activity and focusing on measures other than screen-time. Similarly, research conducted during school or work hours is largely dominated by the correlates and determinants of physical activity rather than sedentary behaviour. Despite these research gaps, we anticipate that the ongoing paradigm shift will lead to an increase in interventions specifically dedicated to device-based measures of sedentary behaviour in school, workplace, and neighbourhood settings.

23.2 Community-Level Sedentary Behaviour Interventions

Publications regarding physical activity interventions at the community level are prevalent; however, more recent interventions are focusing on reducing sedentary behaviour. To demonstrate the evolution of sedentary behaviour research at the community level, we first use the school community as a case example to discuss the varying strategies and outcomes when measuring sedentary behaviour as an indicator of insufficient physical activity levels. We suggest that the evolution of community-level intervention experimental design (illustrated in Fig. 23.2) is a good representation of the paradigm shift towards the focused study of sedentary behaviour independent of physical activity. Finally, we migrate to more recent community interventions that specifically implement sedentary behaviour reduction strategies in recent years (see Fig. 23.2). For the purpose of this chapter, we do not discuss all interventions listed in Fig. 23.2 in detail but identify them to illustrate their evolution and to facilitate further reading.

23.2.1 Measuring Sedentary Behaviour as an Indicator of Insufficient Physical Activity Levels in Schools

Early research in the school environment primarily focused on measuring sedentary behaviour as an indicator of insufficient physical activity. Traditional methods were implemented, such as adapting the curriculum to include lessons dedicated to

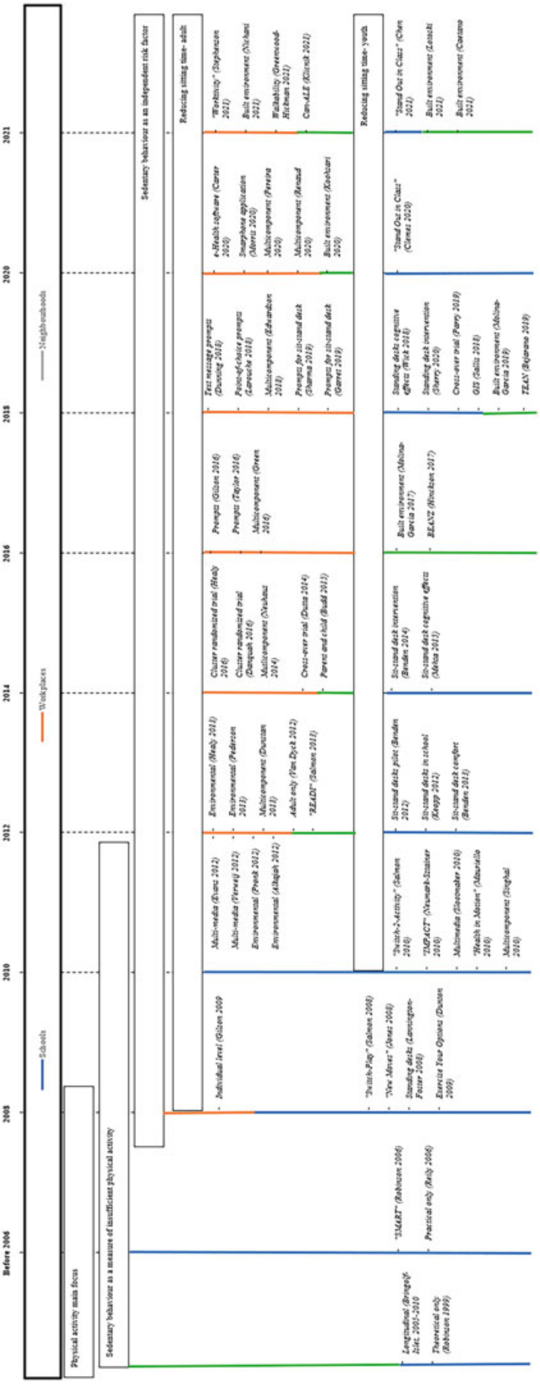

Fig. 23.2 The evolution of sedentary behaviour interventions

increasing physical activity and reducing sedentary behaviour. Findings have proved to be inconsistent. An earlier study conducted by Robinson [94] randomly assigned third and fourth graders in one of two public elementary schools to receive an 18-lesson, 6-month classroom curriculum to reduce TV, video, and video game use, in addition to lessons promoting physical activity. No structured practical lessons (sedentary behaviour- or physical activity-based) were implemented, and all content was delivered via traditional teaching methods in the classroom. The intervention group consisted of 92 children (9.0 ± 0.6 years) vs 100 children (8.9 ± 0.7 years) in the control group. Overall, reduced levels of TV use were reported (8.8 vs 14.5 hours/week); however, no significant changes were reported in video viewing and video game use. A subsequent classroom curriculum follow-up study with the same experimental design (Student Media Awareness to Reduce Television [SMART]) supported these findings [95]. Children in the treatment group significantly decreased their weekday TV viewing (1.1 vs. 2.0 hours/day [intervention vs control]), weekday video game playing (0.2 vs. 0.5 hours/day), and Saturday video game playing (0.3 vs. 0.9 hours/day). Greater effects were also detected among boys and adult-supervised children. Although no practical sedentary behaviour techniques were used, we suggest that reinforcement (required for behaviour change) for this experimental design was high due to the regular face-to-face interaction with the teacher, a home device seen daily, and the newsletter content that may be reinforced at the parental level.

In contrast, a classroom-based group randomised trial called “Switch-Play” was delivered to 311 children in grade level five [96]. Within three primary schools, classes were randomly assigned to one of four groups: (1) control group, (2) behavioural modification group (BM), (3) fundamental skills group (FMS), and a combined behavioural modification and fundamental skills group (BM/FMS). In this section, we focus on the BM results. The BM consisted of 19 lessons based on social cognitive theory [97] and targeted self-monitoring, decision-making, identifying alternative activities, intelligent viewing, and advocacy (via posters and role-playing) to reduce TV viewing time [96]. However, compared to the control, the BM group reported higher levels of TV viewing post-intervention. As children learned more about TV viewing and how to monitor it, reporting accuracy may have improved over time. This phenomenon is known as a “response shift bias” and suggests that based on learning effects, there is a differential favourable shift in the accuracy of reporting among children in the intervention group compared with those in the control group [98]. To further investigate teaching methods solely reliant on behavioural modification content, Salmon et al. conducted a follow-up intervention, “Switch-2-Activity” [93], based on the BM arm of the “Switch-Play” intervention [96]. This translational study aimed to determine real-world feasibility and efficacy of the BM intervention. A total of 908 children ages 9–12 years were exposed to an abbreviated six-lesson curriculum over a 7-week period delivered by classroom teachers. Although no significant intervention effects were detected, sex emerged as a significant moderator of the intervention after adjusting for baseline variables. Small but positive effects on boys’ self-reported weekend screen time (20 minutes difference between arms). No significant effects were detected for girls. Using practical sessions only (with no theoretical teaching) has shown similar low levels of success. A preschool level, 24-week intervention aimed to reduce TV viewing time among 545 Scottish children (age 4.3 ± 0.3 years) using practical sessions with no theoretical lessons [99]. The intervention strategy included three blocks of increased activity each week across 24 weeks. Accelerometer data indicated no significant differences in total sedentary time between the intervention and control. It is suggested that although a direct measure of TV viewing may have yielded a different result, the inability to show an intervention effect on overall sedentary time suggests that children may have replaced TV viewing with other sedentary actions [100].

There is a need to consider cohorts within communities based on factors such as age and sex, which may influence the type of strategy and content delivered theoretically and practically. Furthermore, age and sex may also be associated with different levels of risk. For example, it is documented that physical activity decreases during adolescence [101, 102], and youth spend a great deal of their time both at home and in school being sedentary [18–20]. Therefore, interventions that aim to reduce sedentary behaviour and increase physical activity among adolescents in a school-based environment are urgently needed [12, 19]. However, findings show conflicting results. In a systematic review conducted by Hynynen et al. [103], only four studies that targeted sedentary behaviour in adolescent populations (15–19-year-olds) were identified. Of the four, only one objectively measured sedentary behaviour via accelerometery [104]. The remaining three utilised measures of TV-viewing time [105, 106], board games, and attending classes in school [106], and the 3-Day Physical Activity Recall (3-DPAR) questionnaire previously mentioned [107]. Although very different in experimental design, both Neumark-Sztainer et al. [107] and Slootmaker et al. [104] reported significant treatment effects. Slootmaker et al. [104] utilised an alternative method of intervention delivery to 87 students (63% female, 15.1 years ±1.2 years). Rather than conventional teaching methods, an accelerometer and web-based service was used to encourage behaviour change. Using a gadget combined with internet interaction (a popular medium for adolescents) successfully reduced sedentary behaviour levels. Neumark-Sztainer et al. [107] implemented a school-based program targeting socio-environmental factors, personal factors, and behavioural factors to facilitate change in physical activity, sedentary behaviours, eating, and weight control behaviours in adolescent girls. The intervention included physical education classes, nutrition and self-empowerment components, individual motivational interviewing sessions, lunch meetings, and parent outreach and resulted in significant improvements in sedentary behaviours (i.e., decreased sedentary behaviours by one 30-minute block per day).

We posit for the aforementioned research, awareness and consideration of sedentary behaviour as an independent risk factor was still in its infancy and effective strategies were only just emerging (see Fig. 23.2). It was not until the past decade that research conducted in adult-based populations, began to report the importance of changing posture, moving more and avoiding long periods of sitting [108–110]. Such findings initiated a paradigm shift that primarily identified sedentary behaviour as an independent risk factor to that of insufficient physical activity.

Additionally, sedentary behaviours have been reported to track from childhood to adolescence and into adulthood [111], which has further initiated a gradual transition from adult- to youth-based populations. Ultimately, the need to design interventions that target sedentary behaviour as the *primary aim* in school environments has emerged. We discuss this paradigm shift in the following section.

23.2.2 The Emergence of Interventions Targeting Sedentary Behaviour as a Primary Aim

The evolution of school-based intervention experimental design is a clear representation of the ongoing paradigm shift. As depicted in Fig. 23.2, until recently, school interventions were dominated by increasing physical activity levels and measuring sedentary behaviour as an indicator of insufficient physical activity. Interventions also focused on the ability to reduce sedentary behaviour outside of school hours and measuring TV viewing time. However, following the trend in the adult workplace, and the need to reduce prolonged periods of sitting, sit–stand desks have emerged as feasible solutions to the sedentary school environment. As a relatively new concept and given the cost implications, completed studies are exploratory in nature and of smaller sample sizes; however, initial results are promising. One of the first studies to implement standing desks (not height adjustable) in a traditional classroom was conducted by Lanningham-Foster [112]. In a three-arm comparison, the researchers aimed to compare an "activity-permissive" environment referred to as the "neighbourhood" and a traditional classroom with standing desks to a traditional classroom. No significant differences were reported between the traditional classroom settings; however, detecting changes in posture to reduce prolonged periods of sitting was not the primary aim. Although sedentary behaviour was emerging as a concern at this time, increasing physical activity was the goal of this study. In later years, a pilot study conducted by Benden et al. [113] monitored 9 children (between ages 6 and 8) across two semesters (each semester = 5 months). One semester utilised traditional desks, and the other utilised sit–stand desks in the classroom. The purpose of this study was to determine if a difference existed in energy expenditure within children when using traditional classroom desks compared to sit–stand desks. The results indicated a mean difference of 0.3 kcal $\pm$0.1 kcal·min-1. Ultimately, this study found a 25.7% increase in average energy expenditure within-subjects using a sit–stand desk compared to the traditional desk. In addition, there was a 17.6% increase in steps within subjects with the use of sit–stand desks. Another pilot study investigated the feasibility of sit–stand desks in a school environment among eight children (aged 11.3 $\pm$ 0.5 years) [114]. Although a 19% increase in pedometer activity was recorded and no negative behavioural effects were detected in the classroom, results were not statistically significant, most likely due to the small sample size. In response to the need for larger studies, a larger intervention ($n = 374$) was conducted by Benden et al. [115]. The results supported preliminary research and indicated that sit–stand desks elicited a higher mean step count (+1.61 steps/min) compared to the control group. More recently, Wick et al. [116] conducted an 11-week non-randomised controlled pilot intervention testing the effects of standing desks in classrooms on cognitive function in children between 10 and 12 years. The intervention classroom ($n = 19$) received standing desks and teachers encouraged students to work at the desk for 60 minutes a day in at least 10-minute bouts, whereas the control classroom ($n = 19$) attended their regular lessons with no standing desk. Following the 11 weeks, compared to the control classroom, the intervention classroom had lower sitting time (12.7 min) and higher standing time (13.4 min) during lessons and higher standing time during breaks (2.5 min). Similarly, in another pilot controlled trial, Sherry et al. [117] found reduced class time sitting (19.9%) in a class of 9–10-year-olds after receiving adjustable sit–stand desks. Following a repeated-measures crossover design study, Parry et al. [118] found that following the provision of standing desks, students in a Grade 4 class increased standing time and reduced sitting time during the school day. While promising, the effects of these recent studies were small and limited by the pilot designs. In a larger sample, Clemes et al. [78] conducted a two-armed pilot cluster randomised controlled trial examining the effect of a sit–stand desk intervention named "Stand out in Class", in primary school (children ages 9–10 years). Teachers used a rotation system to encourage students to use the sit–stand desks for at least one hour per day. Although preliminary, results show that the intervention resulted in less sitting time (30.6 min/day) compared to the usual care control group. A following study conducted by Chen et al. [119] of the "Stand out in Class" intervention found that compared to the control group, the intervention group decreased the proportion of class time spent sitting and increased in time spent standing, stepping, and in light-intensity physical activity. Importantly, the study found no evidence for compensatory increases in sitting outside of school. The conclusion drawn from these studies is that giving children the opportunity to stand throughout the school day encourages them to move more, which may provide several additional benefits related to increasing energy expenditure levels.

Postural and comfort effects of sit–stand desks have also been documented by Benden et al. The results indicated no significant differences between traditional desk and sit–stand desk use on evaluated ergonomic support and discomfort. Further, students in the study conducted by Parry et al. [118] were less likely to report neck and shoulder discomfort when using a standing desk over a full school-year. Finally, feasibility and acceptability of sit–stand desks are highly dependent on maintaining an environment that is still conducive to learning and does not inhibit concentration, focus, or cognitive performance. Although exploratory in nature, initial results are promising. Results from the pilot study conducted by Benden et al. indicated that teachers reported a positive effect on classroom behaviour and focus in those using standing desks. As part of the larger study conducted by Benden et al., neurocognitive effects were also evaluated using a comprehensive battery. Positive effects for reaction times, response times, and error rates were detected. However, the cognitive results were not compared to a control group, reducing the ability to draw conclusions from these findings. More recently, results from the pilot study conducted by Wick et al. [116] showed that following an 11-week standing desk intervention in the classroom, students improved slightly in working memory and short-term memory scores. The authors suggested that the use of standing desks within the classroom may be a feasible and effective opportunity to improve cognitive function. Replication of large-scale experimental designs that include cognitive effects as a primary outcome are required.

23.2.3 Workplace Interventions to Reduce Sedentary Behaviour

Individual-level approaches to reduce sitting in the workplace have typically included strategies such as behavioural counselling, use of computer prompts, or use of walking or other physical activity-based interventions. A recent review examined the effectiveness of pedometer interventions in the workplace for increasing physical activity [120]. While some of the individual studies included in the review showed some small effects for increasing physical activity (e.g., steps) following the pedometer intervention, the authors of the review concluded that the low quality of evidence resulted in low certainty in the effects. Thus, although exercise interventions may be a promising approach, the authors could not conclude whether workplace pedometer interventions are the most effective option. Further, the investigators reported that the effect of workplace pedometer interventions on reducing sedentary behaviours is uncertain. The use of computer prompts (i.e., point-of-choice prompts on a computer) has received further attention in the past 10 years. Two short-term studies evaluated the use of computer prompts + standardised information relative to information alone. Evans et al. [121], following a brief 10-day intervention, investigated the effects of point-of-choice (PoC) prompting software, on the computer used at work (PC), to reduce long uninterrupted sedentary periods and total sedentary time at work. Results reported non-significant reductions in sitting time but significant reductions in the number of 30 min continuous bouts of sitting. Pedersen et al. [122] focused on prompts to increase sitting breaks with walking in a longer 13-week intervention, finding significant reductions in sitting time of 55 minutes per day. More recently, many studies have focused on the effect of computer-based software on workplace sedentary behaviours. Gilson et al. [123] conducted an efficacy trial testing real-time computer prompts that prompted employees to take a 5-minute break from desk sitting every 30–60 minutes over 5 months. They found a significant reduction in worktime sedentary behaviour and an increase in light-intensity physical activity in employees who used the real-time computer prompts. Taylor et al. [124] found that consistent users of a computer-prompt software that prompted workers to get up and walk increased their weekly pedometer counts, increased their light-intensity physical activity, decreased their sedentary behaviours during the weekends, and had no change in their sedentary behaviours during the week. More recently, Carter et al. [125] pilot tested an 8-week e-health computer-based software that was installed onto participant's work computers and prompted employees to interrupt prolonged sitting time with bouts of physical activity every 45 minutes. The software resulted in large effects for reduced workplace and overall sitting time as well as increased workplace and overall standing time. Small effects were found for steps (time and count) and sit-to-stand transitions. In an effort to increase the use of sit–stand desks, Sharma et al. [126] and Garret et al. [127] used computer software to send reminders to change desk positions after 30 minutes. Both interventions resulted in significant and positive changes (i.e., decreased sitting time, increased standing time, increased use of sit–stand desks).

Studies have also examined the effect of prompts using e-health approaches (e.g., smartphone applications, text messages). Morris et al. [128] conducted a feasibility study to test the effect of an e-health smartphone application over 12 weeks that incorporated no prompts or prompts every 30 or 60 minutes. They found that prompts every 60 minutes were associated with reduced sitting time during work, which was primarily replaced with standing. Also, prompts of both the 30- and 60-minute frequencies were associated with a decrease in prolonged sitting bouts. However, there were no changes in steps following any prompts. Dunning et al. [129] examined the use of activity-promoting text messages every 30 minutes during office hours for 10 weeks and found that while employees sat less (1.1 hours/day) during the message-receiving periods, this reduced sitting time was not sustained after the intervention. Thus, while these studies have found promising results for using prompts to reduce workplace sitting time, many have suggested the need for longer interventions to determine whether these improved behaviours can be sustained.

To summarise the effects of prompts on workplace sedentary behaviours, two recent reviews have been conducted. Shrestha et al. [130] conducted a meta-analysis of workplace interventions for reducing workplace sitting time and reported pooled effects of computer prompts. The authors found that computer prompting led to a non-significant reduction in workplace sitting in the short-term (< 3 months), a significant reduction in workplace sitting in the medium-term (3–12 months), and a reduction in sitting bouts lasting 30 minutes or more. Taylor et al. [131] conducted a recent review of six publications examining whether computer prompt software programs reduced workplace sitting and increased workplace physical activity. With only four of the six studies showing that computer prompt software programs decreased sedentary behaviours and increased physical activity at work, the authors concluded that while promising, future high-quality and long-term studies are needed. Interestingly, Larouche et al. [132] found that the content of point-of-choice prompts may matter. For example, the authors found that while prompts decreased time spent in prolonged sitting bouts during work, prompts that included atheoretical basic reminders were more efficacious at reducing sitting time than when prompts were theoretically driven prompts. However, the authors also found that the theoretically driven prompts were rated with higher preference and acceptability potentially suggesting the need for individually tailored messaging.

23.2.4 Physical Changes to the Workplace Environment

The use of multi-level, ecological approaches to reduce sedentary time is ideal for the workplace, given the opportunity for more robust and comprehensive changes to the environment that are possible. The most common environmental approach to reduce occupational sedentary time has been the use of "activity-permissive" workstations (i.e., treadmill desks, pedal desks, height-adjustable workstations). There has been a rapid increase of laboratory- and field-based studies on this topic, with the majority published in the last 10 years. Josaphat et al. [133] reported the results of a systematic review of the effect of active workstations on sedentary behaviours, physical activity, energy expenditure, and work outcomes in adults with overweight or obesity. Of the 19 total studies included, eight were conducted in the workplace; of the eight, five used treadmill desks and three used standing desks. The authors reported that the majority of the studies that used sit–stand desks and treadmill desks resulted in beneficial effects of decreased workplace sitting for adults with overweight or obesity. These findings are in line with past reviews in adults of all weight statuses. For example, a Cochrane review [130] found that multi-component interventions and interventions using sit–stand desks, either alone or within a multi-component intervention, reduced workplace sitting time by 100 minutes per workday in the short-term (<3 months) and by 57 minutes per workday in the medium term (3–12 months). The authors, however, were unable to conclude the effects on other active workstations such as treadmills or cycling desks. More recently, Oye-Somefun et al. [134] conducted a systematic review and meta-analysis of six studies examining the effect of treadmill desks on workplace energy expenditure, sitting, and cardiometabolic health. They reported a pooled effect of 1.7-minute reduction in sitting time per hour among users of a treadmill desk compared to a conventional desk. Other metabolic outcomes showed no change. However, the authors noted that the quality of the included studies was highly variable and that there is a high need to conduct cluster randomised controlled trials to reduce the risk of treatment group contamination.

A number of these studies are ongoing or have been recently published in Finland, Australia, the United Kingdom, and the United States, with the majority of these studies conducting group-randomised trials of multiple worksites with study durations of one year or longer. Recent large-scale studies have delivered programmes that targeted individual, social, environmental, and policy factors, alongside the installation of sit–stand workstations, to reduce sedentary time. Healy et al. [22], in a 12-month intervention of Australian public health workers (n worksites = 14; n subjects = 231), observed 45 min/8-hour workday reductions relative to usual practice control. In a 12-month multicomponent intervention of desk-based workers in England (n worksites = 37; n subjects = 146), Edwardson et al. [135] found an 83 min/8-hour workday reduction in sitting time compared to usual practice control. In a 12-month multi-component intervention of US academic, industry, and government workers (n worksites = 24; n subjects = 630) named Stand & Move at Work, Pereira et al. [136] found a 59.2 min/8-hour workday reduction in sitting time in the intervention arm with sit–stand workstations relative to the intervention without sit–stand workstations. In contrast, Renaud et al. [137], in an 8-month pragmatic cluster-randomised trial of a multi-component intervention in a Dutch insurance company (n departments = 14; n subjects = 244), observed no reductions in sitting time relative to the usual practice control. The investigators attributed this to the low intensity of the intervention (i.e., only 25% of sit desks were replaced with sit–stand desks). Nevertheless, the majority of these studies provide strong evidence for the effect of sit–stand workstations and underscore the value of including environment and policy-level interventions to support their implementation. Additional questions remain with respect to the translation of the multi-component approach to a more diverse set of workplace sectors, the sustainability of this approach in the long term (e.g., beyond 12 months and when intervention is withdrawn), and its impact on cardiometabolic health, healthcare savings, and workplace productivity.

23.2.5 Workplace Policy Approaches

Few studies have explicitly examined the effects of policy-level approaches to reducing occupational sitting time. Policy approaches include formal actions by the organisation to change the social or physical environment to support reductions in sitting or increases in walking. These changes might include the formation of walking groups, walking meetings, provision of short breaks, use of standing meeting rooms, or similar efforts. While a number of studies are evaluating the use of multi-level approaches to reducing occupational sitting [22, 103, 135–138] —which may include policy—and organisational-level approaches named above—it is difficult to identify the unique impact these approaches may have on sitting. Knox et al. [139] sought to identify commonly used workplace policies in England that work to increase physical activity and reduce sedentary time during the workday. The provision of information and opportunities for physical activity during and outside of work was associated with less workplace sedentary behaviours. Further, the presence of onsite facilities and classes was also associated with less workplace sedentary behaviours; however, these structures were rarely found in workplaces. There is a need for more formal studies testing the unique and combined effects of policy-level approaches to reducing occupational sitting.

23.2.6 Observational Studies of the Neighbourhood Environment and Sedentary Behaviour

A recent review reported that inactivity tends to be lower in children as well as young, middle-age, and older adults in neighbourhoods that promote greater walkability, safety, have mixed land use (residential, commercial, parks), and are supported by a strong active transport infrastructure (e.g., street connectivity, walking/biking paths, etc.) [30]. Research on the built environment and sedentary behaviours is often examined by assessing the objective or perceived built environment. Following objective assessments of the built environment, Lotoski et al. [140] found that children (9–14 years) living in high-density neighbourhoods and neighbourhoods with the greatest number of destinations, as well as activity friendliness, were associated with less sedentary behaviours. These associations were more prominent during warmer months (i.e., spring, summer) of the year. These findings are fairly consistent with past research. Bringolf-Isler et al. [141] examined the association between the objectively assessed built and social environments of neighbourhoods and physical activity and sedentary behaviour of 1742 children between the ages of 4 and 17 years in Switzerland. Data were pooled from seven studies conducted between 2005 and 2010. The amount of green space around the child's home, expressed as hectares of parks, playgrounds, and meadows, was inversely associated with sedentary time and positively associated with total physical activity with adjustment in the model for the confounding effects of age, sex, season of data collection, accelerometer wear time, and all other neighbourhood attributes under investigation. While "building density" was also positively associated with physical activity, its inverse association with sedentary behaviour did not reach statistical significance. Several other neighbourhood characteristics examined in these studies did not appear to have a significant, independent association with physical activity or sedentary time, including main street density, population density, intersection density, mixed land use, woods, schoolchildren density, and socioeconomic neighbourhood position. A limitation of the analysis was that physical activity and sedentary time did not appear to be included together in the same model. Sallis et al. [29] used geographic information systems (GIS) to measure residential density, street connectivity, retail floor area ratio, and land use mix to create a walkability score. In 928 adolescents [12–17] participating in the Teen Environment and Neighbourhood (TEAN) observational study, high walkability was associated with high physical activity and low sedentary time and TV time. Koohsari et al. [142] objectively calculated built environment attributes and examined their association with objectively assessed sedentary behaviours in adults (40–64 years) in Japan. Population density and availability of destinations were associated with more sedentary behaviours, whereas the number of intersections was associated with less sedentary behaviours. Surprisingly, increased walkability was associated with higher sedentary time; the authors attributed this to environmental attributes such as the fact that the more walkable areas may also have higher population densities. Similarly, Nichani et al. [143] examined the association between objective neighbourhood built environment characteristics and sedentary behaviours in 14,785 adults in Canada and found that walkability, 3-way intersections, and population count were associated with more sitting time, whereas business destinations and greenness were associated with less sitting time.

Aside from objectively measured neighbourhood characteristics, perceptions of the environment may influence sedentary behaviour. While research has established an association between the perceived environment and sedentary behaviour, these associations have been found in both the expected and unexpected directions. Greenwood-Hickman et al. [144] examined the association between perceived neighbourhood walkability and physical activity and sedentary behaviours in 1077 older adults (≥65 years). Higher perceived walkability was associated with higher steps and sit-to-stand transitions. Owen et al. examined perceived neighbourhood attributes (residential density, land use mix, street connectivity, infrastructure and safety for walking, aesthetics, traffic safety, safety from crime, number of cul-de-sacs, and physical barriers to walking) and their association with sedentary time in 5712 adults (18–66 years) in ten different countries. High residential density, infrastructure and safety of walking, and lack of physical barriers to walking were associated with higher sedentary time, whereas aesthetics and street connectivity were associated with less sedentary time. The remaining perceived neighbourhood attributes had no association with sedentary time. Although the findings related to the perceived neighbourhood attributes and high sedentary time contrast with past research on physical activity, the authors suggested this may be due to differences in population characteristics. For example, residents in high-density areas may spend more time sitting in other aspects of their life (e.g., work) regardless of how they perceive their neighbourhood environment. Similarly, Caetano et al. [145] examined the association between perceived neighbourhood environment characteristics and physical activity and sedentary behaviours in adolescents (14–16 years) in Brazil. The authors used latent class analysis to identify three classes based on how the adolescents perceived their built environment (i.e., land use mix, street connectivity, walking/cycling facilities, and traffic safety): [1] Best Perceived Environment; [2] Moderate Perceived Environment; and [3] Worst Perceived Environment. Adolescents in the Best Perceived Environment class reported the highest sitting time compared to the other classes. While this is inconsistent with the current literature, the authors noted that the Best Perceived Environment class also had the highest socioeconomic status. Thus, adolescents in this class may engage in more sedentary promoting activities (e.g., sedentary transportation, studying, sedentary extracurricular activities). For example, studies have shown that children [146] and university students [147] living in higher socioeconomic neighbourhoods report lower active commuting to and from school.

In addition to socioeconomic status and income, past studies have also shown the moderating effect of other factors such as urbanicity and race on the association between the perceived built environment and sedentary behaviours. The Resilience for Eating and Activity Despite Inequality (READI) study examined the perceived home and neighbourhood environment in association with children's activity and sedentary behaviour in urban and rural areas of Australia [148]; 613 children and their mothers were included in the study. Physical activity and sedentary time were objectively assessed with the Actigraph accelerometer. Urban/rural location moderated the associations between having a strong perceived neighbourhood social network and road safety concerns with children's screen time. As neighbourhood social network perception increased, screen time increased for urban children but decreased for rural children. The opposite was true for neighbourhood road safety concerns, which had a positive association with the rural children's screen time, but inverse for the urban children's screen time. Similar results for the total sedentary time were observed for neighbourhood road safety concerns. These findings, along with others in this study, are important for understanding differences in how perceptions of the environment can influence physical activity and sedentary behaviour differentially between urban and rural settings, which may be particularly helpful in planning interventions or influencing policy.

While the READI study just discussed was aimed at urban vs rural differences, a study by Budd et al. [149] hypothesised that race may modify the association between parental perceptions of the neighbourhood and children's physical activity behaviour. This study included 196 parents in St. Louis, Missouri, US. Data were collected by a mailed survey. Among white parents, but not among non-white parents, the perception that drivers exceed speed limits was a positive predictor of children's sedentary behaviour time. On the other hand, only among non-white parents was perceived neighbourhood crime rate a positive predictor of children's sedentary behaviour time. It would appear that race, and also urban vs rural neighbourhoods, as we learned from the READI study, are important fixed characteristics that need to be taken into account in further research in this area.

Although perceptions of the environment may provide insight into neighbourhood sedentary levels, one limitation is that the perception of attributes of the neighbourhood may differ between individuals. Thus, researchers have suggested the need for research to include both perceived and objective measures of the built environment. Hinckson et al. [150] examined associations between perceived and objective neighbourhood environments with physical activity and sedentary behaviours in 524 adolescents (12–18 years) participating in the Built Environment in Adolescent New Zealanders (BEANZ) study. Of the perceived environment characteristics, land use mix-diversity, street connectivity, and aesthetics were associated with increased physical activity. Land use mix-diversity, street connectivity, aesthetics, and traffic safety were associated with low sedentary time, whereas perceived physical barriers to walking were associated with high sedentary time. Of the objective environment characteristics, gross residential density and number of parks were associated with increased physical activity, whereas no objective characteristics were associated with sedentary time. Bejarano et al. [151] examined the association between perceived and objective neighbourhood environment with objectively assessed sedentary time and physical activity in 524 adolescents (12–16 years) in the US participating in the previously mentioned TEAN observational study of neighbourhood environments and physical activity. Perceived neighbourhood environment factors including land use mix-access, accessibility of walking routes, perceived neighbourhood aesthetics, perceived greater crime safety, and perceived neighbourhood index score (i.e., overall perception of activity-supportiveness of the neighbourhood environment) were inversely associated with sedentary time. With respect to objective neighbourhood environment variables, street connectivity (i.e., more intersections), mixed use of land, and objective neighbourhood environment index (i.e., overall activity-supportiveness of the neighbourhood environment) were associated with more total sedentary time, whereas cul-de-sac density was associated with less sedentary time. The authors noted that the discrepancy between the perceived and objective environment findings suggests a complex and unclear role of the neighbourhood environment on sedentary time in youth. This finding is in contrast to a more recent study examining perceptual and researcher-rated neighbourhood-built environments and physical activity and sedentary behaviours in youth (9–14 years) in Canada. Goon et al. [152] found that children's perceived availability of parks and recreational facilities and having adult role models who are active in the neighbourhood were both associated with less sedentary time and more physical activity, whereas a perceived absence of sidewalks was associated with more sedentary time and less physical activity. With respect to the researcher-rated build environment factors, activity friendliness, and pedestrian accessibility were associated with less sedentary time. Unexpectedly, researcher-rated safety from crime was associated with increased sedentary time. The authors suggested that perceptions of the built environment may be more salient that researcher-rated and objective measures of the built environment for youth physical activity and sedentary behaviours.

Heterogeneity of results for sedentary behaviour reduction strategies at the community level is prevalent and continues to impede clear inferences. Although insightful results are presented in earlier interventions, a fundamental missing component is demonstrating how to practically reduce sedentary behaviour by simply "standing and moving more". Tackling this both theoretically and practically has now become a new challenge. The lack of environment-level techniques may be related to financial resources and difficulties in implementing changes at a macro-level. Initiating major changes in the school's physical environment without efficacious evidence may be considered too risky and costly [103]. Understanding the costs related to recruitment and implementation of an intervention and its potential cost-effectiveness are important aspects to consider to determine how best to use the finite resources that are available in community or school settings [67]. It should be considered that not all interventions discussed in this review are feasible in practice, given the typical time and budgetary constraints. Similarly, this is not an exhaustive list but is instead designed to demonstrate the evolution of sedentary behaviour interventions. Nonetheless, these findings provide a starting point to reduce sedentary time at the community level.

23.3 The Role of Communication Technologies and the Media in Decreasing Sitting Time

Technological advances have enabled effective, motivational applications for monitoring sedentary time, causing behaviour change techniques (BCTs) to evolve. Contemporary elements of BCT's include self-monitoring, feedback, and social support [153] and are now used in several forms, such as activity monitors, web-based applications and mobile phones [154, 155]. With the abundance of technological strategies, there has been a shift from face-to-face interventions toward multi-component interventions to reduce sedentary behaviour using self-monitoring devices, web-based support, and sophisticated mobile media [156–158]. Self-monitoring is rapidly becoming a popular and effective method for reducing sedentary behaviour due to the associated portability, cost-effectiveness, convenience, accessibility, and sense of user control [159]. As a result, we have seen a burgeoning industry for accelerometer-based wearable activity monitors, online support platforms, online feedback platforms, and mobile apps targeting the consumer market [154, 157]. These platforms vary in medium (wrist-worn device, phone, email), delivery (textual, visual, sound, vibration), and content (personalised, generic, short, long, motivational, educational, feedback), but all aim to reduce sedentary behaviour.

23.3.1 Electronic Activity Monitors

The most prevalent of self-monitoring technologies are Electronic Activity Monitors (EAMs), more commonly known as “fitness trackers”, such as those manufactured by Apple [Apple Inc., Cupertino, CA], Garmin [Garmin Ltd., Canton of Schaffhausen, Switzerland], Jawbone [Jawbone San Francisco, CA, USA], Nike [Nike, Inc., Beaverton, OR, USA], Fitbit [Fitbit, San Francisco, CA, USA], and Gruve [Gruve Technologies, Inc., Anoka, MN, USA]. Although originally designed to track physical activity and energy expenditure, increased awareness regarding the detrimental effects of sedentary behaviour (or sitting too much) has generated a new set of user requirements the industry is pursuing. More specifically, in addition to physical activity data, these devices now include feedback features to communicate information related to sedentary behaviour. Commercially available EAMs are growing in popularity, with 19% of Americans using a wearable fitness device. Based on these growth rates, it is anticipated that sales of wearable fitness devices will double in the next year by 2022, becoming a $27 billion market, and the smartwatch category will become the most-worn wearable device. EAMs can now objectively measure physical activity and periods of inactivity and provide feedback, beyond the display of basic activity count information, via the monitor display or through a partnering application to elicit continual self-monitoring of activity behaviour [157, 158]. Feedback strategies include simplistic prompts that serve as a “reminder” to stand up or move at a set time and frequency (see Table 23.1). More sophisticated devices are able to detect periods of uninterrupted sitting and serve as an “alert” to communicate to the user that they have been sitting too long (see Table 23.1). Users may receive the alert or prompt using vibration, sound, or visual feedback to instruct the user to stand or move. It should be noted that the vast majority of these consumer-based devices—with the exception of Lumoback (Lumo Bodytech, Inc., Mountain View, CA, USA)—currently rely on movement-based algorithms and not postural inclinometers. This technical consideration may limit their utility for reducing sitting behaviours.

Table 23.1 Technology designed to reduce sedentary behaviour available at the consumer level

Electronic activity monitors (EAMs)				
Platform	Detects inactivity	Period of inactivity	Type of alert	Feedback
Garmin vivosmart	Yes	1 hour	Vibration and alert	Numerical display on the device
Garmin vivofit	Yes	1 hour	Alert and visual display	Real-time "move bar" display to show how long you have been inactive
Jawbone UP/UP24	Yes	Can manually set the period as "idle alert"	Vibration	No display, pairs with app and mobile device
Apple watch	Yes	At least one minute each hour	Tap on the wrist and a notification	Has display and user interface. Goal setting—Set number of hours to stand per day (default 12). Feedback- graph to show hours you missed
iFit active	No	Manually set inactivity interval	Vibration	Syncs via Bluetooth to iFit app
Nike Fuelband	Yes	At least 5 minutes each hour	Move reminder visually flashes at 45 and 50 minutes of inactivity	Links with iOS app, send reminder to mobile device. If you move at least 5 mins that hour, you "win the hour". Can see how many hours you "won" by the end of the day
Fitbit surge	No	N/A	Visual display to show your inactivity but no "move" reminders.	Continual visual feedback
Fitbit zip	No	Manually set inactivity interval	Vibrating alarm must be manually set by the user	No objective inactivity feedback
MUVE Gruve	Yes	From 45 to 90 minutes	Vibrates	Display changes colour based on progress, but data must be uploaded via a USB cable
Mobile apps				
Platform	**Detects inactivity**	**Period of inactivity**	**Type of alert**	**Feedback**
Move more app	No	Manually set inactivity interval and alerts	Tap the app to record data, e.g., sitting and log it	Graphical user Interface. Links with iPhone or iPad. Serves as a log, not a sensor
Break Time app	No	Manually set	Alert only	

(continued)

Table 23.1 (continued)

Electronic activity monitors (EAMs)				
Platform	Detects inactivity	Period of inactivity	Type of alert	Feedback
		inactivity interval and alerts		For iOS and mac. Serves as an alert system, does not provide feedback or GUI
Get moving app	Yes	Manually set inactivity interval and alerts	Customisable alerts of your mobile phone.	Tracks as a pedometer, the clock starts when inactivity is detected. Provide weekly summaries on how long you were inactive, where and when
Email and software				
Platform	**Detects inactivity**	**Period of inactivity**	**Type of alert**	**Feedback**
Point of Choice software (Evans 2012)	No	Reminder sent every 30 minutes	Simple reminder	Does not provide objective "sitting time" feedback
Email	No	Daily, weekly, bi weekly	Motivational, educational	Varied may provide feedback on the number of times a user read or viewed email. Does not provide objective "sitting time" feedback

There are supporting data to suggest that EAMs may be an effective tool to reduce sedentary behaviour. Ellingson et al. [160] evaluated the effectiveness of a Fitbit in increasing physical activity and reduce sedentary behaviours with or without motivational interviewing and habit development in 91 adults in the US after 12 weeks. Participants were randomised to either receive the Fitbit alone or the Fitbit plus motivational interviewing and habit formation education. The results indicated that the change in sitting time between the two interventions was not significant, with the authors suggesting that activity trackers alone may have beneficial effects on physical activity and sedentary behaviours. Brakenridge et al. [161] evaluated the effectiveness of an activity tracker that targets sitting time to reduce workplace sitting over 12 months in 153 desk-based office workers in Australia. Participants were randomised to receive organisational support strategies (e.g., managerial support, emails) or organisational support plus the waist-worn LUMOback tracker. The LUMOback tracker provided real-time feedback on sitting, standing, sit-to-stand transitions, walking, running, steps, posture, and sleep. Participants were able to set posture alerts to have the tracker vibrate when poor lumbar posture and/or periods of sitting (i.e., 15, 30, 45, 60, 120 min) were detected. Participants reported that the LUMOback was easy to use and greater use of the tracker was significantly associated with an increase in non-prolonged sitting ($<$30 min) during work and a reduction in prolonged sitting ($\geq$30 min) during waking hours. It is important to note that the LUMOback is no longer being produced or sold. Nevertheless, these studies are consistent with past research. Barwais et al. [162] evaluated the effectiveness of wearing a commercially available EAM [Gruve, Gruve Technologies, Inc., Anoka, MN, USA] for four weeks. The multi-dimensional behavioural intervention used an online personal activity monitor with a built-in vibrating function to notify the user when they had been sedentary for longer than the set threshold. The reminder to stand up and move provided a prompt for behaviour change and goal achievement. The online software enabled participants to visualise sedentary patterns with simple 24 h/day graphs and charts. Motivational support was provided via a personalised homepage and goalsetting based on baseline results. The results indicated a 33% reduction in sedentary time (3.1 h/day) at the end of the 4-week intervention (6.3 ± 0.8 h/day) compared to baseline (9.4 ± 1.1 h/day). These results suggest that EAM use may be an effective sedentary behaviour reduction strategy; however, the longevity of the effects is still unknown.

23.3.2 Mobile Apps

Currently, 97% of Americans own a cell phone, of which 85% own a smartphone [163]. The features and functions of a cell phone have long surpassed that of telecommunication alone. The advent of mobile communication technologies has thus created a vast potential for collecting and delivering time and context-sensitive sedentary behaviour information [164]. The ability to collect and deliver "just-in-time" information and the advances in built-in smartphone activity sensors (i.e., accelerometers) have seen an explosion in mobile applications—"apps" geared toward reducing sedentary behaviour [165]. A recent review [166] examined the effectiveness of smartphone-based interventions on health outcomes including sedentary behaviours in individuals across age groups and special populations (e.g., general, pregnant women, cancer survivors, etc.). Some studies reported reductions in sedentary behaviours following app-based interventions. However, while the findings were promising, the authors suggested the need for more conclusive evidence. Similarly, Buckingham et al. [167] conducted a review of mobile health interventions to reduce workplace sitting time and found that most studies reported a significant reduction in workplace sitting time following the interventions (e.g., study-specific smartphone apps). However, more research is needed to confirm the long-term effects on sedentary behaviour.

23.3.3 Email and Software

Email and software-based strategies designed to alert and prompt users to avoid prolonged sitting are most applicable to the workplace environment. The prevalence of desk-bound work has unveiled an opportune setting for sedentary behaviour interventions. Email strategies can be tailored to provide motivational and educational support that exploits habitual email interaction. Software lends itself more to regular reminders [126, 127]. Email-based strategies show inconsistent results. Hutchinson et al. [168] examined an intervention that included a one-time face-to-face consultation session followed by weekly emails for 16 weeks. The emails were designed to target affective and cognitive attitudes towards sedentary behaviours and included varying content in the form of simple messages, visualisations, information sharing, and specific tips to break up sitting. While daily sitting did not change, the number of prolonged sedentary bouts (>30 min) was significantly reduced. Another sedentary behaviour reduction intervention in office workers used email to send out prompts plus education to break up sitting at work [169]. While the emails plus education were able to reduce workplace sitting time, the authors found that it did not reduce sitting time any more than when employees received education only without email prompts. This finding contrasts with the previously mentioned past study conducted by Evans et al. [121], who indicated that point-of-choice prompting software on work computers that recommended breaks from sitting in addition to education was superior to education alone in reducing long uninterrupted sedentary periods at work. More research is needed to understand whether combining both reminders with educational support (via email) is required to educate but also prompt the use.

23.3.4 The Role of the Media

The influential role that the media can play in health behaviours, particularly during times of critical need such as during the COVID-19 pandemic has been recently affirmed [170]. Commercial marketing principles of combining mass media with product distribution were well established long before their adoption into the public health domain [171]. Over time, refinement of communication theories and campaign strategies and their application to an extensive range of health behaviours have led to more sophisticated campaigns. A recent review indicated that mass media health communication campaigns allowed for timely interventions to increase healthy behaviours [170]. Health communication campaigns apply integrated strategies to deliver messages designed to inform, influence, and persuade target audiences' attitudes about changing or maintaining healthful behaviours [172]. Messages can be transmitted through a variety of channels [170], such as traditional mass media (e.g., TV, radio, newspapers); the Internet and social media (e.g., websites, Facebook, Twitter); small media (e.g., brochures, posters, fliers); group interactions (e.g., workshops, community forums); and one-on-one interactions (e.g., hotline counselling).

Media coverage on the topic of sedentary behaviour is rising rapidly. As this trend continues, the opportunity to design multi-component interventions is pertinent. In particular, the continued rise of social media as a communicative platform also lends itself well to health interventions and creating awareness. According to a new eMarketer report, "Global Social Network Users 2020" [173], 2.99 billion people worldwide, were social network users in 2019, before the COVID-19 pandemic. In 2020, it was estimated that 3.23 billion people globally were social network users during the COVID-19 pandemic. It is estimated that by 2024, the global social network audience will total 3.64 billion people. We suggest that rather than being considered a barrier, it instead poses an opportunity to harness the reach and effectiveness of social media as a tool to communicate the detriments of sedentary behaviour to the abundant target audience. Such high levels of social media interaction may provide the most opportune platform for intervention strategies and employment of prompts/alerts.

The combination of public awareness, mass media reach, interaction with people who may be employing sedentary behaviour reduction strategies and actively using devices to track their sedentary behaviour, may have a substantial and influential effect on behaviour. It is suggested that as awareness regarding sedentary behaviour as an independent risk factor continues to grow, mass media campaigns with a strong social media focus should be employed to strengthen intervention strategies that aim for long-term behavioural change. Development of new health communication and social marketing campaigns and programs could play an important role in reducing sedentary behaviours. Health-related behaviours are determined by an interplay of personal, behavioural, and environmental factors. Given the unique attributes of sedentary behaviour (e.g., ubiquitous, habitual, socially reinforced), understanding the factors that underpin sedentary behaviour is critical and is a required step to effectively design interventions to reduce sedentary behaviour. Applying advanced user cantered design approaches to deliver "just-in-time" prompts and interventions to reduce sedentary behaviour should be a primary concern to industries when designing devices and supporting communicative platforms. Future work should focus on assessing "in the moment" contextual factors related to sedentary behaviour. Such findings would provide a basis for developing devices that detect the ecological conditions that coincide with or predict sedentary behaviour. Long-term interventions are also needed to determine how strategies perform over extended periods of time. The chronic effect would provide invaluable data informing the level of adaptive technology needed to withstand likely fluctuations in user interest over time.

23.4 Organisations Promoting Health Behaviour

Changing attitudes and behaviours is reliant upon organisational research, funding, and support at local, national, and international levels. Governing bodies and policymakers that influence health, education, and welfare provide the most influential platform for population change and therefore need to understand and communicate the importance of sedentary behaviour. We discuss those that may impact policies and understanding that may be disseminated at the community level. Ultimately these include research institutions, health, welfare, and neighbourhood organisations.

23.4.1 Research Institutions

There is a broad research agenda that must be pursued by research institutions including understanding the unique and shared contribution of sedentary behaviour on health outcomes and developing effective strategies to reduce sedentary behaviour in various subgroups and contexts. Research institutions must endeavour to pursue translational research in real-world settings to design interventions that have scalable public health impact. Research in the behavioural science field must aim to be both "contextual" and "practical" [174]. Worksites, schools and neighbourhoods pose numerous challenges within different contexts—environmental, organisational, social, and cultural. The research purpose and design must be applicable to the context for which it is intended to ensure that it is both practical and effective. Collaboration between institutions is crucial to conducting such large-scale, impactful studies and may be facilitated by organisations such as the Sedentary Behaviour Research Network (SBRN). The SBRN is the only organisation for researchers and health professionals that focuses specifically on the health impact of sedentary behaviour. SBRN's mission is to connect sedentary behaviour researchers and health professionals working in all fields of study and to disseminate this research to the academic community and to the public at large. Continuing to develop such powerful networks will broaden understanding and outreach across organisations and communities.

23.4.2 Funding Organisations

Funding organisations such as the National Institutes of Health (NIH) have the power to dictate the type of research that can be conducted and therefore are major influencers in promoting health. Findings can shape government recommendations that may directly or indirectly facilitate changes in public health. By leveraging current knowledge and growing momentum, funding organisations such as the NIH should continue to provide access to small and large-scale funding that aims to establish preventative measures, particularly in high-risk populations. Increased awareness and adoption of preventative measures hinges upon the strategies that have demonstrated feasibility, efficacy, and effectiveness. Considering the real-world barriers is vital to future studies. Funding organisations such as the NIH must continue to fund longitudinal experimental designs that tackle "real-world" settings in order to truly impact public health.

23.4.3 Health Organisations

One of the most notable health organisations with an extensive reach and influence in all aspects of health is the WHO. The WHO is a specialised agency of the United Nations (UN) that is concerned with international public health. In an effort to increase awareness regarding sedentary behaviour, they have formed and funded several collaborative programs. The WHO recently released updated guidelines for physical activity and sedentary behaviours by age group (i.e., children/adolescents, adults, older adults) and for special populations (e.g., pregnant and postpartum women, individuals with chronic conditions and/or with disabilities) [7]. For the first time, these guidelines now include recommendations on the associations between sedentary behaviours and health outcomes. The guidelines recommend that individuals of all age groups should limit sedentary time (screen time in particular for children) and that this time should be replaced with physical activity, particularly levels of moderate-to-vigorous physical activity. Similarly, the US Department of Health and Human Services released updated guidelines for physical activity in 2018 [6]. These guidelines now also include, for the first time, a discussion regarding the risk of sedentary behaviours and its relation to physical activity. While a specific recommendation for total sedentary time could not be made, the guidelines recommend limiting time spent in sedentary behaviours.

At the school level, Health Behaviour in School-aged Children (HBSC) was formed as part of a WHO initiative. This cross-national, school-based research study collects information on health-related attitudes and behaviours of young people. These studies are based on nationally independent surveys in as many as 30 participating countries and are conducted every four years since the 1985–1986 school year. With the emergence of sedentary behaviour as an independent risk factor, sedentary behaviours are now included in the survey battery. This effort not only aids research understanding, but it also reinforces the importance of monitoring sedentary behaviour in the target population. Such findings may inform future research directions to ultimately support more efficacious strategies to reduce the associated risks of sedentary behaviour and may lead to policy changes at a national level. For example, in 2018, the national physical activity recommendations for Americans released the first guidelines for pre-school aged children (3–5 years) and expanded on strategies to help youth achieve the recommendations in a variety of settings including childcare, school, and the community [6]. The WHO and US Department of Health and Human Services have the ability to reach an expansive population. Ensuring that scientific research is communicated effectively and appropriately should be a main focus. Working with funding organisations to prioritise and define issues of major public health concern is crucial. Transferring intervention effects to the real-world setting is the only way public health will be positively impacted.

23.4.4 Health Coalitions

Coalitions are aptly defined as an "organization of individuals representing diverse organizations, factions or constituencies who agree to work together in order to achieve a common goal" [175]. For example, collaboration between Ergotron, Inc. (Eagan, Minnesota, US) facilitated the occupational sitting in the Stand & Move at Work [176] project previously discussed. Such collaborative relationships across academia and industry enable the pooling of resources, expertise, and funding. Reducing sedentary behaviour on a global scale is reliant upon the continued growth and development of coalitions that merge different areas of expertise and access to populations. The number of funded community health projects that rely on coalitions represents a considerable investment of resources. There are opportunities to gain research efficiencies by leveraging existing epidemiologic cohorts and health systems. Health systems can provide an excellent setting for pragmatic trials and observational studies examining relationships of sedentary behaviour with health outcomes, health costs, and utilisation [177].

23.5 Evaluation of Community-Based Interventions

Overall, it is clear that assessing the correlates of sedentary behaviour at the community level is one helpful tool towards ultimately slowing the significant impact of sedentary behaviour on both child and adult health. By identifying socio-demographic correlates of worktime, school-time, and leisure-time sedentary behaviour, higher-risk sub-populations may be identified. Community-level interventions provide access to large numbers of adults and children from differing backgrounds, varied social economic, or ethnic minority families. Therefore, these interventions have the potential to have an extensive impact on public health.

While demographic, psychosocial, and environmental correlates of occupational sitting are emerging and provide potential insight into key intervention strategies, there are a number of limitations worth noting. First, although the use of objective assessments has increased in past years, many studies continue to rely on self-reported sitting. Since the context of sitting remains challenging to measure with an objective monitor, and many cross-sectional studies rely on retrospective recall in large samples, this will likely continue to be a key limitation to future studies. Second, the majority of studies included short- or medium-term (< 12 months) effects on sedentary behaviours. Future research is needed to assess the long-term effects of community-based interventions on reducing sedentary behaviours. Third, most studies report an under-specified set of demographic, psychosocial, and micro- and macro-environmental factors to understand the unique contribution of each level of the social–ecological spectrum of potential influences on sedentary behaviour. For example, notably lacking in the reviewed workplace studies was careful documentation of micro-level environmental features such as office spatial configurations as well as worksite policy and social determinants (e.g., implantation of standing/walking meetings, cohesion in the workplace). Furthermore, the vast majority of recent studies reviewed have focused on the US, Australian, or UK samples of desk-based employees. These samples may not be generalisable to other developed or developing countries as school and work practices are likely to differ substantially from one country to another. Future community-level interventions should focus on the direct impact of sedentary behaviour during school and work hours and investigate specific sedentary activities (rather than screen time) in relation to sex, grade level, occupation, location, public vs private schooling, worksite leadership, and teaching strategies. Future interventions must focus on multi-level approaches that unify various local coalitions and influence health, education, welfare, and government policies. Initial results indicate both objectively measured neighbourhood characteristics as well as individual perceptions of characteristics appear to be important. Furthermore, findings may differ depending on socioeconomic status, race, and urban vs rural settings. These observational studies are critical to inform the design of interventions and policies.

Across multiple settings, it is still largely unknown how the dose and frequency of breaks to sitting time may reduce the potential negative effects of prolonged sedentary periods. Understanding the dose–response relationships at community levels is crucial to intervention success and will inform future national and international guidelines around sedentary behaviour. Such findings also may improve the feasibility and acceptability of community-based interventions which face more complex organisational, socioeconomic, cultural, and political barriers. It is also important to note that individual-level factors influencing sedentary behaviour and intervention success may become more or less effective at the community levels due to a number of other influencing factors. For example, age may not play a significant role at the individual level, however, in a school environment, correlates and determinants may differ based on grade level. Such knowledge may help develop more tailored, effective strategies. Overall, at the community level, there is a predominance of cross-sectional studies, which may inhibit the determination of causality between variables. More randomised controlled trials should be conducted to confirm deleterious effects attributed to some sedentary behaviours. Future epidemiological studies need to assess multiple sedentary behaviours as there is growing epidemiological evidence that certain sedentary activities are more detrimental for health than others. To increase the current knowledge of sedentary behaviour, future studies must incorporate more accurate methods suited for their research question (e.g., inclinometers for time spent sitting vs self-report for contextual information) to obtain an accurate measure and contextual information of sedentary behaviour [178]. Finally, in contrast to early research, physical activity should be measured as a confounding and/or interactive factor in all experimental designs.

23.6 Summary

The "drivers" of sedentary behaviour include both elements of conscious decision-making and habitual responses cued or required by public policy. Thus, interventions should take advantage of changes in the built and social environments, the use of social networks, and the promotion of relevant public policy changes that are all accessible at the community level [179]. The acceleration of new and innovative technology also presents a need to determine how new technologies can be integrated with principles of behavioural science to reduce sedentary behaviour at the community level. The ability to track sedentary behaviour and communicate it to the user is a potential effective sedentary behaviour reduction strategy. The magnitude, long-term effects, and optimal design in various environments and contexts are still unknown. The technological capability to alert or remind the user to stand or move is no longer a novel feat. However, understanding the underlying contexts of sedentary behaviour to determine when and how to use prompts effectively continues to be a challenge. Technology industries and researchers alike must now generate context-driven approaches that consider both opportunity and receptivity of the user to optimise intervention strategies. Integrating behavioural science theory with an iterative user-oriented design process is needed to optimise multi-component strategies that can adapt over time. Conversely, identifying strategies associated with less promising interventions can ensure that intervention designers do not devote time and resources to developing futile strategies. Advances in technology should be employed at multiple intervention levels to accommodate the determinants of sedentary behaviour across the life course.

There is a need to evaluate the feasibility, acceptability, and effectiveness of different sedentary reduction strategies across the life course. The power of qualitative information must not be overlooked as it is vital in understanding the causes of excessive sedentary behaviour. Such information is needed to help researchers understand community barriers, beliefs, attitudes, and acceptability of different intervention and measurement approaches. Sedentary behaviour is a complex epidemic with various contributing factors at multiple levels. Although conclusive evidence is lacking, it is suggested that multi-level approaches that include individual, community, and organisational levels, across and within different settings, will produce larger and longer lasting effects [180]. Ultimately, a combined effort of strategies that target sedentary behaviour as an independent risk factor, across multiple settings, such as schools, workplaces, and neighbourhoods, is required.

References

1. Keadle SK, Conroy DE, Buman MP, Dunstan DW, Matthews CE. Targeting reductions in sitting time to increase physical activity and improve health. Med Sci Sports Exerc [Internet]. 2017 Aug 1 [cited 2021 Nov 30];49(8):1572–82. Available from: https://pubmed.ncbi.nlm.nih.gov/28272267/

2. Parise I. The built environment and obesity: You are where you live. Aust J Gen Pract [Internet]. 2020 Apr 1 [cited 2021 Nov 30];49(4):226–30. Available from: https://pubmed.ncbi.nlm.nih.gov/32233351/
3. Meyer J, McDowell C, Lansing J, Brower C, Smith L, Tully M, et al. Changes in physical activity and sedentary behavior in response to COVID-19 and their associations with mental health in 3052 US adults. Int J Environ Res Public Health [Internet]. 2020 Sep 2 [cited 2021 Nov 30];17(18):1–13. Available from: https://pubmed.ncbi.nlm.nih.gov/32899495/
4. Senerat AM, Pope ZC, Rydell SA, Mullan AF, Roger VL, Pereira MA. Psychosocial and behavioral outcomes and transmission prevention Behaviors: working during the coronavirus disease 2019 pandemic. Mayo Clin Proc Innov Qual Outcomes. 2021 Dec 1;5(6):1089–99.
5. Jones SA, Wen F, Herring AH, Evenson KR. Correlates of US adult physical activity and sedentary behavior patterns. J Sci Med Sport [Internet]. 2016 Dec 1 [cited 2021 Nov 30];19(12):1020–7. Available from: https://pubmed.ncbi.nlm.nih.gov/27053434/
6. USDHHS. Physical activity guidelines for Americans 2nd edition. 2018;
7. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med [Internet]. 2020 Dec 1 [cited 2021 Dec 21];54(24):1451–62. Available from: https://pubmed.ncbi.nlm.nih.gov/33239350/
8. Tremblay MS, Carson V, Chaput JP, Connor Gorber S, Dinh T, Duggan M, et al. Canadian 24-hour movement guidelines for children and youth: an integration of physical activity, sedentary behaviour, and sleep. Appl Physiol Nutr Metab [Internet]. 2016 [cited 2021 Dec 20];41(6 Suppl 3):S311–27. Available from: https://pubmed.ncbi.nlm.nih.gov/27306437/
9. Hidding LM, Altenburg TM, van Ekris E, Chinapaw MJM. Why do children engage in sedentary behavior? Child- and parent-perceived determinants. Int J Environ Res Public Health [Internet]. 2017 Jul 1 [cited 2021 Dec 20];14(7). Available from: https://pubmed.ncbi.nlm.nih.gov/28640232/
10. Zhang Z, Kuzik N, Adamo KB, Ogden N, Goldfield GS, Okely AD, et al. Associations between the child care environment and children's in-care physical activity and sedentary time. Health Educ Behav [Internet]. 2021 Feb 1 [cited 2021 Dec 20];48(1):42–53. Available from: https://pubmed.ncbi.nlm.nih.gov/33190548/
11. Chai LK, Rice-Mcneil K, Trost SG. Patterns and correlates of sedentary behavior in children attending family child care. Int J Environ Res Public Health [Internet]. 2020 Jan 2 [cited 2021 Dec 20];17(2). Available from: https://pubmed.ncbi.nlm.nih.gov/31952208/
12. Barnett TA, Kelly CAS, Young DR, Perry CK, Pratt CA, Edwards NM, et al. Sedentary behaviors in today's youth: approaches to the prevention and management of childhood obesity: a scientific statement from the american heart association. Circulation [Internet]. 2018 [cited 2021 Dec 20];138(11):E142–59. Available from: https://pubmed.ncbi.nlm.nih.gov/30354382/
13. Lau M, Wang L, Acra S, Buchowski MS. Energy expenditure of common sedentary activities in youth. J Phys Act Health [Internet]. 2016 [cited 2021 Dec 20];13(6 Suppl 1):S17–20. Available from: https://pubmed.ncbi.nlm.nih.gov/27392371/
14. Shakir RN, Coates AM, Olds T, Rowlands A, Tsiros MD. Not all sedentary behaviour is equal: children's adiposity and sedentary behaviour volumes, patterns and types. Obes Res Clin Pract [Internet]. 2018 Nov 1 [cited 2021 Dec 20];12(6):506–12. Available from: https://pubmed.ncbi.nlm.nih.gov/30228035/
15. Arundell L, Fletcher E, Salmon J, Veitch J, Hinkley T. A systematic review of the prevalence of sedentary behavior during the after-school period among children aged 5-18 years. Int J Behav Nutr Phys Act [Internet]. 2016 Aug 22 [cited 2021 Dec 20];13(1):1–9. Available from: https://ijbnpa.biomedcentral.com/articles/10.1186/s12966-016-0419-1
16. Cabanas-Sánchez V, Martínez-Gómez D, Esteban-Cornejo I, Pérez-Bey A, Castro Piñero J, Veiga OL. Associations of total sedentary time, screen time and non-screen sedentary time with adiposity and physical fitness in youth: the mediating effect of physical activity. J Sports

Sci [Internet]. 2019 Apr 18 [cited 2021 Dec 20];37(8):839–49. Available from: https://www.tandfonline.com/doi/abs/10.1080/02640414.2018.1530058
17. Private School Universe Survey (PSS).
18. McLellan G, Arthur R, Donnelly S, Buchan DS. Segmented sedentary time and physical activity patterns throughout the week from wrist-worn ActiGraph GT3X+ accelerometers among children 7–12 years old. J Sport Heal Sci [Internet]. 2020 Mar 1 [cited 2021 Dec 20];9(2):179–88. Available from: https://pubmed.ncbi.nlm.nih.gov/32099726/
19. Egan CA, Webster CA, Beets MW, Weaver RG, Russ L, Michael D, et al. Sedentary Time and Behavior during school: a systematic review and meta-analysis. 2019 Sep 3 [cited 2021 Dec 20];50(5):283–90. Available from: https://www.tandfonline.com/doi/abs/10.1080/19325037.2019.1642814
20. Grao-Cruces A, Velásquez-Romero MJ, Rodriguez-Rodríguez F. Levels of physical activity during school hours in children and adolescents: A Systematic Review. Int J Environ Res Public Health [Internet]. 2020 Jul 1 [cited 2021 Dec 20];17(13):1–23. Available from: https://pubmed.ncbi.nlm.nih.gov/32630760/
21. Physical strength required for jobs in different occupations in 2016 : The Economics Daily: U.S. Bureau of Labor Statistics [Internet]. [cited 2021 Dec 20]. Available from: https://www.bls.gov/opub/ted/2017/physical-strength-required-for-jobs-in-different-occupations-in-2016.htm
22. Healy GN, Eakin EG, Owen N, LaMontagne AD, Moodie M, Winkler EAH, et al. A cluster randomized controlled trial to reduce office workers' sitting time: effect on activity outcomes. Med Sci Sports Exerc [Internet]. 2016 Sep 1 [cited 2021 Dec 20];48(9):1787–97. Available from: https://pubmed.ncbi.nlm.nih.gov/27526175/
23. Rosenkranz SK, Mailey EL, Umansky E, Rosenkranz RR, Ablah E. Workplace sedentary behavior and productivity: a cross-sectional study. Int J Environ Res Public Health [Internet]. 2020 Sep 2 [cited 2021 Dec 20];17(18):1–14. Available from: https://pubmed.ncbi.nlm.nih.gov/32911740/
24. Prince SA, Elliott CG, Scott K, Visintini S, Reed JL. Device-measured physical activity, sedentary behaviour and cardiometabolic health and fitness across occupational groups: a systematic review and meta-analysis. Int J Behav Nutr Phys Act [Internet]. 2019 Apr 2 [cited 2021 Dec 20];16(1). Available from: https://pubmed.ncbi.nlm.nih.gov/30940176/
25. Yang Y, An R, Zhu W. Physical activity and prolonged sedentary behavior in US working adults. Arch Environ Occup Health [Internet]. 2016 Nov 1 [cited 2021 Dec 20];71(6):362–5. Available from: https://pubmed.ncbi.nlm.nih.gov/26862663/
26. Bláfoss R, Micheletti JK, Sundstrup E, Jakobsen MD, Bay H, Andersen LL. Is fatigue after work a barrier for leisure-time physical activity? Cross-sectional study among 10,000 adults from the general working population. Scand J Public Health [Internet]. 2019 May 1 [cited 2021 Dec 20];47(3):383–91. Available from: https://pubmed.ncbi.nlm.nih.gov/29609495/
27. Smith M, Hosking J, Woodward A, Witten K, MacMillan A, Field A, et al. Systematic literature review of built environment effects on physical activity and active transport - an update and new findings on health equity. Int J Behav Nutr Phys Act [Internet]. 2017 Nov 16 [cited 2021 Dec 20];14(1). Available from: https://pubmed.ncbi.nlm.nih.gov/29145884/
28. Barnett DW, Barnett A, Nathan A, Van Cauwenberg J, Cerin E. Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. Int J Behav Nutr Phys Act [Internet]. 2017 Aug 7 [cited 2021 Dec 20];14(1). Available from: https://pubmed.ncbi.nlm.nih.gov/28784183/
29. Sallis JF, Conway TL, Cain KL, Carlson JA, Frank LD, Kerr J, et al. Neighborhood built environment and socioeconomic status in relation to physical activity, sedentary behavior, and weight status of adolescents. Prev Med (Baltim) [Internet]. 2018 May 1 [cited 2021 Dec 20];110:47–54. Available from: https://pubmed.ncbi.nlm.nih.gov/29432790/
30. Laddu D, Paluch AE, LaMonte MJ. The role of the built environment in promoting movement and physical activity across the lifespan: Implications for public health. Prog Cardiovasc Dis

[Internet]. 2021 Jan 1 [cited 2021 Dec 20];64:33–40. Available from: https://pubmed.ncbi.nlm.nih.gov/33428966/
31. Zullig KJ, Koopman TM, Patton JM, Ubbes VA. School climate: Historical review, instrument development, and school assessment. J Psychoeduc Assess [Internet]. 2010 Apr [cited 2021 Dec 20];28(2):139–52. Available from: https://www.researchgate.net/publication/233858309_School_Climate_Historical_Review_Instrument_Development_School_Assessment
32. Ferreira RW, Rombaldi AJ, Ricardo LIC, Hallal PC, Azevedo MR. [Prevalence of sedentary behavior and its correlates among primary and secondary school students]. Rev Paul Pediatr [Internet]. 2016 Mar [cited 2021 Dec 20];34(1):56–63. Available from: https://pubmed.ncbi.nlm.nih.gov/26826878/
33. Zhang P, Liu Y, Gu X, Chen S. Toward active living: SES- and race-based disparities in knowledge and behaviors. J racial Ethn Heal disparities [Internet]. 2020 Apr 1 [cited 2021 Dec 20];7(2):374–82. Available from: https://pubmed.ncbi.nlm.nih.gov/31721109/
34. Mah SK, Nettlefold L, Macdonald HM, Winters M, Race D, Voss C, et al. Does parental support influence children's active school travel? Prev Med reports [Internet]. 2017 Jun 1 [cited 2021 Dec 20];6:346–51. Available from: https://pubmed.ncbi.nlm.nih.gov/28507889/
35. Sims D, Bopp M. Using parental active travel behavior and beliefs to predict active travel to school among children. https://doi.org/101080/1556831820181558469 [Internet]. 2019 May 3 [cited 2021 Dec 20];14(5):343–8. Available from: https://www.tandfonline.com/doi/abs/10.1080/15568318.2018.1558469
36. Turrisi TB, Bittel KM, West AB, Hojjatinia SS, Hojjatinia SS, Mama SK, et al. Seasons, weather, and device-measured movement behaviors: a scoping review from 2006 to 2020. Int J Behav Nutr Phys Act [Internet]. 2021 Dec 1 [cited 2021 Dec 20];18(1). Available from: https://pubmed.ncbi.nlm.nih.gov/33541375/
37. Dunton GF, Do B, Wang SD. Early effects of the COVID-19 pandemic on physical activity and sedentary behavior in children living in the U.S. BMC Public Health [Internet]. 2020 Sep 4 [cited 2021 Dec 20];20(1). Available from: https://pubmed.ncbi.nlm.nih.gov/32887592/
38. Moore SA, Faulkner G, Rhodes RE, Brussoni M, Chulak-Bozzer T, Ferguson LJ, et al. Impact of the COVID-19 virus outbreak on movement and play behaviours of Canadian children and youth: a national survey. Int J Behav Nutr Phys Act [Internet]. 2020 Jul 6 [cited 2021 Dec 20];17(1). Available from: https://pubmed.ncbi.nlm.nih.gov/32631350/
39. Xiang M, Zhang Z, Kuwahara K. Impact of COVID-19 pandemic on children and adolescents' lifestyle behavior larger than expected. Prog Cardiovasc Dis [Internet]. 2020 Jul 1 [cited 2021 Dec 20];63(4):531–2. Available from: https://pubmed.ncbi.nlm.nih.gov/32360513/
40. King DL, Delfabbro PH, Billieux J, Potenza MN. Problematic online gaming and the COVID-19 pandemic. J Behav Addict [Internet]. 2020 Apr 29 [cited 2022 Jan 24];9(2):184–6. Available from: https://akjournals.com/view/journals/2006/9/2/article-p184.xml
41. Lozic JKDVD. The impact of COVID 19 pandemic on global video gaming market. Econ Soc Dev B Proc. 2021:166–74.
42. Amin KP, Griffiths MD, Dsouza DD. Online gaming during the COVID-19 pandemic in India: strategies for work-life balance. Int J Ment Heal Addict 2020 [Internet]. 2020 Jul 10 [cited 2022 Jan 24];1–7. Available from: https://link.springer.com/article/10.1007/s11469-020-00358-1
43. Romero-Blanco C, Rodríguez-Almagro J, Onieva-Zafra MD, Parra-Fernández ML, Prado-Laguna MDC, Hernández-Martínez A. Physical activity and sedentary lifestyle in university students: changes during confinement due to the COVID-19 pandemic. Int J Environ Res Public Health [Internet]. 2020 Sep 2 [cited 2021 Dec 20];17(18):1–13. Available from: https://pubmed.ncbi.nlm.nih.gov/32916972/
44. Bertrand L, Shaw KA, Ko J, Deprez D, Chilibeck PD, Zello GA. The impact of the coronavirus disease 2019 (COVID-19) pandemic on university students' dietary intake, physical activity, and sedentary behaviour. Appl Physiol Nutr Metab [Internet]. 2021 [cited 2021 Dec 20];46(3):265–72. Available from: https://pubmed.ncbi.nlm.nih.gov/33449864/

45. Gallè F, Sabella EA, Ferracuti S, De Giglio O, Caggiano G, Protano C, et al. Sedentary Behaviors and Physical activity of Italian undergraduate students during lockdown at the time of CoViD-19 pandemic. Int J Environ Res Public Health [Internet]. 2020 Sep 1 [cited 2021 Dec 20];17(17):1–11. Available from: https://pubmed.ncbi.nlm.nih.gov/32854414/
46. Rodríguez-Larrad A, Mañas A, Labayen I, González-Gross M, Espin A, Aznar S, et al. Impact of COVID-19 confinement on physical activity and sedentary behaviour in spanish university students: role of gender. Int J Environ Res Public Health [Internet]. 2021 Jan 2 [cited 2021 Dec 20];18(2):1–14. Available from: https://pubmed.ncbi.nlm.nih.gov/33418907/
47. Castañeda-Babarro A, Coca A, Arbillaga-Etxarri A, Gutiérrez-Santamaría B. Physical activity change during COVID-19 confinement. Int J Environ Res Public Health [Internet]. 2020 Sep 1 [cited 2021 Dec 20];17(18):1–10. Available from: https://pubmed.ncbi.nlm.nih.gov/32967091/
48. Olsen HM, Brown WJ, Kolbe-Alexander T, Burton NW. Flexible work: the impact of a new policy on employees' sedentary behavior and physical activity. J Occup Environ Med [Internet]. 2018 Jan 1 [cited 2021 Dec 20];60(1):23–8. Available from: https://pubmed.ncbi.nlm.nih.gov/29023342/
49. Barone Gibbs B, Kline CE, Huber KA, Paley JL, Perera S. Covid-19 shelter-at-home and work, lifestyle and well-being in desk workers. Occup Med (Lond) [Internet]. 2021 Apr 9 [cited 2021 Dec 20];71(2):86–94. Available from: https://pubmed.ncbi.nlm.nih.gov/33598681/
50. Bick A, Blandin A, Mertens K. Work from home before and after the COVID-19 outbreak. Fed Reserv Bank Dallas, Work Pap [Internet]. 2021 Feb [cited 2021 Dec 20];2020(2017). Available from: https://www.dallasfed.org:443/research/papers/2020/wp2017
51. McDowell CP, Herring MP, Lansing J, Brower C, Meyer JD. Working from home and job loss due to the COVID-19 pandemic are associated with greater time in sedentary behaviors. Front public Heal [Internet]. 2020 Nov 5 [cited 2021 Dec 20];8. Available from: https://pubmed.ncbi.nlm.nih.gov/33224922/
52. Fukushima N, Machida M, Kikuchi H, Amagasa S, Hayashi T, Odagiri Y, et al. Associations of working from home with occupational physical activity and sedentary behavior under the COVID-19 pandemic. J Occup Health [Internet]. 2021 Jan 1 [cited 2021 Dec 20];63(1): e12212. Available from: https://pubmed.ncbi.nlm.nih.gov/33683779/
53. Mitra R, Moore SA, Gillespie M, Faulkner G, Vanderloo LM, Chulak-Bozzer T, et al. Healthy movement behaviours in children and youth during the COVID-19 pandemic: exploring the role of the neighbourhood environment. Health Place [Internet]. 2020 Sep 1 [cited 2021 Dec 20];65. Available from: https://pubmed.ncbi.nlm.nih.gov/32871499/
54. Hall G, Laddu DR, Phillips SA, Lavie CJ, Arena R. A tale of two pandemics: how will COVID-19 and global trends in physical inactivity and sedentary behavior affect one another? Prog Cardiovasc Dis [Internet]. 2021 Jan 1 [cited 2021 Dec 20];64:108–10. Available from: https://pubmed.ncbi.nlm.nih.gov/32277997/
55. Bates LC, Zieff G, Stanford K, Moore JB, Kerr ZY, Hanson ED, et al. COVID-19 impact on behaviors across the 24-hour day in children and adolescents: physical activity, sedentary behavior, and sleep. Child (Basel, Switzerland) [Internet]. 2020 Sep 1 [cited 2021 Dec 20];7(9). Available from: https://pubmed.ncbi.nlm.nih.gov/32947805/
56. Kallio J, Hakonen H, Syväoja H, Kulmala J, Kankaanpää A, Ekelund U, et al. Changes in physical activity and sedentary time during adolescence: gender differences during weekdays and weekend days. Scand J Med Sci Sports [Internet]. 2020 Jul 1 [cited 2021 Dec 20];30(7): 1265–75. Available from: https://pubmed.ncbi.nlm.nih.gov/32248577/
57. da Costa BGG, da Silva KS, Malheiros LEA, Minatto G, de Lima LRA, Petroski EL. Are adolescents really being sedentary or inactive when at school? An analysis of sedentary behaviour and physical activity bouts. Eur J Pediatr [Internet]. 2018 Nov 1 [cited 2021 Dec 20];177(11):1705–10. Available from: https://pubmed.ncbi.nlm.nih.gov/30182218/
58. da Costa BGG, da Silva KS, George AM, de Assis MAA. Sedentary behavior during school-time: sociodemographic, weight status, physical education class, and school performance

correlates in Brazilian schoolchildren. J Sci Med Sport [Internet]. 2017 Jan 1 [cited 2021 Dec 20];20(1):70–4. Available from: https://pubmed.ncbi.nlm.nih.gov/27374756/
59. Prince SA, Roberts KC, Melvin A, Butler GP, Thompson W. Gender and education differences in sedentary behaviour in Canada: an analysis of national cross-sectional surveys. BMC Public Health [Internet]. 2020 Jul 27 [cited 2021 Dec 20];20(1). Available from: https://pubmed.ncbi.nlm.nih.gov/32718356/
60. Smith L, McCourt O, Sawyer A, Ucci M, Marmot A, Wardle J, et al. A review of occupational physical activity and sedentary behaviour correlates. Occup Med (Lond) [Internet]. 2016 Apr 1 [cited 2021 Dec 20];66(3):185–92. Available from: https://pubmed.ncbi.nlm.nih.gov/27016747/
61. Wilkerson AH, Usdan SL, Knowlden AP, Leeper JL, Birch DA, Hibberd EE. Ecological influences on employees' workplace sedentary behavior: a cross-sectional study. Am J Health Promot [Internet]. 2018 Nov 1 [cited 2021 Dec 20];32(8):1688–96. Available from: https://pubmed.ncbi.nlm.nih.gov/29660987/
62. Wilkerson AH, Usdan SL, Knowlden AP, Leeper JL, Birch DA, Hibberd EE. Workplace-related factors associated with employees' standing time at work: a research brief. Am J Health Promot [Internet]. 2019 May 1 [cited 2021 Dec 20];33(4):606–10. Available from: https://pubmed.ncbi.nlm.nih.gov/30370784/
63. Lakerveld J, Loyen A, Schotman N, Peeters CFW, Cardon G, van der Ploeg HP, et al. Sitting too much: a hierarchy of socio-demographic correlates. Prev Med (Baltim) [Internet]. 2017 Aug 1 [cited 2021 Dec 20];101:77–83. Available from: https://pubmed.ncbi.nlm.nih.gov/28551361/
64. Kazi A, Haslam C, Duncan M, Clemes S, Twumasi R. Sedentary behaviour and health at work: an investigation of industrial sector, job role, gender and geographical differences. Ergonomics [Internet]. 2019 Jan 2 [cited 2021 Dec 20];62(1):21–30. Available from: https://pubmed.ncbi.nlm.nih.gov/29925296/
65. Kurosawa S, Shibata A, Ishii K, Koohsari MJ, Oka K. Accelerometer-measured diurnal patterns of sedentary behavior among japanese workers: a descriptive epidemiological study. Int J Environ Res Public Health [Internet]. 2020 Jun 1 [cited 2021 Dec 20];17(11). Available from: https://pubmed.ncbi.nlm.nih.gov/32471293/
66. Engelen L, Held F. Understanding the office: using ecological momentary assessment to measure activities, posture, social interactions, mood, and work performance at the workplace. Build 2019, Vol 9, Page 54 [Internet]. 2019 Feb 25 [cited 2021 Dec 20];9(2):54. Available from: https://www.mdpi.com/2075-5309/9/2/54/htm
67. Owens A, Candipan J. Social and spatial inequalities of educational opportunity: a portrait of schools serving high- and low-income neighbourhoods in US metropolitan areas: https://doi.org/101177/0042098018815049 [Internet]. 2019 Feb 14 [cited 2021 Dec 20];56(15):3178–97. Available from: https://journals.sagepub.com/doi/10.1177/0042098018815049
68. Cabanas-Sánchez V, Esteban-Cornejo I, Izquierdo-Gómez R, Padilla-Moledo C, Castro-Piñero J, Veiga ÓL. How socio-demographic and familiar circumstances are associated with total and domain-specific sedentary behaviour in youth? The UP&DOWN study. Eur J Sport Sci [Internet]. 2020 Sep 13 [cited 2021 Dec 20];20(8):1102–12. Available from: https://pubmed.ncbi.nlm.nih.gov/31699004/
69. Michael RD, Webster CA, Egan CA, Nilges L, Brian A, Johnson R, et al. Facilitators and barriers to movement integration in elementary classrooms: a systematic review. Res Q Exerc Sport [Internet]. 2019 Apr 3 [cited 2021 Dec 20];90(2):151–62. Available from: https://pubmed.ncbi.nlm.nih.gov/30794089/
70. Lafrenz A, Lust T, Cleveland M, Mirka A, Downs A, Goodin B, et al. Association between psychosocial and organizational factors and objectively measured sedentary behavior in desk-dependent office workers. Occup Heal Sci 2018 24 [Internet]. 2018 Nov 1 [cited 2021 Dec 20];2(4):323–35. Available from: https://link.springer.com/article/10.1007/s41542-018-0028-2

71. Mackenzie K, Such E, Norman P, Goyder E. Sitting less at work: a qualitative study of barriers and enablers in organisations of different size and sector. 2019 Jul 4 [cited 2021 Dec 20];19(1): 1–13. Available from: https://pubmed.ncbi.nlm.nih.gov/31272484/
72. Wallmann-Sperlich B, Bipp T, Bucksch J, Froboese I. Who uses height-adjustable desks? - Sociodemographic, health-related, and psycho-social variables of regular users. Int J Behav Nutr Phys Act [Internet]. 2017 Mar 6 [cited 2021 Dec 20];14(1). Available from: https://pubmed.ncbi.nlm.nih.gov/28264685/
73. Education: From disruption to recovery [Internet]. [cited 2021 Dec 20]. Available from: https://en.unesco.org/covid19/educationresponse#schoolclosures
74. Lin CY, Koohsari MJ, Liao Y, Ishii K, Shibata A, Nakaya T, et al. Workplace neighbourhood built environment and workers' physically-active and sedentary behaviour: a systematic review of observational studies. Int J Behav Nutr Phys Act [Internet]. 2020 Dec 1 [cited 2021 Dec 20];17(1):1–24. Available from: https://ijbnpa.biomedcentral.com/articles/10.1186/s12966-020-01055-x
75. Zhu X, Yoshikawa A, Qiu L, Lu Z, Lee C, Ory M. Healthy workplaces, active employees: a systematic literature review on impacts of workplace environments on employees' physical activity and sedentary behavior. Build Environ. 2020 Jan 15;168:106455.
76. Mullane SL, Toledo MJL, Rydell SA, Feltes LH, Vuong B, Crespo NC, et al. Social ecological correlates of workplace sedentary behavior. Int J Behav Nutr Phys Act [Internet]. 2017 Aug 31 [cited 2021 May 11];14(1). Available from: /pmc/articles/PMC5580289/.
77. Spinney R, Smith L, Ucci M, Fisher A, Konstantatou M, Sawyer A, et al. Indoor tracking to understand physical activity and sedentary behaviour: exploratory study in UK office buildings. PLoS One [Internet]. 2015 May 20 [cited 2021 Dec 20];10(5). Available from: https://pubmed.ncbi.nlm.nih.gov/25993515/
78. Clemes SA, Bingham DD, Pearson N, Chen YL, Edwardson CL, McEachan RRC, et al. Stand Out in Class: restructuring the classroom environment to reduce sitting time - findings from a pilot cluster randomised controlled trial. Int J Behav Nutr Phys Act [Internet]. 2020 Apr 29 [cited 2021 Dec 20];17(1). Available from: https://pubmed.ncbi.nlm.nih.gov/32349761/
79. Rowland TW. The biological basis of physical activity. Med Sci Sports Exerc [Internet]. 1998 [cited 2021 Dec 20];30(3):392–9. Available from: https://pubmed.ncbi.nlm.nih.gov/9526885/
80. Khan A, Mandic S, Uddin R. Association of active school commuting with physical activity and sedentary behaviour among adolescents: a global perspective from 80 countries. J Sci Med Sport [Internet]. 2021 Jun 1 [cited 2021 Dec 20];24(6):567–72. Available from: https://pubmed.ncbi.nlm.nih.gov/33376077/
81. Kontou E, McDonald NC, Brookshire K, Pullen-Seufert NC, LaJeunesse S. U.S. active school travel in 2017: prevalence and correlates. Prev Med Rep. 2020 Mar 1;17:101024.
82. Ikeda E, Hinckson E, Witten K, Smith M. Assessment of direct and indirect associations between children active school travel and environmental, household and child factors using structural equation modelling. Int J Behav Nutr Phys Act [Internet]. 2019 Apr 5 [cited 2021 Dec 20];16(1). Available from: https://pubmed.ncbi.nlm.nih.gov/30953526/
83. Masoumi HE. Associations of built environment and children's physical activity: a narrative review. Rev Environ Health [Internet]. 2017 Dec 20 [cited 2021 Dec 22];32(4):315–31. Available from: https://pubmed.ncbi.nlm.nih.gov/28809754/
84. Wilson K, Clark AF, Gilliland JA. Understanding child and parent perceptions of barriers influencing children's active school travel. BMC Public Health [Internet]. 2018 Aug 22 [cited 2021 Dec 22];18(1). Available from: https://pubmed.ncbi.nlm.nih.gov/30134889/
85. Rothman L, Macpherson AK, Ross T, Buliung RN. The decline in active school transportation (AST): A systematic review of the factors related to AST and changes in school transport over time in North America. Prev Med (Baltim). 2018 Jun 1;111:314–22.
86. González SA, Sarmiento OL, Lemoine PD, Larouche R, Meisel JD, Tremblay MS, et al. Active school transport among children from Canada, Colombia, Finland, South Africa, and the United States: a tale of two journeys. Int J Environ Res Public Health [Internet]. 2020 Jun 1 [cited 2021 Dec 20];17(11). Available from: https://pubmed.ncbi.nlm.nih.gov/32481728/

87. Kim YJ, Lee C. Built and natural environmental correlates of parental safety concerns for children's active travel to school. Int J Environ Res Public Health [Internet]. 2020 Jan 2 [cited 2021 Dec 20];17(2). Available from: https://pubmed.ncbi.nlm.nih.gov/31947555/
88. Young DR, Cradock AL, Eyler AA, Fenton M, Pedroso M, Sallis JF, et al. Creating built environments that expand active transportation and active living across the united states: a policy statement from the american heart association. Circulation [Internet]. 2020 [cited 2021 Dec 20];142(11):167–83. Available from: https://pubmed.ncbi.nlm.nih.gov/32787443/
89. Atkin AJ, Sharp SJ, Harrison F, Brage Sø, Van Sluijs EMF. Seasonal variation in children's physical activity and sedentary time. Med Sci Sports Exerc [Internet]. 2016 Mar 1 [cited 2021 Dec 20];48(3):449–56. Available from: https://pubmed.ncbi.nlm.nih.gov/26429733/
90. Amagasa S, Inoue S, Murayama H, Fujiwara T, Kikuchi H, Fukushima N, et al. Changes in rural older adults' sedentary and physically-active behaviors between a non-snowfall and a snowfall season: compositional analysis from the NEIGE study. BMC Public Health [Internet]. 2020 Aug 17 [cited 2021 Dec 20];20(1). Available from: https://pubmed.ncbi.nlm.nih.gov/32807133/
91. Zheng C, Huang WY, Wong SHS. Associations of weather conditions with adolescents' daily physical activity, sedentary time, and sleep duration. Appl Physiol Nutr Metab [Internet]. 2019 [cited 2021 Dec 20];44(12):1339–44. Available from: https://pubmed.ncbi.nlm.nih.gov/31063697/
92. Ferguson T, Curtis R, Fraysse F, Lagiseti R, Northcott C, Virgara R, et al. Annual, seasonal, cultural and vacation patterns in sleep, sedentary behaviour and physical activity: a systematic review and meta-analysis. BMC Public Health [Internet]. 2021 Dec 1 [cited 2021 Dec 20];21(1). Available from: https://pubmed.ncbi.nlm.nih.gov/34256712/
93. Salmon J, Jorna M, Hume C, Arundell L, Chahine N, Tienstra M, et al. A translational research intervention to reduce screen behaviours and promote physical activity among children: switch-2-activity. Health Promot Int [Internet]. 2011 Sep [cited 2021 Dec 20];26(3):311–21. Available from: https://pubmed.ncbi.nlm.nih.gov/21177770/
94. Robinson TN. Reducing children's television viewing to prevent obesity: a randomized controlled trial. JAMA [Internet]. 1999 Oct 27 [cited 2021 Dec 20];282(16):1561–7. Available from: https://pubmed.ncbi.nlm.nih.gov/10546696/
95. Robinson TN, Borzekowski DLG. Effects of the SMART classroom curriculum to reduce child and family screen time. J Commun [Internet]. 2006 Mar 1 [cited 2021 Dec 20];56(1):1–26. Available from: https://academic.oup.com/joc/article/56/1/1/4102676
96. Salmon J, Ball K, Hume C, Booth M, Crawford D. Outcomes of a group-randomized trial to prevent excess weight gain, reduce screen behaviours and promote physical activity in 10-year-old children: switch-play. Int J Obes (Lond) [Internet]. 2008 Apr [cited 2021 Dec 20];32(4):601–12. Available from: https://pubmed.ncbi.nlm.nih.gov/18253162/
97. Bandura A. Social foundations of thought and action: a social cognitive theory. Prentice-Hall, Inc.; 1986.
98. Baranowski T, Klesges LM, Cullen KW, Himes JH. Measurement of outcomes, mediators, and moderators in behavioral obesity prevention research. Prev Med (Baltim) [Internet]. 2004 [cited 2021 Dec 20];38 Suppl(SUPPL.):1–13. Available from: https://pubmed.ncbi.nlm.nih.gov/15072854/
99. Reilly JJ, Kelly L, Montgomery C, Williamson A, Fisher A, McColl JH, et al. Physical activity to prevent obesity in young children: cluster randomised controlled trial. BMJ [Internet]. 2006 Nov 18 [cited 2021 Dec 20];333(7577):1041–3. Available from: https://pubmed.ncbi.nlm.nih.gov/17028105/
100. Salmon J, Tremblay MS, Marshall SJ, Hume C. Health risks, correlates, and interventions to reduce sedentary behavior in young people. Am J Prev Med [Internet]. 2011 [cited 2021 Dec 20];41(2):197–206. Available from: https://pubmed.ncbi.nlm.nih.gov/21767728/
101. Kemp BJ, Cliff DP, Chong KH, Parrish AM. Longitudinal changes in domains of physical activity during childhood and adolescence: a systematic review. J Sci Med Sport [Internet].

2019 Jun 1 [cited 2021 Dec 20];22(6):695–701. Available from: https://pubmed.ncbi.nlm.nih.gov/30630743/

102. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. Lancet Child Adolesc Heal [Internet]. 2020 Jan 1 [cited 2021 Dec 20];4(1):23–35. Available from: https://pubmed.ncbi.nlm.nih.gov/31761562/
103. Hynynen ST, Van Stralen MM, Sniehotta FF, Araújo-Soares V, Hardeman W, Chinapaw MJM, et al. A systematic review of school-based interventions targeting physical activity and sedentary behaviour among older adolescents. 2016 Jan 1 [cited 2021 Dec 20];9(1). Available from: /pmc/articles/PMC4706019/.
104. Slootmaker SM, Chinapaw MJM, Seidell JC, van Mechelen W, Schuit AJ. Accelerometers and Internet for physical activity promotion in youth? Feasibility and effectiveness of a minimal intervention [ISRCTN93896459]. Prev Med (Baltim) [Internet]. 2010 Jul [cited 2021 Dec 20];51(1):31–6. Available from: https://pubmed.ncbi.nlm.nih.gov/20380847/
105. Mauriello LM, Ciavatta MMH, Paiva AL, Sherman KJ, Castle PH, Johnson JL, et al. Results of a multi-media multiple behavior obesity prevention program for adolescents. Prev Med (Baltim) [Internet]. 2010 Dec [cited 2021 Dec 20];51(6):451–6. Available from: https://pubmed.ncbi.nlm.nih.gov/20800079/
106. Singhal N, Misra A, Shah P, Gulati S. Effects of controlled school-based multi-component model of nutrition and lifestyle interventions on behavior modification, anthropometry and metabolic risk profile of urban Asian Indian adolescents in North India. Eur J Clin Nutr [Internet]. 2010 Apr [cited 2021 Dec 20];64(4):364–73. Available from: https://pubmed.ncbi.nlm.nih.gov/20087379/
107. Neumark-Sztainer DR, Friend SE, Flattum CF, Hannan PJ, Story MT, Bauer KW, et al. New moves-preventing weight-related problems in adolescent girls a group-randomized study. Am J Prev Med [Internet]. 2010 Nov [cited 2021 Dec 20];39(5):421–32. Available from: https://pubmed.ncbi.nlm.nih.gov/20965379/
108. Thorp AA, Healy GN, Owen N, Salmon JO, Ball K, Shaw JE, et al. Deleterious associations of sitting time and television viewing time with cardiometabolic risk biomarkers: Australian diabetes, obesity and lifestyle (AusDiab) study 2004–2005. Diabetes Care [Internet]. 2010 Feb [cited 2021 Dec 20];33(2):327–34. Available from: https://pubmed.ncbi.nlm.nih.gov/19918003/
109. Dunstan DW, Kingwell BA, Larsen R, Healy GN, Cerin E, Hamilton MT, et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes Care [Internet]. 2012 May [cited 2021 Dec 20];35(5):976–83. Available from: https://pubmed.ncbi.nlm.nih.gov/22374636/
110. Latouche C, Jowett JBM, Carey AL, Bertovic DA, Owen N, Dunstan DW, et al. Effects of breaking up prolonged sitting on skeletal muscle gene expression. J Appl Physiol [Internet]. 2013 Feb 15 [cited 2021 Dec 20];114(4):453–60. Available from: https://pubmed.ncbi.nlm.nih.gov/23271697/
111. Yang L, Cao C, Kantor ED, Nguyen LH, Zheng X, Park Y, et al. Trends in sedentary behavior among the US population, 2001–2016. JAMA [Internet]. 2019 Apr 23 [cited 2021 Dec 20];321(16):1587–97. Available from: https://pubmed.ncbi.nlm.nih.gov/31012934/
112. Lanningham-Foster L, Foster RC, McCrady SK, Manohar CU, Jensen TB, Mitre NG, et al. Changing the school environment to increase physical activity in children. Obesity (Silver Spring) [Internet]. 2008 Aug [cited 2021 Dec 20];16(8):1849–53. Available from: https://pubmed.ncbi.nlm.nih.gov/18535550/
113. Benden ME, Wendel ML, Jeffrey CE, Zhao H, Morales ML. Within-subjects analysis of the effects of a stand-biased classroom intervention on energy expenditure. J Exerc Physiol Online. 2012;15(2):9–19.
114. Koepp GA, Snedden BJ, Flynn L, Puccinelli D, Huntsman B, Levine JA. Feasibility analysis of standing desks for sixth graders: http://dx.doi.org/101177/1941406412439414 [Internet].

2012 Mar 14 [cited 2021 Dec 20];4(2):89–92. Available from: https://journals.sagepub.com/doi/10.1177/1941406412439414
115. Benden ME, Zhao H, Jeffrey CE, Wendel ML, Blake JJ. The evaluation of the impact of a stand-biased desk on energy expenditure and physical activity for elementary school students. Int J Environ Res Public Health [Internet]. 2014 Sep 10 [cited 2021 Dec 20];11(9):9361–75. Available from: https://pubmed.ncbi.nlm.nih.gov/25211776/
116. Wick K, Faude O, Manes S, Zahner L, Donath L. I Can stand learning: a controlled pilot intervention study on the effects of increased standing time on cognitive function in primary school children. Int J Environ Res Public Health [Internet]. 2018 Feb 17 [cited 2021 Dec 20];15(2). Available from: https://pubmed.ncbi.nlm.nih.gov/29462986/
117. Sherry AP, Pearson N, Ridgers ND, Johnson W, Barber SE, Bingham DD, et al. Impacts of a standing desk intervention within an english primary school classroom: a pilot controlled trial. Int J Environ Res Public Health [Internet]. 2020 Oct 1 [cited 2021 Dec 20];17(19):1–19. Available from: https://pubmed.ncbi.nlm.nih.gov/32993142/
118. Parry S, De Oliveira BIR, McVeigh JA, Ee J, Jacques A, Straker L. Standing desks in a grade 4 classroom over the full school year. Int J Environ Res Public Health [Internet]. 2019 Oct 1 [cited 2021 Dec 20];16(19). Available from: https://pubmed.ncbi.nlm.nih.gov/31557874/
119. Chen YL, Tolfrey K, Pearson N, Bingham DD, Edwardson C, Cale L, et al. Stand out in class: investigating the potential impact of a sit-stand desk intervention on children's sitting and physical activity during class time and after school. Int J Environ Res Public Health [Internet]. 2021 May 1 [cited 2021 Dec 20];18(9). Available from: https://pubmed.ncbi.nlm.nih.gov/33946984/
120. Freak-Poli RLA, Cumpston M, Albarqouni L, Clemes SA, Peeters A. Workplace pedometer interventions for increasing physical activity. Cochrane database Syst Rev [Internet]. 2020 Jul 22 [cited 2021 Dec 20];7(7). Available from: https://pubmed.ncbi.nlm.nih.gov/32700325/
121. Evans RE, Fawole HO, Sheriff SA, Dall PM, Grant PM, Ryan CG. Point-of-choice prompts to reduce sitting time at work: a randomized trial. Am J Prev Med [Internet]. 2012 Sep [cited 2021 Dec 20];43(3):293–7. Available from: https://pubmed.ncbi.nlm.nih.gov/22898122/
122. Pedersen SJ, Cooley PD, Mainsbridge C. An e-health intervention designed to increase workday energy expenditure by reducing prolonged occupational sitting habits. Work [Internet]. 2014 [cited 2021 Dec 20];49(2):289–95. Available from: https://pubmed.ncbi.nlm.nih.gov/23787256/
123. Gilson ND, Ng N, Pavey TG, Ryde GC, Straker L, Brown WJ. Project Energise: using participatory approaches and real time computer prompts to reduce occupational sitting and increase work time physical activity in office workers. J Sci Med Sport [Internet]. 2016 Nov 1 [cited 2021 Dec 20];19(11):926–30. Available from: https://pubmed.ncbi.nlm.nih.gov/26922132/
124. Taylor WC, Paxton RJ, Shegog R, Coan SP, Dubin A, Page TF, et al. Impact of booster breaks and computer prompts on physical activity and sedentary behavior among desk-based workers: a cluster-randomized controlled trial. Prev Chronic Dis [Internet]. 2016 Nov 17 [cited 2021 Dec 20];13:E155. Available from: https://pubmed.ncbi.nlm.nih.gov/27854422/
125. Carter SE, Draijer R, Maxwell JD, Morris AS, Pedersen SJ, Graves LEF, et al. Using an e-health intervention to reduce prolonged sitting in UK office workers: a randomised acceptability and feasibility study. Int J Environ Res Public Health [Internet]. 2020 Dec 1 [cited 2021 Dec 20];17(23):1–21. Available from: https://pubmed.ncbi.nlm.nih.gov/33271884/
126. Sharma PP, Mehta RK, Pickens A, Han G, Benden M. Sit-stand desk software can now monitor and prompt office workers to change health behaviors. Hum Factors [Internet]. 2019 Aug 1 [cited 2021 Dec 20];61(5):816–24. Available from: https://pubmed.ncbi.nlm.nih.gov/30296174/
127. Garrett G, Zhao H, Pickens A, Mehta R, Preston L, Powell A, et al. Computer-based Prompt's impact on postural variability and sit-stand desk usage behavior; a cluster randomized control trial. Appl Ergon [Internet]. 2019 Sep 1 [cited 2021 Dec 20];79:17–24. Available from: https://pubmed.ncbi.nlm.nih.gov/31109458/

128. Morris AS, Mackintosh KA, Dunstan D, Owen N, Dempsey P, Pennington T, et al. Rise and recharge: effects on activity outcomes of an e-health smartphone intervention to reduce office workers' sitting time. Int J Environ Res Public Health [Internet]. 2020 Dec 2 [cited 2021 Dec 20];17(24):1–18. Available from: https://pubmed.ncbi.nlm.nih.gov/33322678/
129. Dunning JR, McVeigh JA, Goble D, Meiring RM. The effect of interrupting sedentary behavior on the cardiometabolic health of adults with sedentary occupations: a pilot study. J Occup Environ Med [Internet]. 2018 [cited 2021 Dec 20];60(8):760–7. Available from: https://pubmed.ncbi.nlm.nih.gov/29608541/
130. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Pedisic Z. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev [Internet]. 2018 Jun 20 [cited 2021 Dec 20];2018(6). Available from: https://pubmed.ncbi.nlm.nih.gov/29926475/
131. Taylor WC, Williams JR, Harris LE, Shegog R. Computer prompt software to reduce sedentary behavior and promote physical activity among desk-based workers: a systematic review. Hum Factors [Internet]. 2021. [cited 2021 Dec 20]; Available from: https://pubmed.ncbi.nlm.nih.gov/34392738/
132. Larouche ML, Mullane SL, Toledo MJL, Pereira MA, Huberty JL, Ainsworth BE, et al. Using point-of-choice prompts to reduce sedentary behavior in sit-stand workstation users. Front public Heal [Internet]. 2018 Nov 21 [cited 2021 Dec 20];6(NOV). Available from: https://pubmed.ncbi.nlm.nih.gov/30525017/
133. Josaphat KJ, Kugathasan TA, Reid RER, Begon M, Léger PM, Labonté-Lemoyne E, et al. Use of active workstations in individuals with overweight or obesity: a systematic review. Obesity (Silver Spring) [Internet]. 2019 Mar 1 [cited 2021 Dec 20];27(3):362–79. Available from: https://pubmed.ncbi.nlm.nih.gov/30719877/
134. Oye-Somefun A, Azizi Z, Ardern CI, Rotondi MA. A systematic review and meta-analysis of the effect of treadmill desks on energy expenditure, sitting time and cardiometabolic health in adults. BMC Public Health [Internet]. 2021 Dec 1 [cited 2021 Dec 20];21(1). Available from: https://pubmed.ncbi.nlm.nih.gov/34774020/
135. Edwardson CL, Yates T, Biddle SJH, Davies MJ, Dunstan DW, Esliger DW, et al. Effectiveness of the Stand More AT (SMArT) Work intervention: cluster randomised controlled trial. BMJ [Internet]. 2018 [cited 2021 Dec 20];363. Available from: https://pubmed.ncbi.nlm.nih.gov/30305278/
136. Pereira MA, Mullane SL, Toledo MJL, Larouche ML, Rydell SA, Vuong B, et al. Efficacy of the "Stand and Move at Work" multicomponent workplace intervention to reduce sedentary time and improve cardiometabolic risk: a group randomized clinical trial. Int J Behav Nutr Phys Act [Internet]. 2020 Dec 1 [cited 2021 Dec 20];17(1). Available from: https://pubmed.ncbi.nlm.nih.gov/33109190/
137. Renaud LR, Jelsma JGM, Huysmans MA, van Nassau F, Lakerveld J, Speklé EM, et al. Effectiveness of the multi-component dynamic work intervention to reduce sitting time in office workers - results from a pragmatic cluster randomised controlled trial. Appl Ergon [Internet]. 2020 Apr 1 [cited 2021 Dec 20];84. Available from: https://pubmed.ncbi.nlm.nih.gov/31987512/
138. Danquah IH, Kloster S, Holtermann A, Aadahl M, Bauman A, Ersbøll AK, et al. Take a Stand!-a multi-component intervention aimed at reducing sitting time among office workers-a cluster randomized trial. Int J Epidemiol [Internet]. 2017 Feb 1 [cited 2021 Dec 20];46(1): 128–40. Available from: https://pubmed.ncbi.nlm.nih.gov/27094749/
139. Knox ECL, Musson H, Adams EJ. Workplace policies and practices promoting physical activity across England: what is commonly used and what works? Int J Work Heal Manag [Internet]. 2017 [cited 2021 Dec 20];10(5):391–403. Available from: https://pubmed.ncbi.nlm.nih.gov/29721039/
140. Lotoski L, Fuller D, Stanley KG, Rainham D, Muhajarine N. The effect of season and neighbourhood-built environment on home area sedentary behaviour in 9-14 year old children. Int J Environ Res Public Health [Internet]. 2021 Feb 2 [cited 2021 Dec 20];18(4):1–15. Available from: https://pubmed.ncbi.nlm.nih.gov/33670599/

141. Bringolf-Isler B, Kriemler S, Mäder U, Dössegger A, Hofmann H, Puder JJ, et al. Relationship between the objectively-assessed neighborhood area and activity behavior in Swiss youth. Prev Med Reports [Internet]. 2014 Oct 1 [cited 2021 Dec 20];1:14. Available from: /pmc/articles/PMC4721338/.
142. Koohsari MJ, Shibata A, Ishii K, Kurosawa S, Yasunaga A, Hanibuchi T, et al. Built environment correlates of objectively-measured sedentary behaviours in densely-populated areas. Health Place [Internet]. 2020 Nov 1 [cited 2021 Dec 20];66. Available from: https://pubmed.ncbi.nlm.nih.gov/33017753/
143. Nichani V, Turley L, Vena JE, McCormack GR. Associations between neighbourhood built characteristics and sedentary behaviours among Canadian men and women: findings from Alberta's Tomorrow Project. Prev Med (Baltim) [Internet]. 2021 Sep 1 [cited 2021 Dec 20];150. Available from: https://pubmed.ncbi.nlm.nih.gov/34087320/
144. Greenwood-Hickman MA, Walker R, Bellettiere J, LaCroix AZ, Kim B, Wing D, et al. Associations between perceived neighborhood walkability and device-based physical activity and sedentary behavior patterns in older adults. J Aging Phys Act [Internet]. 2021 Aug 13 [cited 2021 Dec 20];1–9. Available from: https://pubmed.ncbi.nlm.nih.gov/34388701/
145. Caetano IT, Miranda VPN, dos Santos FK, dos Santos Amorim PR. Adolescent's movement behaviors and built environment: a latent class analysis. BMC Public Health [Internet]. 2021 Dec 1 [cited 2021 Dec 20];21(1). Available from: https://pubmed.ncbi.nlm.nih.gov/34696762/
146. Molina-García J, Queralt A. Neighborhood built environment and socioeconomic status in relation to active commuting to school in children. J Phys Act Health [Internet]. 2017 Oct 1 [cited 2021 Dec 20];14(10):761–5. Available from: https://pubmed.ncbi.nlm.nih.gov/28513318/
147. Molina-García J, Menescardi C, Estevan I, Martínez-Bello V, Queralt A. Neighborhood built environment and socioeconomic status are associated with active commuting and sedentary behavior, but not with leisure-time physical activity, in university students. Int J Environ Res Public Health [Internet]. 2019 Sep 1 [cited 2021 Dec 20];16(17). Available from: https://pubmed.ncbi.nlm.nih.gov/31480418/
148. Salmon J, Veitch J, Abbott G, ChinAPaw M, Brug JJ, teVelde SJ, et al. Are associations between the perceived home and neighbourhood environment and children's physical activity and sedentary behaviour moderated by urban/rural location? Health Place [Internet]. 2013 [cited 2021 Dec 20];24:44–53. Available from: https://pubmed.ncbi.nlm.nih.gov/24036187/
149. Budd EL, Aaron Hipp J, Geary N, Dodson EA. Racial differences in parental perceptions of the neighborhood as predictors of children's physical activity and sedentary behavior. Prev Med Reports [Internet]. 2015 Jun 1 [cited 2021 Dec 20];2:397. Available from: /pmc/articles/PMC4721463/.
150. Hinckson E, Cerin E, Mavoa S, Smith M, Badland H, Stewart T, et al. Associations of the perceived and objective neighborhood environment with physical activity and sedentary time in New Zealand adolescents. Int J Behav Nutr Phys Act [Internet]. 2017 [cited 2021 Dec 20];14(1). Available from: https://pubmed.ncbi.nlm.nih.gov/29065897/
151. Bejarano CM, Carlson JA, Cushing CC, Kerr J, Saelens BE, Frank LD, et al. Neighborhood built environment associations with adolescents' location-specific sedentary and screen time. Health Place [Internet]. 2019 Mar 1 [cited 2021 Dec 20];56:147–54. Available from: https://pubmed.ncbi.nlm.nih.gov/30743089/
152. Goon S, Kontulainen S, Muhajarine N. Neighborhood built environment measures and association with physical activity and sedentary time in 9-14-year-old children in Saskatoon, Canada. Int J Environ Res Public Health [Internet]. 2020 Jun 1 [cited 2021 Dec 20];17(11). Available from: https://pubmed.ncbi.nlm.nih.gov/32481683/
153. Michie S, Richardson M, Johnston M, Abraham C, Francis J, Hardeman W, et al. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. Ann Behav Med [Internet]. 2013 Aug [cited 2021 Dec 20];46(1):81–95. Available from: https://pubmed.ncbi.nlm.nih.gov/23512568/

154. Cheng Chia GL, Anderson A, McLean LA. Behavior change techniques incorporated in fitness trackers: content analysis. JMIR mHealth uHealth [Internet]. 2019 [cited 2021 Dec 20];7(7). Available from: https://pubmed.ncbi.nlm.nih.gov/31339101/
155. Tate DF, Lytle LA, Sherwood NE, Haire-Joshu D, Matheson D, Moore SM, et al. Deconstructing interventions: approaches to studying behavior change techniques across obesity interventions. Transl Behav Med [Internet]. 2016 Jun 1 [cited 2021 Dec 20];6(2): 236–43. Available from: https://pubmed.ncbi.nlm.nih.gov/27356994/
156. Lewis BA, Napolitano MA, Buman MP, Williams DM, Nigg CR. Future directions in physical activity intervention research: expanding our focus to sedentary behaviors, technology, and dissemination. J Behav Med [Internet]. 2017 Feb 1 [cited 2021 Dec 20];40(1):112–26. Available from: https://pubmed.ncbi.nlm.nih.gov/27722907/
157. Bunn JA, Navalta JW, Fountaine CJ, Reece JD. Current state of commercial wearable technology in physical activity monitoring 2015–2017. Int J Exerc Sci [Internet]. 2018 [cited 2021 Dec 20];11(7):503–15. Available from: https://pubmed.ncbi.nlm.nih.gov/29541338/
158. Greiwe J, Nyenhuis SM. Wearable technology and how this can be implemented into clinical practice. Curr Allergy Asthma Rep [Internet]. 2020 Aug 1 [cited 2021 Dec 20];20(8). Available from: https://pubmed.ncbi.nlm.nih.gov/32506184/
159. Compernolle S, Desmet A, Poppe L, Crombez G, De Bourdeaudhuij I, Cardon G, et al. Effectiveness of interventions using self-monitoring to reduce sedentary behavior in adults: a systematic review and meta-analysis. Int J Behav Nutr Phys Act [Internet]. 2019 Aug 13 [cited 2021 Dec 20];16(1). Available from: https://pubmed.ncbi.nlm.nih.gov/31409357/
160. Ellingson LD, Lansing JE, DeShaw KJ, Peyer KL, Bai Y, Perez M, et al. Evaluating motivational interviewing and habit formation to enhance the effect of activity trackers on healthy adults' activity levels: randomized intervention. JMIR mHealth uHealth [Internet]. 2019 Feb 1 [cited 2021 Dec 20];7(2). Available from: https://pubmed.ncbi.nlm.nih.gov/30762582/
161. Brakenridge CL, Healy GN, Winkler EA, Fjeldsoe BS. Usage, acceptability, and effectiveness of an activity tracker in a randomized trial of a workplace sitting intervention: mixed-methods evaluation. Interact J Med Res [Internet]. 2018 Mar 2 [cited 2021 Dec 20];7(1):e5. Available from: https://pubmed.ncbi.nlm.nih.gov/29500158/
162. Barwais FA, Cuddihy TF. Empowering sedentary adults to reduce sedentary behavior and increase physical activity levels and energy expenditure: a pilot study. Int J Environ Res Public Health [Internet]. 2015 Jan 5 [cited 2021 Dec 20];12(1):414. Available from: /pmc/articles/PMC4306870/.
163. Demographics of Mobile Device Ownership and Adoption in the United States | Pew Research Center [Internet]. [cited 2021 Dec 20]. Available from: https://www.pewresearch.org/internet/fact-sheet/mobile/
164. Daryabeygi-Khotbehsara R, Islam SMS, Dunstan D, McVicar J, Abdelrazek M, Maddison R. Smartphone-based interventions to reduce sedentary behavior and promote physical activity using integrated dynamic models: systematic review. J Med Internet Res [Internet]. 2021 Sep 1 [cited 2021 Dec 20];23(9). Available from: https://pubmed.ncbi.nlm.nih.gov/34515637/
165. Nahum-Shani I, Smith SN, Spring BJ, Collins LM, Witkiewitz K, Tewari A, et al. Just-in-Time Adaptive Interventions (JITAIs) in mobile health: key components and design principles for ongoing health behavior support. Ann Behav Med [Internet]. 2018 May 18 [cited 2021 Dec 20];52(6):446–62. Available from: https://pubmed.ncbi.nlm.nih.gov/27663578/
166. Emberson MA, Lalande A, Wang D, Mcdonough DJ, Liu W, Gao Z. Effectiveness of smartphone-based physical activity interventions on individuals' health outcomes: a systematic review. Biomed Res Int [Internet]. 2021 [cited 2021 Dec 20];2021. Available from: https://pubmed.ncbi.nlm.nih.gov/34409104/
167. Buckingham SA, Williams AJ, Morrissey K, Price L, Harrison J. Mobile health interventions to promote physical activity and reduce sedentary behaviour in the workplace: a systematic

review. Digit Heal [Internet]. 2019 Mar 1 [cited 2021 Dec 20];5. Available from: /pmc/articles/PMC6437332/.
168. Hutchinson J, Headley S, Matthews T, Spicer G, Dempsey K, Wooley S, et al. Changes in sitting time and sitting fragmentation after a workplace sedentary behaviour intervention. Int J Environ Res Public Health [Internet]. 2018 Jun 1 [cited 2021 Dec 20];15(6). Available from: https://pubmed.ncbi.nlm.nih.gov/29865177/
169. O'Dolan C, Grant M, Lawrence M, Dall P. A randomised feasibility study to investigate the impact of education and the addition of prompts on the sedentary behaviour of office workers. Pilot feasibility Stud [Internet]. 2018 Apr 25 [cited 2021 Dec 20];4(1). Available from: https://pubmed.ncbi.nlm.nih.gov/29372071/
170. Anwar AA, Malik M, Raees V, Anwar AA. Role of mass media and public health communications in the COVID-19 pandemic. Cureus [Internet]. 2020 Sep 14 [cited 2021 Dec 20];12(9). Available from: https://pubmed.ncbi.nlm.nih.gov/33072461/
171. Rothschild ML. Carrots, sticks, and promises: a conceptual framework for the management of public health and social issue behaviors: https://doi.org/101080/15245004200009961146 [Internet]. 2016 Aug 1 [cited 2021 Dec 20];6(4):86–114. Available from: https://journals.sagepub.com/doi/abs/10.1080/15245004.2000.9961146
172. Gateway to Health Communication | Gateway to Health Communication | CDC [Internet]. [cited 2021 Dec 20]. Available from: https://www.cdc.gov/healthcommunication/index.html
173. Report Em. Global Social Network Users 2020 - Insider Intelligence Trends, Forecasts & Statistics [Internet]. 2020 [cited 2021 Dec 20]. Available from: https://www.emarketer.com/content/global-social-network-users-2020
174. Glasgow RE. What types of evidence are most needed to advance behavioral medicine? Ann Behav Med [Internet]. 2008 Feb [cited 2021 Dec 20];35(1):19–25. Available from: https://pubmed.ncbi.nlm.nih.gov/18347901/
175. Feighery E, Rogers T. Building and maintaining effective coalitions. Palo Alto: Stanford Health Promotion Resource Center. 1989
176. Buman MP, Mullane SL, Toledo MJ, Rydell SA, Gaesser GA, Crespo NC, et al. An intervention to reduce sitting and increase light-intensity physical activity at work: design and rationale of the "Stand & Move at Work" group randomized trial. Contemp Clin Trials [Internet]. 2017 Feb 1 [cited 2021 Dec 20];53:11–9. Available from: https://pubmed.ncbi.nlm.nih.gov/27940181/
177. Rosenberg DE, Lee IM, Young DR, Prohaska TR, Owen N, Buchner DM. Novel strategies for sedentary behavior research. Med Sci Sports Exerc [Internet]. 2015 Jun 4 [cited 2021 Dec 20];47(6):1311–5. Available from: https://pubmed.ncbi.nlm.nih.gov/25222817/
178. Aunger J, Wagnild J. Objective and subjective measurement of sedentary behavior in human adults: a toolkit. Am J Hum Biol [Internet]. 2020 [cited 2021 Dec 20]; Available from: https://pubmed.ncbi.nlm.nih.gov/33277954/
179. Manini TM, Carr LJ, King AC, Marshall S, Robinson TN, Rejeski WJ. Interventions to reduce sedentary behavior. Med Sci Sports Exerc [Internet]. 2015 Jun 4 [cited 2021 Dec 20];47(6):1306–10. Available from: https://pubmed.ncbi.nlm.nih.gov/25222818/
180. Mullane SL, Toledo MJL, Rydell SA, Feltes LH, Vuong B, Crespo NC, et al. Social ecological correlates of workplace sedentary behavior. Int J Behav Nutr Phys Act [Internet]. 2017 Aug 31 [cited 2021 Dec 20];14(1). Available from: https://pubmed.ncbi.nlm.nih.gov/28859679/

Chapter 24
Sedentary Behaviour and the Social and Physical Environment

Trish Gorely, Simone A. Tomaz, and Gemma C. Ryde

Abstract Sedentary behaviour is influenced by factors across all levels of the social-ecological model. This chapter focuses on the physical and social environmental levels of analysis. The chapter summarises environmental correlates of sedentary behaviour, addresses potential theoretical approaches and examines the evidence for the effectiveness of environmental interventions on sedentary behaviour. Where relevant the discussion is separated into early years, children and adolescents, adults and older adults. Where data are available, specific populations such as young people with disabilities are discussed. Some features of the home and workplace have been shown to be associated with sedentary behaviour; however, less is known about influences on sedentary behaviour in other contexts. Theoretical perspectives that may be particularly relevant when considering environmental influences are discussed, including social cognitive theory, habit theory, social network analysis and systems theory. The theories employed need to try and capture the complex inter-relationships between individuals, the groups they operate within and the physical and social context. There is some evidence to suggest that incorporating environmental modifications into sedentary behaviour interventions is likely to be effective for both young people and adults.

T. Gorely (✉)
Department of Nursing and Midwifery, University of the Highlands and Islands, Centre for Health Science, Inverness, Scotland
e-mail: trish.gorely@uhi.ac.uk

S. A. Tomaz
Faculty of Health Sciences and Sport, Pathfoot Building, University of Stirling, Stirling, UK
e-mail: simone.tomaz@stir.ac.uk

G. C. Ryde
BHF Glasgow Cardiovascular Research Centre, Institute of Cardiovascular and Medical Sciences, College of Medical, Veterinary and Life Sciences, University of Glasgow, 126 University Place, Glasgow, UK
e-mail: gemma.ryde@glasgow.ac.uk

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_24

What Is New?

- In line with movement behaviour recommendations and an increasing evidence base, we have drawn a distinction between early years and school-aged children as the nature of sedentary behaviour and the influence of social and physical environments differ across these age groups.
- Reflecting the increased attention to sedentary behaviour among older adults, these sections have been expanded and also highlight the challenges with evidence within this group due to assumptions around 'who is an older adult?'.
- More correlates have been explored across the lifespan; however, there remain issues with consistency in the definitions of individual correlates, and many social and physical environment correlates have still been studied too few times to draw strong conclusions.
- There is evidence of increased interventions targeting sedentary behaviour; however, the specific influence of social environmental factors within interventions is difficult to tease out. Physical environment interventions remain largely focused on standing desks within schools and workplaces.

24.1 Introduction: Social and Physical Environment

Sedentary behaviour is ubiquitous, and to understand this behaviour we need to first understand the influences upon it. Social-ecological models have been widely used to explain health behaviours. At their core is the suggestion that behaviour is the product of individual factors (see Chap. 16), organisational/community factors (see Chap. 23), social context or circumstances, the physical environment and wider socio-political influences such as policy (see Chap. 25). The factors influencing a given behaviour interact across these different levels. This wide view of influences is important because it suggests that in order for behaviour change interventions to be effective, they must not only provide the individual with the skills to change and regulate their behaviour but also work to create social and physical environments that support the desired behaviour. This chapter focuses on the relationship between the physical and social environments and sedentary behaviour.

The physical and social environment/context together create a behaviour setting in which a person operates. The behaviour setting construct is central to social-ecological approaches and highlights the importance of context when considering different behaviours [1]. Behaviour settings can present a cue(s) to an individual, which prompts a predictable behavioural response [2]. For example, a behaviour setting comprising a living room centred around a television (TV) and the presence of family might cue an evening spent sitting watching a film. Changing an element of the behaviour setting may result in a different behavioural outcome. For example, a young person may behave quite differently when they get home from school, depending on whether there is an adult present. Understanding the interaction between the social and physical environment within different behaviour settings is therefore important.

24.2 Influence of the Social Environment on Sedentary Behaviour

24.2.1 Early Years (0–5 Years)

Since the previous edition of this book, there has been a substantial increase in the number of studies looking at sedentary behaviour in children aged five and under. For this reason, the five and under age group (also referred to as the 'early years' from this point) has been differentiated from the 'children and adolescents' group. This is consistent with the age stratification of various published movement behaviours guidelines across the life course [3–6].

The home and preschool environments have been identified as important settings in which children under the age of five years spend much of their time. Systematic reviews of the correlates or determinants of sedentary behaviour in the early years have identified only a few consistent home-based social factors associated with sedentary behaviour. Pereira et al. [7] assessed 19 different social and cultural correlates. Parental attitudes towards physical activity were the most reported correlates (whether positive or negative), but these were consistently classified as having no association.

There are conflicting results for the relationship between parental rules around screen-use and sedentary behaviour in young children, with one systematic review reporting a positive relationship [8] and three reporting an indeterminate relationship [7, 9, 10]. There is some evidence that parents are role models for sedentary behaviour, as parent electronic media use and sedentary time is positively associated with electronic media use in early childhood [9–12]. However, Pereira et al. [7] reported that parent screen time (maternal or paternal) was not consistently associated with children's sedentary time. It is notable that neither maternal sedentary level, nor parental sedentary level, were reported enough times to determine a direction of the findings, although both appeared to display positive associations with sedentary time in children [7]. A systematic review of qualitative studies exploring barriers and facilitators of physical activity and sedentary behaviour identified and synthesised several correlates across the social-ecological model [13]. The role of parents (in the context of modelling TV-based behaviour and using sedentary forms of travel such as strollers and cars when time-pressed) was identified as an important correlate.

24.2.2 Children and Adolescents

Children and adolescents spend significant periods of time either at home or at school and these represent important behavioural settings in which to understand their behaviour. Systematic reviews have identified only a few consistent home-based social factors associated with sedentary behaviour in children and adolescents. Systematic reviews have reported an inverse relationship between parental rules around screen-use and sedentary behaviour in children and early adolescents [14, 15]. One study reported within the Maitland et al. [15] review investigated the relationship between the physical environment and the social environment and found an inverse relationship between parental rules and TV use only when there was a TV in the bedroom demonstrating the inter-relationships of physical (e.g., TV in bedroom) and social (e.g., parental rules) environment correlates. These reviews also suggest that parents are role models for sedentary behaviour, as parent electronic media use or sedentary time was positively associated with electronic media use in young people [14, 15]. Positive relationships have also been reported between family support and sedentary time [15]. These family-related influences may present a challenge within intervention design as parents often perceive their co-viewing and modelling behaviours as important components of family life that foster communication and enjoyment and that the implementation of rules around screen use caused conflict between parents and children and between siblings [16].

A note of caution should be applied to the systematic review findings reported above, as when reviews only included prospective studies (i.e., studies of a research design that allows prediction or causality to be examined), it was reported that there was insufficient evidence to support any of the potential social determinants of sedentary behaviour [17–19]. The basis for this conclusion was that although a variety of social correlates have been examined within prospective studies, specific social correlates have been studied too few times for conclusions to be drawn.

Based on their extensive work involving literature reviews, secondary data analysis of the Canadian Health Measures Survey, input from expert panel members and stakeholder consultations, Rhodes et al. [20] published a consensus statement on the role of the family in the physical activity, sedentary and sleep behaviours of children and youth. The consensus statement supports the influence of family and reads:

> Families can support children and youth in achieving healthy physical activity, sedentary and sleep behaviours by encouraging, facilitating, modelling, setting expectations and engaging in healthy movement behaviours with them. Other sources of influence are important (e.g., childcare, school, health care, community, governments) and can support families in this pursuit (p. 2).

They also developed a conceptual model illustrating the relationships linking family and the physical activity, sedentary and sleep behaviours of young people (see Fig. 24.1). The model places the child or young person and their movement behaviours at the centre. The surrounding concentric circles portray the immediate influence of family while also demonstrating that other sources and settings also

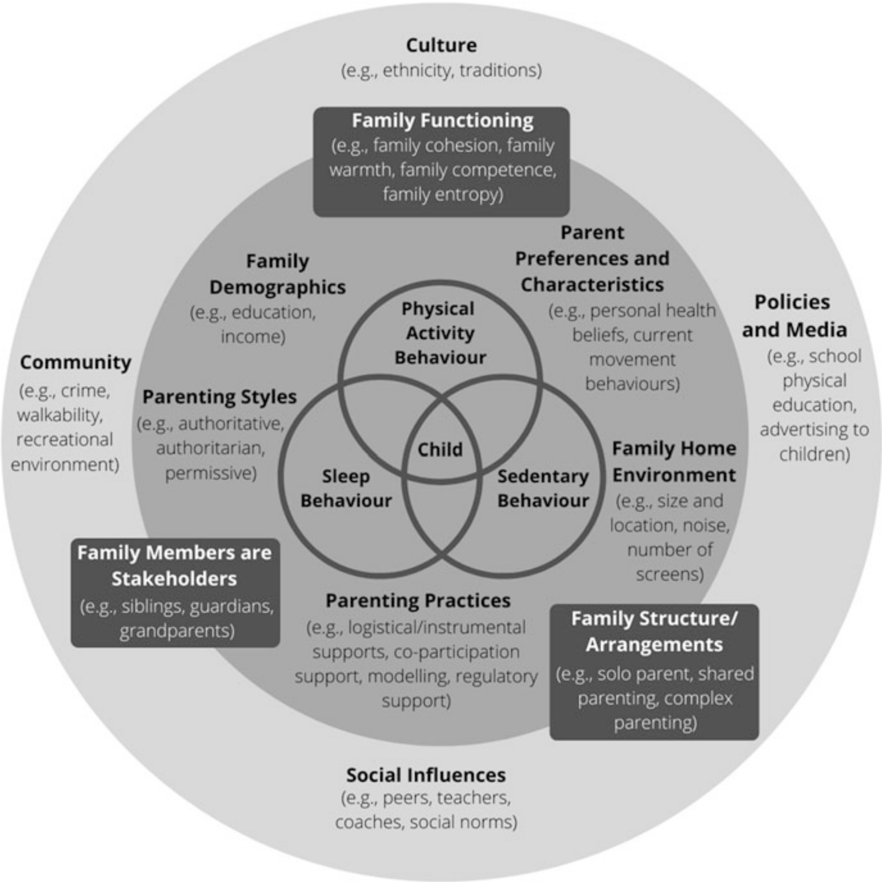

Fig. 24.1 Conceptual model illustrating the complexity of the family's role in influencing movement behaviours (adapted from: Rhodes et al. [19])

influence young people's movement behaviours. Within the family, influence may come from parenting styles, parenting practice and parent preferences and characteristics. The three boxes represent core family system constructs that might be sources of influence. Finally, the model acknowledges the influence of family demographics and family home environment on behaviour. This model captures the complexity of family influences within and between families and consistent with social-ecological approaches situates family influences within the broader social, physical and policy context. This is important as when looking at individual correlates, we should not lose sight of the fact that any one correlate is only a small part of the explanation and interacts with other levels of the social-ecological model.

Friends and peers may also influence the health behaviours of young people, particularly as they get older [21]. While the pathways of influence are likely to be complex, the processes of friend and peer influence may include modelling, peer pressure, group norms and co-participation. In a meta-synthesis of qualitative studies focused on reducing youth screen time, Minges et al. [16] reported that the absence of peer social support networks promoted screen time. In addition, Sawka et al. [21] reviewed the evidence for the influence of friendship networks on physical activity and sedentary behaviour in young people 6–18 years of age. The authors identified three studies focused on sedentary behaviour with contradicting results. One study found no consistent evidence to support peer effects on TV viewing [22]. However, another study reported a positive relationship between friends gaming and internet use and individual's gaming and internet use for girls in the three different friendship networks studied, but only in one of the three studied networks for boys [23]. Finally, using a measure of popularity, Strauss and Pollock [24] reported that as an individual's popularity increased, daily TV time decreased. The findings of the Sawka et al. [21] review suggest that the influence of friendship networks on sedentary behaviour may vary by gender and the type of sedentary behaviour studied.

A systematic review by Morton et al. [25] focused on the school environment and physical activity and sedentary behaviour in 11–18-year-olds. Both quantitative and qualitative studies were included. The authors concluded that while there has been research attention on elements of the social environment and physical activity, there has been very little attention given to how the school social environment either facilitates or inhibits sedentary behaviour, and that there is a need for more work in this area. This conclusion is consistent with an earlier review by Verloigne et al. [14].

Reviews are starting to emerge focused on specific countries (e.g., Indonesia [26]; Thailand [27]), populations (e.g., Downs Syndrome [28]; Autism Spectrum Disorder [29]) or time periods (after school period [30]). The country-specific reviews acknowledge that differences in social, cultural, environmental and economic factors mean that the correlates or determinants of sedentary behaviour may vary between countries, and therefore there is a need to understand these at a country level if effective interventions are to be developed [27]. They also reflect a growing acknowledgement of the need to look beyond research evidence from high-income countries [26]. While neither of these reviews identifies specific social correlates of sedentary behaviour due to insufficient primary papers, the rationale for the reviews tacitly supports the influence of the social environment on behaviour. Young people with disabilities are at increased risk of sedentary behaviour, and an understanding of the correlates in these groups would contribute to the design of targeted interventions, see, for example, reviews by Agiovlasitis et al. [28] and Jones et al. [29]. While it is encouraging to see the emergence of this focus, both of these reviews identified insufficient evidence from which to draw conclusions about the influence of social environment factors, although there is preliminary evidence of familial influences on the sedentary behaviour of people with Downs Syndrome [28]. Likewise, Arundell et al. [30] in their review of the correlates of afterschool behaviour among children found insufficient papers including social correlates to draw conclusions but argued for a more nuanced exploration of the effect of setting on children's sedentary behaviour.

24.2.3 Adults: Settings Excluding the Workplace

Review evidence on the correlates of sedentary behaviour in adults has expanded greatly since 2016 when only two key papers were identified that examined the correlates of sedentary behaviour in the general, adult population (aged 18–65 years) [31, 32]. For social correlates, the 2012 review by Rhodes et al. [31] did not identify any potential social-environmental correlates with mainly intrapersonal correlates reported. In contrast, O'Donoghue et al. [32] conducted a review based on the social-ecological model and identified two domains of social correlates: family-related factors and social factors. For these, inconsistent relationships were found between sedentary behaviour and the family-related factors of marital status, living arrangements (i.e., whether people lived alone or not), family commitments and number of children. There were no clear relationships between sedentary behaviour and social factors such as social norms, social cohesion, interaction, support and sense of community. The authors suggested these results were unexpected, and there was a need for further research investigating the potential interaction between individual, social and physical environmental factors.

Studies published since then have expanded their scope when assessing correlates of sedentary behaviour across different domains and populations. Perhaps the most comprehensive review was published by Prince et al. [33]. Although the majority of included papers focused on the general population, some focused on clinical populations. However, in general, there is a paucity of literature exploring the social and environmental correlates of sedentary behaviour in 'special populations' (e.g., pregnant people or people with disabilities). Compared with previous reviews, a wider range of social-environment correlates were reported by Prince et al. [33]. However, many of these were inconsistent and varied by the type of sedentary behaviour and domain assessed (e.g., leisure, transport). For social environment correlates a consistent lack of association was found between social support, crime/ safety and sedentary behaviour (leisure-time sedentary behaviour, sitting and total sedentary time). Other social correlates were studied, but on too few occasions for conclusions to be drawn. Whilst some conclusions about the relationship between sedentary behaviour and social correlates were made, these were cautious due to the limited number of studies and the heterogeneity of outcomes reported [33].

Other recent reviews have addressed more specific adult populations (e.g., university students [34], Asian adults [35], Thai population [27], adults with intellectual disabilities [36]). As with the more general reviews, too few studies (1 or 2 per correlate) or studies of poor quality/high risk of bias were reported making conclusions difficult. Muller et al. [35] reviewed correlates of sedentary behaviours in Asian adults including 19 studies that investigated social factors. They reported that marital status was positively associated with sedentary behaviour for married women in Middle East Asia; however, this was based on only two studies. Likewise, Oppewal et al. [36] in a review of sedentary behaviour correlates in adults with intellectual disabilities reported that living arrangements were not a correlate of sedentary behaviour, but this was based on only three studies.

Heterogeneity of terminology and the subsequent large number of variables assessed by studies makes drawing conclusions on the relationships between sedentary behaviour and social factors challenging. Furthermore, some correlates such as socio-economic status (SES) and marital status are grouped within different correlate areas across reviews. For example, marital status is sometimes classed as a social correlate under the family factor [32, 35], but others categorise this as an intrapersonal correlate [33]. A key future priority is for standardisation of definitions and classifications of correlates [33].

24.2.4 Adults: Workplace

An important sedentary behaviour setting for many adults is the workplace. The social environment at work, including cultural norms and colleague expectations, is likely to contribute to how sedentary adults are in this setting. For example, if you have a predominantly computer-based role, then whether your manager supports taking a break from sitting at your desk is likely to influence how much you sit. Alternatively, an employee using a standing desk when their colleagues are all sitting down might feel it is not acceptable to do so and may therefore sit more [37]. Review-level evidence suggests there is still limited evidence on the effect of the workplace social environment on sedentary behaviour [38]. Early work using self-reported measures of sedentary behaviour reported neither perceived social norms about sitting less at work nor perceived social support to sit less at work were associated with occupational sitting time [39], but employees who reported more visible co-workers were more likely to break from sitting [40]. More recent cross-sectional studies have explored similar social correlates at work using device-based measures of sedentary behaviour. Mullane et al. [41] found that face-to-face interaction with colleagues was negatively associated with prolonged sitting, and Kurita et al. reported that 'seeing work colleagues taking sedentary breaks' was related to more sedentary breaks and shorter bouts of sedentary time [42]. However, another study found that neither perceived encouragement of breaks by managers nor the perceived social environment was related to sitting or sit-to-stand transitions [43]. With potentially very small differences in sedentary behaviour being reported for social correlates, the relationship between the social environment and sedentary behaviour is likely to become clearer as more research using device-based measures of sedentary behaviour emerges. In addition, how the social environment is defined ('perceived' social norms vs actual social contact and co-worker visibility) and assessed may also influence potential associations, with these issues previously raised in the physical activity literature [44].

There is also expected to be a shift in the direction of research assessing the effects of the workplace social environment and sedentary behaviour with the move towards home working or flexible working. Prior to the 2019 COVID-19 pandemic and mandatory home working in many countries, Olsen et al. [45] conducted a qualitative study 6 months after the introduction of a flexible work policy in a group of Australian office-based employees. Employees suggested that whilst physical activity was not impacted from working at home, sedentary behaviour had increased. Taking this evidence together, there is a need to look more closely at the role of social connections and the social environment (particularly in a working-from-home environment) when exploring sedentary behaviour in the working day.

24.2.5 Older Adults

Older adults have the highest levels of sedentary behaviour when compared with other age groups across the life course. In the context of sedentary behaviour, they are also persistently the least studied age group. Furthermore, the literature describing sedentary behaviour in older adults is often 'compromised' by a lack of consistency in the defined age range. For example, people aged as young as 50 years old are included as 'older adults' in some papers included in systematic reviews. As such, data for older adults is often presented with adults' data. In some contexts, this is appropriate (e.g., an employed 67-year-old may have the same sitting behaviour traits as a 40-year-old in the same workplace). However, there appears to be limited attention paid to more specific older adult populations (e.g., older adults in care homes, retired older adults) in the context of understanding sedentary behaviour and designing appropriate interventions.

Since the previous edition of this book, new evidence regarding the influence of the social environment on sedentary behaviour in older adults has seen limited progression. The evidence describing correlates of sedentary behaviour in older people still appears to focus on individual-level factors (described in Chap. 16) [27, 35, 46]. Chastin et al. [46] identified only two studies that reported on interpersonal factors. In one study loneliness was associated with a small increase in TV time [47] and in another, those living alone watched more TV than those in shared accommodation [48]. In addition, perceptions of the demographic make-up of the neighbourhood may influence TV time. Older adults who perceived they were living in a neighbourhood with not too many other older adults, and not too many youth or migrants, watched less TV.

24.3 Influence of the Physical Environment on Sedentary Behaviour

24.3.1 Early Years

Although the field of sedentary behaviour in the early years has seen an increase in studies exploring the effects of the physical environment, the results of these studies persistently report null or mixed findings, often due to the quality of studies and the number of studies conducted. Physical activity remains the dominant behaviour of interest in this age group.

A review looking at longitudinal studies exploring the relationship between non-parental childcare (attendance and details thereof) and sedentary behaviour (among other health behaviours and diet) reported little to no relationship, although this was based on only 3 studies (out of 13 eligible) exploring sedentary behaviour [49]. However, a review conducted by Azevedo et al. [50] looking at the determinants of change in objectively measured sedentary behaviour in 0–6-year-olds found that parts of the day (the after childcare/after school period) and developmental progression (transition from childcare to school) were associated with an increase in sedentary behaviour. More research is needed to establish how the physical environments within these time periods influence sedentary behaviour.

In addition to assessing the social correlates described above, Pereira et al. [7] also assessed 15 different physical-environmental correlates. The most frequently studied correlate of sedentary time was 'spaces outside the home', which had no association with sedentary time in toddlers or preschool-aged children. Additionally, other correlates that had null association included home indoor environment, screen or other electronic devices inside the house and usage of parks; although it was noted that there is a general lack of studies to draw robust conclusions [7]. In contrast, the systematic review of qualitative studies by Hesketh et al. [13] identified that having a home environment that gave rise to sedentary behaviours, including having a TV on persistently, was associated with increased sedentary time. Furthermore, they identified poor weather as a correlate, and this was more prominent where covered playground space was limited, and TV time was used as an alternative.

There is some evidence to suggest that within preschool (early years education) settings, the presence of outdoor environments is associated with lower levels of sedentary behaviour (and conversely, positively associated with physical activity) [51]. There is much work still to be done to understand the role of the physical environment on sedentary behaviour (especially as a behaviour that is distinct from physical activity, rather than the absence of it) in the early years.

24.3.2 Children and Adolescents

There is some evidence that having a TV in the bedroom is associated with greater sedentary behaviour [15, 52], although this relationship is not consistent across reviews [14, 17]. It is possible that this relationship may be changing with changes in technology and the way people consume TV [17]. For example, in a review conducted as part of the development of a consensus statement on the role of the family in movement behaviours within young people, Rhodes et al. [20] reported a positive relationship between electronics (as opposed to simply TV) in children and youth's bedrooms and screen-viewing behaviour. Mixed results have been reported for the relationship between the number of TV sets in the home and viewing time in young people [14, 15, 52], and the effect may be stronger in girls compared with boys [52]. Looking more broadly, Rhodes et al. [20] also reported the number of electronics in a household as a positive predictor of screen-viewing. When synthesising qualitative studies, Minges et al. [16] concluded that ready access to screen-based entertainment in the home promoted screen time and the absence of safe and affordable alternatives outside the home acted as a barrier to reducing screen time. There is some evidence that the availability of physical activity equipment in the home is inversely associated with sedentary behaviour [15]. As with the school social environment, little attention has been given to how the physical environment of the school influences sedentary behaviour [14, 25]. No other physical environment influences have been consistently identified within recent systematic reviews (e.g., [28, 30]), with reviews demonstrating that potential physical environment influences have not been examined frequently enough to draw conclusions.

24.3.3 Adults: Settings Excluding the Workplace

Whilst O'Donoghue et al. [32] found only a limited number of studies that had examined physical environment influences on sedentary behaviour in adults, more recent studies largely support these previous findings. At the home level, O'Donoghue et al. identified two studies that suggest that after adjustment for socio-economic factors, the size of the largest TV and the number of computers in a household was positively associated with TV and internet usage. Prince et al. [33] reported five of seven studies where ownership or number of TV/media was positively associated with leisure time sedentary behaviour. For other environmental factors such as neighbourhood characteristics and geography, the relationship with sedentary behaviour is less clear. Several studies have reported more urban environments to be associated with higher levels of total sitting time and sedentary behaviour [33]. In contrast, in a review looking specifically at neighbourhood environmental attributes and adult's sedentary behaviour, it was reported that people living in urban areas had lower levels of sedentary behaviour compared to residents of regional areas [53]. Other studies suggest living in a rural area was associated with more time spent sitting for transport [32, 54, 55]. Inconsistent results are also reported for the relationship between sedentary behaviour and other neighbourhood characteristics such as proximity to destinations and facilities, land mix-use and connectivity. One review found a consistent lack of association between these factors and total sitting time [33], whilst another suggested having better access to destinations was associated with lower levels of sedentary behaviour, and this result is more consistent when domain-specific (e.g., transport, leisure) rather than total sedentary time is examined [32]. In addition, inconsistent or non-significant results were reported for walkability, social and safety issues, aesthetics and route characteristics (e.g., traffic, pedestrian infrastructure) [33].

As was found with social environmental factors, the relationship between neighbourhood characteristics and sedentary behaviour may depend on the type of sedentary behaviour measured. Kooshari et al. [53] concluded that while the evidence to date suggests that sedentary behaviours are not closely associated with neighbourhood characteristics, measurement limitations in the extant research mean that we should continue to investigate them with stronger designs. For example, there has been a lack of congruence between the settings where sedentary behaviour takes place (e.g., indoors, home, work) and the settings in which the environment was measured (e.g., outdoors, neighbourhood). Further research is required to determine the potential impact of neighbourhood characteristics on sedentary behaviour.

24.3.4 Adults: Workplace

This is a broad area and may include aspects such as furniture design, workplaces with poor transport connections but ample parking for cars, lack of active transport facilities such as bicycle parking or showers, and how the physical workplace is laid out including space to move about and the visibility and aesthetic appeal of stairwells [1, 56]. As with the social work environment, research into workplace physical environment correlates is developing with many studies published since 2016 and more correlates being assessed beyond that of merely the internal work environment. For example, a review by Lin et al. [57] assessed the workplace neighbourhood and employees' physical activity and sedentary behaviour. Of 55 studies included, 7 reported on sedentary behaviour, all of which were in the transport domain. They suggested that destination-related attributes including longer commuting distances and access to car parking were associated with more transport-related sedentary behaviour.

Looking at the internal workplace physical environment, there is some cross-sectional evidence that office configuration and proximity to your colleagues might be correlates to consider. For example, Duncan et al. [40] reported that for shared and open-plan offices, workers who perceived that there was more local connectivity between desks took more breaks from sitting. The same result was not found in private offices. In contrast, Sawyer et al. [43] found neither perceived distance to office destinations nor perceived office aesthetics to be related to device-measured physical activity or sitting outcomes. Duncan et al. [40] also reported that co-worker proximity was associated with more breaks in sitting for those in open-plan offices. Similarly, Mullane et al. [41] using device-based measures reported that individuals in private as opposed to public office spaces sat more, stood less and engaged in more prolonged sitting but that sector of employment was an important moderator for several correlates. However, whilst co-worker proximity might be a potential correlate of sedentary behaviour, more evidence is needed to support these findings, and it is hard to distinguish whether this would be classed as a physical or social environmental correlate.

More evidence is also emerging on having a standing desk as a correlate of sedentary behaviour as opposed to standing desks being implemented as part of intervention strategies. In a naturalist, cross-sectional study, Wallmann-Sperlich et al. [58] interviewed 680 employees based in Germany, where standing desks are routinely provided in workplaces, and assessed the availably of standing desks, frequency of use and potential correlates. Only 16% had a standing desk, with 50% of these reporting regular usage. Having a standing desk was not reported as a correlate of the proportion of the workday spent sitting. Whilst further evidence is needed to confirm such findings and more robust study designs, merely providing a standing desk may not be enough to influence workplace sedentary behaviour.

24.3.5 Older Adults

Consistent with social correlates of sedentary behaviour, since the previous edition there has been limited work done to expand our understanding of environmental correlates of older people's sedentary behaviour. In a systematic review describing built environment attributes between high- and low-income countries and the association with sedentary behaviour (and physical activity), Cleland et al. [59] found only 4 studies (out of 64 studies included) to compare built environment attributes. According to this review, there were no differences in the influence of the built environments between high- and low-income countries on the domains of older adults' sedentary behaviour. However, this finding was driven by a paucity of literature. There is conflicting evidence for the effect of other environmental correlates (e.g., land mix use/accessibility and street pattern) and how these influence older adults sedentary behaviour [59].

24.4 Models and Theories of Sedentary Behaviour at the Social and Physical Environmental Level

It is generally accepted that interventions based on theory are more effective than those that are not. In this section, we overview theories that might be particularly relevant when considering environmental influences on sedentary behaviour. Some theories, such as social cognitive theory (see Chap. 16), include the influence of the environment as a key component and provide a potentially useful framework for considering the inter-play between influences at different levels of the socio-ecological model. A core concept of social cognitive theory is reciprocal determinism, which means individuals can act as both agents of, and responders to, change. Under this idea, changes in the environment or the examples of role models can be used in attempts to change behaviour.

Dual-process models acknowledge that both conscious and non-conscious processes have a role in regulating behaviour [60], and evidence indicates that a dual-process framework might be particularly relevant for explaining ubiquitous behaviours like sedentary behaviour [61]. Theories like social cognitive theory largely focus on conscious processes, but taking a dual-process approach may lead to a greater understanding of sedentary behaviour (see, e.g. [62, 63]). This approach suggests that information processing occurs along a continuum, with deliberate conscious decision making at one end and at the other end behaviours/decisions occurring automatically in response to environmental cues. In Chap. 16, it was suggested that many sedentary behaviours are frequently undertaken with little conscious processing or decision making and therefore theories allied to notions of habit or unconscious processing need to be considered when designing interventions to reduce sedentary behaviour. Habit may be particularly important when considering social and physical environmental influences.

Habits are behavioural patterns learned through situation-dependent repetition [64, 65]. As behaviours are performed, a mental association is made between the situation (e.g., the social and physical environment) and the behaviour. Over time, repetition of this behaviour in the same situation strengthens the association and makes alternative behaviours less likely [66]. In the future, when the situation is encountered, it cues the automatic habitual response [67]. This means that habitual behaviours are triggered effortlessly and without conscious processing [68]. For example, a teenager receives a Tablet computer as a gift. They use this to stream videos and play games while lying on their bed. Over time, the act of lying down on their bed is sufficient to automatically cue the habitual response to look for the Tablet and play on it. Thus recognition of the social and physical environmental cues associated with different sedentary behaviours is likely to be an important step in reducing sedentary behaviour. Lally and Gardner [67] suggest that in order to break habits, it is first necessary to identify these social and environmental cues. Individuals can then either restructure their personal environment or plan new responses to those cues, essentially disrupting the environmental factors that drive a habitual behaviour [69].

As already demonstrated, human behaviours are the product of multiple influences. One potentially significant sphere of influence is the different social environments we operate in. While there is limited evidence, to date, for the influence of social factors on sedentary behaviour, further work is recommended in this area. Although the review by Sawka et al. [21] showed mixed results in adolescents, social network analysis has not been widely used in sedentary behaviour research (although see [70] as an example with older adults) but maybe a helpful approach. Social networks are the web of social interactions and relationships around a person (s) [71], and the architecture of social networks influences how information, ideas and behaviours spread through groups. They can be envisaged as consisting of nodes (individual people, groups or organisations) that are joined by ties (relationships between nodes) [72]. Social networks exist at school, at work, at home and in other public places (e.g., churches, clubs). Social network analysis is a set of theories used to understand these social relationships and how they might influence behaviour of both the individual and the group [73]. Underpinning these theories is the hypothesis that individuals are influenced by the people they have contact with and that the degree of influence on behaviour is determined by social position. For example, an individual's position in a network (central or peripheral, highly connected or isolated) will influence the information they are exposed to and the behaviours they adopt [70]. Social networks also have influence at the group level. For example, the density of an individual's personal network (i.e., the degree to which a person's ties are connected to one another) indicates to what extent a person's friends know and like each other. Dense networks may reinforce a given behaviour as once a behaviour is accepted by the majority of the group it becomes the norm for the group [73].

The theoretical underpinning for interventions based on social network analysis is a diffusion of innovations theory [74]. This theory explains how novel ideas or products are initially adopted and then spread (diffused) through a group or social system. Adoption typically does not happen immediately across an entire group, but rather some people are more willing to try something new and others are more reticent. Rogers [74] describes five categories of people: (1) innovators (want to be the first to try an innovation); (2) early adopters (usually represent opinion leaders, often already aware of the need for change and are comfortable adopting new ideas); (3) early majority (not often leaders but after seeing that the innovation works are willing to adopt it); (4) late majority (sceptical of change, and adopt only after the innovation has been tried by the majority) and (5) laggards (very sceptical and conservative, very late to change). It is argued that different intervention strategies will be needed for each of the adopter categories.

Valente [75] contends that while diffusion of innovations theory explains the process of change, it does not explain how to use this knowledge to accelerate change. He proposes four strategies that use social network analysis to encourage change through diffusion. The first approach uses social network analysis to identify individuals who can be champions of change. These are typically your central opinion leaders or those individuals who bridge/link between different sub-groups within the network. The second approach, segmentation, uses network analysis to identify segments or groups of people to change at the same time. Valente [75] argues that people often view themselves as belonging to a group with established norms and practices, and these can only change if everyone changes. In this case, getting a group to change behaviour may be easier and more effective as the group can reinforce the new behaviour and provide social support for the change. The third approach is induction. Induction interventions would force peer-to-peer interaction to diffuse or cascade messages. The final approach is alteration. This approach aims to deliberately alter the network to promote change. This could be done by adding/deleting nodes to the network (e.g., bringing in outside consultants or advisors), adding/deleting links within a network (e.g., working to improve communication between two sub-groups) or rewiring existing links (e.g., buddy systems to connect people with different attributes).

While social network analysis has not been widely used in sedentary behaviour research and interventions, evidence from other health behaviours [76] suggest the potential for the influence of social norms and contexts is strong, perhaps particularly in worksites and schools, with their inherently complex social structures. Integrating learnings and approaches from social network analysis into existing approaches may help us better understand social influences on sedentary behaviour and sedentary behaviour change.

Another approach that may be useful when considering the interplay between individuals and physical and social environment is systems theory or systems thinking. Only a brief overview of systems theory is provided here, and readers are encouraged to explore it further for themselves (see, e.g. [72, 77]). There is no one single systems theory, but all focus on all the different levels of influence from the social-ecological model and the complex interrelationships between them [78]. From a systems theory perspective, individuals 'are complex adaptive systems. . .embedded within other complex adaptive systems (such as dyads, groups, organisations, communities, and societies)' (p. 148; [72]). According to Bartholomew Eldredge [72], complex adaptive systems: (1) include agents (people) who have the capacity to adjust their behaviour to the environment; (2) include agents who interact and exchange information, and while not everyone is directly connected to everyone else, through these many connections information can spread through the system; (3) are not linear, and small 'changes' can have large effects and vice versa; (4) are sensitive to initial pre-change conditions and small differences in initial conditions can lead to large differences in the future; (5) are self-organising, as people adjust their behaviour to meet different demands and (6) are open, with cross-over between systems as individuals move between them. In trying to understand or change systems, it is necessary to consider structure (e.g., people, their activities and their relationships), the meaning people assign to an issue/behaviour, the resources within a system and individual, and power relations (e.g., individuals either possess or need resources in a given context and this creates power relationships within the system). From a systems theory perspective, agents at each level of influence can undertake activities to alter the system and facilitate health behaviour change. Systems theory, by its very definition, is challenging but does point to a way of thinking about health issues and the complex inter-relationships that underpin both sedentary behaviour and sedentary behaviour change.

24.5 A Different Perspective: Social Marketing Approaches to Health Behaviour Change

Social marketing emerged in the 1970s as a way to understand and influence people's behaviour [79]. It draws on knowledge from a diverse range of fields including sociology, psychology, anthropology and communications theory as well as learning from the commercial sector. Social marketing has been described as: 'the application of commercial marketing technologies to the analysis, planning, execution and evaluation of programs designed to influence the voluntary behaviour of target audiences in order to improve their personal welfare and that of society' (p. 7) [80]. Core principles of social marketing have been employed within interventions to influence lifestyle behaviours, such as reducing smoking, increasing fruit and vegetable consumption and increasing physical activity or active travel [81–84].

According to Lee and Kotler [81], social marketing approaches emphasise understanding the perspectives of all people necessary to bring about change and acknowledging the multiple levels of influence on an individual's behaviour. For example, social marketing considers downstream (intrapersonal), mid-stream (interpersonal) and upstream (organisational or policy) influences on behaviour. There are obvious parallels here to the social-ecological model. Social marketing also focuses on the use of research evidence, the development and testing of concepts with key target groups and the marketing mix (i.e., the 4 –P's: product, price, place promotion). Social marketing is fundamentally focused on people's behaviour and aims to improve health and society over merely benefiting an organisation or making money [85].

Although there are similarities between social marketing and conventional health promotion, social marketing uses some distinctly different strategies in its approach to changing behaviour [86]. Both social marketing and conventional health promotion are focused on behaviour change and understanding people lives, engage individuals in the process, extensively use health education approaches and utilise theory. However, when health promotion would view the people involved as co-producers, social marketing would see them as both co-producers and consumers. The customer focus places greater emphasis on knowing and understanding the consumers and the wider social context and place (physical environment) in which the intended behaviour change occurs in order to provide insight into motivation. Place is also an essential element of the marketing mix (i.e., where and when the target audience will perform the intended behaviour). Social marketing also addresses the wider competition to the behaviour change message/campaign and emphasises the wants and needs of the target audience. This broadens the focus of intervention efforts beyond just the desired behaviour to include other factors that might hinder behaviour change or compete for the attention of the participant. At its most basic level, it represents a systematic approach to understanding participant characteristics and the context they operate in, while also offering guidelines for effective communication to different groups [87].

There are not thought to be any studies that have used social marketing approaches with the specific aim of reducing sedentary behaviour. Despite this, there is potential for employing a social marketing framework or approaches to the development of interventions to reduce sedentary behaviour.

24.6 Interventions Targeting the Social and Physical Environment to Influence Sedentary Behaviour

While there has been increased interest in developing interventions to reduce sedentary behaviour, particularly among young people and in worksites, few of these interventions have explicitly targeted the social environment as a vehicle for change. There has been more focus on the physical environment particularly through either TV monitoring devices or the provision of sit-stand desks.

24.6.1 Early Years

Since the previous edition, there has been an increase in the number of interventions targeting sedentary behaviour in the early years. These interventions have often specifically addressed screen time and have sometimes targeted physical activity to replace sedentary time (screen time or not). Interventions have often targeted parents, given that parents have been identified as the ‘gatekeepers’ to screen devices and the role that parents play in young children’s movement behaviours in general.

In a systematic review and meta-analysis of RCTs to reduce sedentary behaviour in children under 6 years (defined as preschool children and younger), Downing et al. [88] reported mean decreases in both sedentary time (−18.91 min/day) and screen time (−17.12 min/day). Interestingly, interventions targeting physical activity (while reporting sedentary behaviour change) tended to be more effective than interventions targeting sedentary time itself. This finding is consistent with other reviews in young children [89]. Characteristics of interventions that worked to reduce screen time included being 6 months or longer in length (noting that most interventions were at least 10 weeks in length) and having been conducted in a community-based setting (vs the home, preschool/childcare/healthcare settings). The authors noted that interventions targeting screen time and conducted in the preschool/childcare setting were most common and showed a significant overall effect in the meta-analysis (−11.97 min/day), despite only three of the seven included studies showing a significant intervention effect. Importantly, most of the studies included in the review were conducted in high-income countries (which appears to be a persistent issue, e.g., Kaur et al. [90] have reported the same), although there was some diversity in socio-economic status across studies.

Given the potential role of the family system in promoting healthy lifestyles and the influence that environmental factors in the home may have on sedentary behaviour, family-based interventions may be particularly relevant for children in the early years. In a systematic review of randomised control trials, the three studies conducted in preschool-aged children showed significant decreases in sedentary behaviour [91].

24.6.2 Children and Adolescents

Early reviews focused on intervention strategies to reduce screen time in children (e.g., Schmidt et al. [92] and Steeves et al. [93]). While most studies employed individual behaviour modification techniques such as goal-setting, self-monitoring, problem-solving and positive reinforcement, a number of early interventions also included electronic monitoring devices (which turn off the TV after a self-prescribed amount of viewing) or contingent TV devices. Steeves et al. [93] reported that the inclusion of these devices reduced TV viewing by between 30% and 90%. While this represents a substantial reduction, there are questions over the long-term effectiveness of such devices [92, 93]. There are also questions over the acceptability of the devices, particularly within families, as the device may impact the viewing of all family members and not just the target individual(s).

More recently, Blackburn et al. [94] examined the effectiveness of interventions targeting sedentary behaviour across the lifespan. Based on their systematic review and meta-analysis they reported that for children (2–19 years) following environmental interventions there was a non-significant reduction (−18.5 mins/day) in sedentary behaviour in the short-term, and a small significant reduction (−8.75 mins/day) in the long-term. However, the long-term result was only based on two studies and was not considered robust. The majority of the environmental interventions were based in schools so little can be said about other contexts, and there is a need to know more about non-school settings, such as home or community. Studies with combined environmental and behavioural components showed significant reductions in sedentary behaviour in the short- (−27.4 mins/day) and long-term (−17.5 mins/day). The authors suggest that multi-component interventions may be the most promising due to the multi-faceted nature of sedentary behaviour. Blackburn et al. [94] also examined the complexity of the intervention and demonstrated that environmental interventions are less complex, but this did not detract from their effectiveness as there was no relationship between complexity and effectiveness.

Lam et al. [95] conducted an umbrella review and meta-analysis evaluating the effectiveness of interventions to reduce sedentary behaviour across the life course. Interventions were grouped as interventions that aim to influence personal behaviour through the provision of information; interventions that aim to influence the social environment; interventions that aim to influence the physical environment; and multicomponent interventions. It was reported that in school children the most effective interventions for reducing total sedentary behaviour were physical environment interventions (−80.76 mins/day), followed by social environment interventions (−24.66 mins/day). This patterning of results also held when looking specifically within the school setting. The authors argue that these findings suggest that sedentary behaviour change in school children works best with strategies that target unconscious processes.

In a systematic review of randomised control trials, inconsistent results for family-based sedentary interventions were found [91]. However, the effectiveness may have been influenced by the level of parental involvement. For example, there were consistent and significant reductions in sedentary time in studies with a medium-to-high intensity parental component (i.e., involved the parent at more than just a supervisory or administrative level). Child age may also be a confounder, with family-based interventions in preschool children showing consistent and significant reductions in sedentary times compared to the inconsistent results in older children. Indeed, dos Santos et al. [96] suggest that strategy effectiveness will likely vary by age, arguing that up to about 6 years of age interventions to reduce sedentary time may be more effective because of strategies focused on parental control and family social support (i.e., familial social factors); however, the effectiveness of these influences changes with age.

The introduction of standing and/or active desks is a popular approach to reduce sitting time during the school day and several reviews have been published examining their effectiveness (e.g., [97–100]). These reviews report inconsistent outcomes from the introduction of standing or active desks, with two reviews reporting positive effects on standing time and sitting time [97, 98], and two reporting mixed results for these outcomes [99, 100]. Despite the mixed results on sedentary time, process evaluations have shown that standing desks are acceptable to teachers and may bring other benefits such as a reduction in sleepiness and a positive influence on task completion [99]. Hinckson et al. [98] reported that in the majority of studies the change to the classroom environment was the only intervention component and no other strategies were employed. It is not clear whether the addition of more individually focused behaviour change techniques would make the interventions more effective. Review authors have been critical of the quality of studies and heterogeneity in research design and methods, which make the comparison between studies difficult and prevent meta-analysis [99, 100]. A further limitation is that studies have primarily taken place in primary/elementary schools, and there is limited evidence of their implementation within the secondary/high school context [100]. This is an important distinction as these are two very different contexts in terms of education and the structure of the school day [101]. Despite these limitations, review authors have concluded standing desks have the potential to reduce sitting time and increase standing time among school children [97–100].

Other reviews have tried to identify specific strategies or Behaviour Change Techniques (BCTs) associated with sedentary behaviour change (e.g., [89, 96, 102]). Some of these strategies could relate to the social or physical environment. However, these reviews have found that the quality of evidence across sedentary behaviour interventions is generally poor [89] and that there is no clear evidence for the effectiveness of specific strategies, with similar BCTs and strategies being associated with both effective and ineffective interventions [102]. In addition, Alternburg et al. [89] reported that the use of multiple strategies within an intervention makes it difficult to identify the most promising strategies, although they identified two promising strategies for reducing children's (0–18 years) sedentary time: TV turn-off week and standing desks. Anselma et al. [102] argue that more effective interventions could be developed if the specific circumstances (e.g., physical and social context) were considered alongside the needs and interests of the target group. Such tailoring could be achieved through the co-creation of interventions with the target audience and key stakeholders acting as key collaborators.

24.6.3 Adults

In an umbrella review of systematic reviews, evidence was found for reductions in sedentary time following interventions focused specifically on reducing sedentary behaviours in adults [103]. With regard to interventions that implemented changes to the physical environment, the majority of studies included in the reviews were in the workplace. In a different umbrella review which included a meta-analysis, it was reported that physical environment interventions reduced total sedentary behaviours in adults, office workers and older adults (note, these populations were grouped together in the analysis) and were the most effective approach in the majority of cases [95]. However, the effectiveness of intervention approaches may be dependent on context as personal behaviour interventions were more effective for reducing leisure-time sedentary behaviour [95]. Interventions outside the workplace have focused on devices that can be attached to screens that monitor and limit screen usage time. However, a review by Wu et al. [104] focused on the effect of such interventions in adults suggested a limited effect on reducing screen time. Evidence for environmental strategies beyond the workplace is therefore limited. Whilst a review of behaviour change strategies employed within sedentary behaviour interventions in adults concluded that incorporating environmental modifications into sedentary behaviour interventions was likely to be fruitful [105], there is a need to explore the impact of this in other contexts.

It is not surprising that the majority of physical environment interventions to influence sedentary behaviour in adults have focused largely on the workplace. In recent times, there has been a significant shift towards computers and desk-orientated offices, and research suggests that almost 6 hours per workday can be spent sitting at a desk [106]. It is also a setting in which working adults spend a large proportion of their week and therefore an ideal setting for reducing sedentary behaviour in adults.

One of the most frequently reported physical environment interventions for targeting sedentary behaviour at work is the installation of sit-stand desks (i.e., a desk that can be used in both a seated or standing position and allows users to alternate between postures). Other common interventions to reduce sedentary behaviour at work using changes to the physical environment include treadmill desks that allow users to walk whilst using their computer, under-desk portable pedal or stepping devices, exercise bikes at the desk and exercise or Swiss balls that replace the office chair and allow for a more active sitting position.

Shrestha et al. [107–109] conducted a series of Cochrane reviews on interventions for reducing sitting at work. In 2015, just three studies were reported that had made changes to the physical environment, with 16 by the 2018 update. For the 10 interventions using sit-stand desks, low-quality evidence for reductions in sitting time at work of 1 hr. 40 minutes per workday were found compared to standard seated desks over the short term (up to 3 months) [109]. This was similar whether stand desks were used alone or combined with other strategies such as information and counselling. Two studies provided follow-up of between 3 to 12 months with an average of 57 minutes per day less workday sitting compared to standard seated desks. There was also some evidence of reductions in total daily sitting time and duration of sitting bouts lasting 30 minutes or more.

Straker et al. [110] suggested that sit-stand desks on their own only have a modest effect and that more radical, system-wide interventions were necessary even beyond additional behavioural interventions in order to affect sedentary behaviour at work such as policy and social changes. In fact, when adding in such additional strategies, Neuhaus et al. [111] showed that the reduction in sedentary time increased from 33 minutes to 1 hour 39 per 8-hour workday. Whilst a broader systems-based approach is intuitive, high-quality evidence on this is not available. Shrestha et al. [109] reported significant but heterogeneous effects of multicomponent interventions on reducing sitting time in the short- and medium-term, but this evidence was from a small number of low-quality studies.

Beyond sit-stand desks, the effect of more active workstations on sedentary behaviour has also been reviewed. There is some evidence that treadmill desks combined with counselling can reduce sitting time at work [109]. A systematic review and meta-analysis by Neuhaus et al. [111], reported on 38 interventions that used activity-permissive workstations (which included sit-stand desks, treadmill desks and under-desk pedalling devices/pedalling workstations) to reduce occupational sedentary time. The authors reported a pooled intervention effect in the reduction of sedentary time of 1 hour 17 minutes per 8-hour workday. For pedalling devices, review-level evidence suggests they are not effective at reducing sitting time [109]. In another review on the impact of alternative workstations as part of a wider review of workplace sedentary behaviour and physical activity, Commissaris et al. [112] performed sub-group analyses for sit-stand desks and treadmill desks (removing pedal machines, etc.) and reported that changes to overall daily sedentary behaviour were mainly attributed to the use of treadmill desks.

Some studies have assessed the effect of changing the physical building layout on sedentary behaviour. These studies primarily assess what happens to sedentary time when people relocate offices to buildings designed with break-out spaces, centralised resources (printer, kitchen and toilets) and attractive central staircases. Jancey et al. [113] looked specifically at the effects on sedentary behaviour and physical activity of switching to such a building and reported a significant reduction in sedentary time (20 minutes) and an increase in light activity (22 minutes). However, some measures of sedentary time (average length and maximum length of sedentary bouts) increased and moderate physical activity was shown to decline. Ensuring such features are incorporated into future workplace building design may be a potential strategy to influence sedentary behaviour at work. However, this study again demonstrates that multiple factors need to be addressed in addition to the physical environment in order to positively influence sedentary behaviour at work.

As previously mentioned, little attention has been paid to the social environment at work with regard to sedentary behaviour. Changing sedentary behaviour through the social environment is not something that tends to be targeted as an intervention on its own. Again, when addressing sedentary behaviour change from a social-ecological perspective, making it socially acceptable to sit less at work without providing a means of doing so may have limited effect. Many workplace interventions to reduce sedentary behaviour have included social-environmental components as part of multi-component interventions (e.g., [114–117]), for example, by including team champions who advocate, promote and role model standing at work, initiate standing in meetings, talk to employees about standing at work and promote the acceptability of things like sit-stand desks within office culture. However, there is very little evidence of the effect of social changes in the workplace alone on sedentary behaviour.

24.6.4 Older Adults

There has been an increase in the number of interventions targeting sedentary behaviour in older adults in recent years. It is worth noting that a number of interventions included in systematic reviews are not always targeted exclusively towards older people, but rather include all adults (e.g., Peachey et al. [118] included studies of adults between 18 and 70 years old in their assessment of environmental, behavioural and multicomponent interventions; Aunger et al. [119] reviewed sedentary behaviour interventions in non-working 'older adults', but the average age was 60 years and participants as young as 45 years were included) and sometimes children and adults are included (e.g., Schoeppe et al. [120] explored the use of apps to improve sedentary behaviour and other outcomes with no age limit; Khoo et al. [121] reviewed mHealth interventions in cancer survivors). On the other hand, some reviews have attempted to assess interventions specifically in older people but have found no studies eligible for inclusion. For example, Shrestha et al. [122] aimed to assess the effectiveness of interventions for reducing non-occupational sedentary behaviour. Out of 19 studies evaluated, the authors did not find any RCTs with a mean age of participants >60 years. Thus, it is challenging to determine which of these interventions work in older adults specifically. Chastin et al. [123] recently reviewed interventions purposefully designed to reduce sedentary time in independently-living adults aged 60 years and older. The seven studies that met the criteria amounted to low-certainty evidence despite finding that there was a reduction in mean sedentary time (mean difference − 44.91 min/day). Another important consideration for this review was that the majority of the participants were white, female and highly educated. The studies were also conducted in high-income countries, highlighting the need for more studies from LMICs in this age group.

24.7 Summary

Understanding the influence of the social and physical environments on sedentary behaviours is important for a deep understanding of sedentary behaviours in a variety of contexts. Awareness of how behaviour settings influence sedentary behaviour can be used to help design more effective interventions. While there has been further attention to the social and physical environment correlates, many have been studied too few times, or within weak study designs, or have focused on only one sedentary behaviour. This means that there remains a need for more evidence on specific environment determinants, in specific contexts, and for specific sedentary behaviours (e.g., in different domains). Where different domains of sedentary behaviour have been examined the correlates have tended to differ across them. Further to this, it is necessary to look at behaviour settings in a more nuanced way that goes beyond age and the obvious social contexts of home, school and workplaces. More work is also needed to explore the interaction between individual, social and physical environmental determinants. There is some evidence that the introduction of standing desks can lead to changes in sitting and standing times both within schools and workplaces. However, there is little evidence for other physical environment strategies or for those targeting the social environment. Returning to the social-ecological model, influences across the multiple levels of the individual (Chap. 16), social and physical environment (current chapter), community (Chap. 23) and policy (Chap. 25) need to be targeted to support behaviour change. We need to create supportive environments and provide individuals with the tools to change and regulate their behaviour.

References

1. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior: determinants and interventions. Am J Prev Med. 2011;41(2):189–96.
2. Spence JC, Lee RE. Toward a comprehensive model of physical activity. Psychol Sport Exerc. 2003;4(1):7–24.
3. Tremblay MS, Chaput J-P, Adamo KB, Aubert S, Barnes JD, Choquette L, et al. Canadian 24-hour movement guidelines for the early years (0–4 years): an integration of physical activity, sedentary behaviour, and sleep. BMC Pub Health. 2017;17(5):874.
4. Draper CE, Tomaz SA, Biersteker L, Cook CJ, Couper J, de Milander M, et al. The south African 24-hour movement guidelines for birth to 5 years: an integration of physical activity, sitting behavior, screen time, and sleep. J Phys Act Health. 2020;17(1):109–19.
5. Okely AD, Ghersi D, Hesketh KD, Santos R, Loughran SP, Cliff DP, et al. A collaborative approach to adopting/adapting guidelines - the Australian 24-hour movement guidelines for the early years (birth to 5 years): an integration of physical activity, sedentary behavior, and sleep. BMC Pub Health. 2017;17(5):869.
6. World Health Organisation. Guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age. Geneva: World Health Organisation; 2019.
7. Pereira JR, Zhang Z, Sousa-Sá E, Santos R, Cliff DP. Correlates of sedentary time in young children: a systematic review. Euro J Sport Sci. 2021;21(1):118–30.
8. Hinkley T, Salmon J, Okely AD, Trost SG. Correlates of sedentary behaviours in preschool children: a review. Int J Behav Nutr Phys Act. 2010;7:66.
9. De Craemer M, De Decker E, De Bourdeaudhuij I, Vereecken C, Deforche B, Manios Y, et al. Correlates of energy balance-related behaviours in preschool children: a systematic review. Obes Rev. 2012;13(Suppl 1):13–28.
10. Xu H, Wen LM, Rissel C. Associations of parental influences with physical activity and screen time among young children: a systematic review. J Obes. 2015;2015:546925.

11. Hoyos Cillero I, Jago R. Systematic review of correlates of screen-viewing among young children. Prev Med. 2010;51(1):3–10.
12. Lindsay AC, Greaney ML, Wallington SF, Mesa T, Salas CF. A review of early influences on physical activity and sedentary behaviors of preschool-age children in high-income countries. J Specialists Ped Nursing. 2017;22(3):e12182.
13. Hesketh KR, Lakshman R, van Sluijs EMF. Barriers and facilitators to young children's physical activity and sedentary behaviour: a systematic review and synthesis of qualitative literature. Obes Rev. 2017;18(9):987–1017.
14. Verloigne M, Van Lippevelde W, Maes L, Brug J, De Bourdeaudhuij I. Family- and school-based correlates of energy balance-related behaviours in 10-12-year-old children: a systematic review within the ENERGY (EuropeaN Energy balance research to prevent excessive weight gain among youth) project. Public Health Nutr. 2012;15(8):1380–95.
15. Maitland C, Stratton G, Foster S, Braham R, Rosenberg M. A place for play? The influence of the home physical environment on children's physical activity and sedentary behaviour. Int J Behav Nutr Phys Act. 2013;10(1):99.
16. Minges KE, Owen N, Salmon J, Chao A, Dunstan DW, Whittemore R. Reducing youth screen time: qualitative metasynthesis of findings on barriers and facilitators. Health Psychol. 2015;34(4):381–97.
17. Stierlin AS, De Lepeleere S, Cardon G, Dargent-Molina P, Hoffmann B, Murphy MH, et al. A systematic review of determinants of sedentary behaviour in youth: a DEDIPAC-study. Int J Behav Nutr Phys Act. 2015;12(1):133.
18. Uijtdewilligen L, Nauta J, Singh AS, van Mechelen W, Twisk JW, van der Horst K, et al. Determinants of physical activity and sedentary behaviour in young people: a review and quality synthesis of prospective studies. Br J Sports Med. 2011;45(11):896–905.
19. Van Der Horst K, Paw MJ, Twisk JW, Van Mechelen W. A brief review on correlates of physical activity and sedentariness in youth. Med Sci Sports Exerc. 2007;39(8):1241–50.
20. Rhodes RE, Guerrero MD, Vanderloo LM, Barbeau K, Birken CS, Chaput J-P, et al. Development of a consensus statement on the role of the family in the physical activity, sedentary, and sleep behaviours of children and youth. Int J Behav Nutr Phys Act. 2020;17(1):74.
21. Sawka KJ, McCormack GR, Nettel-Aguirre A, Hawe P, Doyle-Baker PK. Friendship networks and physical activity and sedentary behavior among youth: a systematized review. Int J Behav Nutr Phys Act. 2013;10:130.
22. Ali MM, Amialchuk A, Heiland FW. Weight-related behavior among adolescents: the role of peer effects. PLoS One. 2011;6(6):e21179.
23. de la Haye K, Robins G, Mohr P, Wilson C. Obesity-related behaviors in adolescent friendship networks. Soc Networks. 2010;32(3):161–7.
24. Strauss RS, Pollack HA. Social marginalization of overweight children. Arch Pediat Adoles Med. 2003;157(8):746–52.
25. Morton KL, Atkin AJ, Corder K, Suhrcke M, van Sluijs EM. The school environment and adolescent physical activity and sedentary behaviour: a mixed-studies systematic review. Obes Rev. 2016;17(2):142–58.
26. Andriyani FD, Biddle SJH, Arovah NI, Cocker K. Physical activity and sedentary behavior research in indonesian youth: a scoping review. Int J Environ Res Public Health. 2020;17(20):7665.
27. Liangruenrom N, Craike M, Biddle SJH, Suttikasem K, Pedisic Z. Correlates of physical activity and sedentary behaviour in the Thai population: a systematic review. BMC Pub Health. 2019;19(1):414.
28. Agiovlasitis S, Choi P, Allred AT, Xu J, Motl RW. Systematic review of sedentary behaviour in people with down syndrome across the lifespan: a clarion call. J Appl Res Intellect Disabil. 2020;33(2):146–59.
29. Jones RA, Downing K, Rinehart NJ, Barnett LM, May T, McGillivray JA, et al. Physical activity, sedentary behavior and their correlates in children with autism Spectrum disorder: a systematic review. PLoS One. 2017;12(2):e0172482.

30. Arundell L, Fletcher E, Salmon J, Veitch J, Hinkley T. The correlates of after-school sedentary behavior among children aged 5-18 years: a systematic review. BMC Pub Health. 2016;16:58.
31. Rhodes RE, Mark RS, Temmel CP. Adult sedentary behavior: a systematic review. Am J Prev Med. 2012;42(3):e3–28.
32. O'Donoghue G, Perchoux C, Mensah K, Lakerveld J, van der Ploeg H, Bernaards C, et al. A systematic review of correlates of sedentary behaviour in adults aged 18-65 years: a socio-ecological approach. BMC Pub Health. 2016;16:163.
33. Prince SA, Reed JL, McFetridge C, Tremblay MS, Reid RD. Correlates of sedentary behaviour in adults: a systematic review. Obes Rev. 2017;18(8):915–35.
34. Castro O, Bennie J, Vergeer I, Bosselut G, Biddle SJH. Correlates of sedentary behaviour in university students: a systematic review. Prev Med. 2018;116:194–202.
35. Müller AM, Chen B, Wang NX, Whitton C, Direito A, Petrunoff N, et al. Correlates of sedentary behaviour in Asian adults: a systematic review. Obes Rev. 2020;21(4):e12976.
36. Oppewal A, Hilgenkamp TIM, Schäfer Elinder L, Freiberger E, Rintala P, Guerra-Balic M, et al. Correlates of sedentary behaviour in adults with intellectual disabilities-a systematic review. Int J Environ Res Public Health. 2018;15(10):2274.
37. Munir F, Biddle SJH, Davies MJ, Dunstan D, Esliger D, Gray LJ, et al. Stand more AT work (SMArT work): using the behaviour change wheel to develop an intervention to reduce sitting time in the workplace. BMC Pub Health. 2018;18(1):319.
38. Smith L, McCourt O, Sawyer A, Ucci M, Marmot A, Wardle J, et al. A review of occupational physical activity and sedentary behaviour correlates. Occup Med. 2016;66(3):185–92.
39. De Cocker K, Duncan MJ, Short C, van Uffelen JGZ, Vandelanotte C. Understanding occupational sitting: prevalence, correlates and moderating effects in Australian employees. Prev Med. 2014;67:288–94.
40. Duncan MJ, Short CE, Rashid M, Cutumisu N, Vandelanotte C, Plotnikoff RC. Identifying correlates of breaks in occupational sitting: a cross-sectional study. Building Res Info. 2015;43:646–58.
41. Mullane SL, Toledo MJL, Rydell SA, Feltes LH, Vuong B, Crespo NC, et al. Social ecological correlates of workplace sedentary behavior. Int J Behav Nutr Phys Act. 2017;14(1):117.
42. Kurita S, Shibata A, Ishii K, Koohsari MJ, Oka K. Social-ecological correlates of accelerometer-measured occupational sitting among Japanese desk-based workers. BMC Pub Health. 2019;19(1):1489.
43. Sawyer A, Smith L, Ucci M, Jones R, Marmot A, Fisher A. Perceived office environments and occupational physical activity in office-based workers. Occup Med. 2017;67(4):260–7.
44. Hipp JA, Reeds DN, van Bakergem MA, Marx CM, Brownson RC, Pamulapati SC, et al. Review of measures of worksite environmental and policy supports for physical activity and healthy eating. Prev Chronic Dis. 2015;12:E65.
45. Olsen HM, Brown WJ, Kolbe-Alexander T, Burton NW. Physical activity and sedentary behaviour in a flexible office-based workplace: employee perceptions and priorities for change. Health Promot J Austr. 2018;29(3):344–52.
46. Chastin SF, Buck C, Freiberger E, Murphy M, Brug J, Cardon G, et al. Systematic literature review of determinants of sedentary behaviour in older adults: a DEDIPAC study. Int J Behav Nutr Phys Act. 2015;12:127.
47. Van Cauwenberg J, De Donder L, Clarys P, De Bourdeaudhuij I, Owen N, Dury S, et al. Relationships of individual, social, and physical environmental factors with older adults' television viewing time. J Aging Phys Act. 2014;22(4):508–17.
48. Kikuchi H, Inoue S, Sugiyama T, Owen N, Oka K, Shimomitsu T. Correlates of prolonged television viewing time in older Japanese men and women. BMC Pub Health. 2013;13:213.
49. Costa S, Benjamin-Neelon SE, Winpenny E, Phillips V, Adams J. Relationship between early childhood non-parental childcare and diet, physical activity, sedentary behaviour, and sleep: a systematic review of longitudinal studies. Int J Environ Res Public Health. 2019;16(23):4652.

50. Azevedo LB, van Sluijs EMF, Moore HJ, Hesketh K. Determinants of change in accelerometer-assessed sedentary behaviour in children 0 to 6 years of age: a systematic review. Obes Rev. 2019;20(10):1441–64.
51. Tonge KL, Jones RA, Okely AD. Correlates of children's objectively measured physical activity and sedentary behavior in early childhood education and care services: a systematic review. Prev Med. 2016;89:129–39.
52. Kaushal N, Rhodes RE. The home physical environment and its relationship with physical activity and sedentary behavior: a systematic review. Prev Med. 2014;67:221–37.
53. Koohsari MJ, Sugiyama T, Sahlqvist S, Mavoa S, Hadgraft N, Owen N. Neighborhood environmental attributes and adults' sedentary behaviors: review and research agenda. Prev Med. 2015;77:141–9.
54. Zolnik EJ. The effects of sprawl on private-vehicle commuting distances and times. Environ Planning B: Plan Design. 2011;38(6):1071–84.
55. Saidj M, Menai M, Charreire H, Weber C, Enaux C, Aadahl M, et al. Descriptive study of sedentary behaviours in 35,444 French working adults: cross-sectional findings from the ACTI-Cités study. BMC Pub Health. 2015;15:379.
56. Bennie JA, Timperio AF, Crawford DA, Dunstan DW, Salmon JL. Associations between social ecological factors and self-reported short physical activity breaks during work hours among desk-based employees. Prev Med. 2011;53(1–2):44–7.
57. Lin CY, Koohsari MJ, Liao Y, Ishii K, Shibata A, Nakaya T, et al. Workplace neighbourhood built environment and workers' physically-active and sedentary behaviour: a systematic review of observational studies. Int J Behav Nutr Phys Act. 2020;17(1):148.
58. Wallmann-Sperlich B, Bipp T, Bucksch J, Froboese I. Who uses height-adjustable desks? - sociodemographic, health-related, and psycho-social variables of regular users. Int J Behav Nutr Phys Act. 2017;14(1):26.
59. Cleland C, Reis RS, Ferreira Hino AA, Hunter R, Fermino RC. Koller de Paiva H, et al. built environment correlates of physical activity and sedentary behaviour in older adults: a comparative review between high and low-middle income countries. Health Place. 2019;57:277–304.
60. Hagger MS. Habit and physical activity: theoretical advances, practical implications, and agenda for future research. Psychol Sport Exerc. 2019;42:118–29.
61. Hagger MS. Non-conscious processes and dual-process theories in health psychology. Health Psychol Rev. 2016;10(4):375–80.
62. Maher JP, Conroy DE. A dual-process model of older adults' sedentary behavior. Health Psychol. 2016;35(3):262–72.
63. Maher JP, Dunton GF. Dual-process model of older adults' sedentary behavior: an ecological momentary assessment study. Psychol & Health. 2020;35(5):519–37.
64. Gardner B, de Bruijn GJ, Lally P. A systematic review and meta-analysis of applications of the self-report habit index to nutrition and physical activity behaviours. Ann Behav Med. 2011;42 (2):174–87.
65. Orbell S, Verplanken B. Changing behavior using habit theory. In: Hagger MS, Cameron LD, Hamilton K, Hankonen N, Lintunen T, editors. The handbook of behavior change. Cambridge: Cambridge University Press; 2020. p. 178–92.
66. Mazar A, Wood W. Defining habit in psychology. In: Verplanken B, editor. The psychology of habit: theory, mechanisms, change, and contexts. Cham: Springer International Publishing; 2018. p. 13–29.
67. Lally P, Gardner B. Promoting habit formation. Health Psychol Rev. 2013;7(Sup 1):S137–S58.
68. Gardner B, Arden MA, Brown D, Eves FF, Green J, Hamilton K, et al. Developing habit-based health behaviour change interventions: twenty-one questions to guide future research. Psychol Health. 2023;38(4):518–40.

69. Hollands GJ, Bignardi G, Johnston M, Kelly MP, Ogilvie D, Petticrew M, et al. The TIPPME intervention typology for changing environments to change behaviour. Nature Human Behav. 2017;1(8):0140.
70. Gesell SB, de la Haye K, Sommer EC, Saldana SJ, Barkin SL, Ip EH. Identifying social network conditions that facilitate sedentary behavior change: the benefit of being a "bridge" in a group-based intervention. Int J Environ Res Pub Health. 2020;17(12):4197.
71. Valente TW. Social networks and health behavior. In: Glanz K, Rimer B, Viswanath K, editors. Health behavior: theory, research and practice. 5th ed. San Francisco: Jossey-Bass; 2015. p. 205–22.
72. Bartholomew Eldredge L, Markham C, Ruiter R, Fernandez M, Kok G, Parcel G. Planning health promotion programs: an intervention mapping approach. 4th ed. San Francisco: Jossey-Bass; 2016.
73. Valente TW, Gallaher P, Mouttapa M. Using social networks to understand and prevent substance use: a transdisciplinary perspective. Subst Use Misuse. 2004;39(10–12):1685–712.
74. Rogers E. Diffusion of innovations. 5th ed. New York: Free Press; 2003.
75. Valente TW. Network interventions. Science. 2012;337(6090):49–53.
76. Montgomery SC, Donnelly M, Bhatnagar P, Carlin A, Kee F, Hunter RF. Peer social network processes and adolescent health behaviors: a systematic review. Prev Med. 2020;130:105900.
77. Leischow SJ, Milstein B. Systems thinking and modeling for public health practice. Am J Public Health. 2006;96(3):403–5.
78. National Cancer Institute. Greater than the sum: Systems thinking in tobacco control. Publication No. 06–6085 Tobacco control monograph No. 18. US Department of Health and Human Sevices, National Institutes of Health, National Cancer Institute; 2007.
79. Kotler P, Zaltman G. Social marketing: an approach to planned social change. J Mark. 1971;35 (3):3–12.
80. Andreasen A. Marketing and social change: changing behaviour to promote health, social development, and the environment. San Francisco, CA: Jossey-Bass; 1995.
81. Lee N, Kotler P. Social marketing: changing behaviors for good. Thousand Oaks, CA: Sage Publications; 2015.
82. Luecking CT, Hennink-Kaminski H, Ihekweazu C, Vaughn A, Mazzucca S, Ward DS. Social marketing approaches to nutrition and physical activity interventions in early care and education centres: a systematic review. Obes Revi. 2017;18(12):1425–38.
83. Goethals L, Barth N, Hupin D, Mulvey MS, Roche F, Gallopel-Morvan K, et al. Social marketing interventions to promote physical activity among 60 years and older: a systematic review of the literature. BMC Pub Health. 2020;20(1):1312.
84. Sauvage-Mar C, Naylor PJ, Wharf Higgins J, VonBuchholz H. Way2Go! Social marketing for girls' active transportation to school. Prev Med Rep. 2019;14:100828.
85. Gordon R, McDermott L, Stead M, Angus K. The effectiveness of social marketing interventions for health improvement: what's the evidence? Pub Health. 2006;120(12):1133–9.
86. Griffiths J, Blair-Stevens C, Thorpe A. Social marketing for health and specialised health promotion: stronger together - weaker apart. A paper for debate. National Social Marketing Centre and Royal Society for Public Health.; 2008.
87. Storey JD, Hess R, Saffitz G. Social marketing. In: Glanz K, Rimer B, Viswanath K, editors. Health behavior: theory, research, and practice. San Francisco: Jossey-Bass; 2015. p. 411–38.
88. Downing KL, Hnatiuk JA, Hinkley T, Salmon J, Hesketh KD. Interventions to reduce sedentary behaviour in 0–5-year-olds: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 2018;52(5):314.
89. Altenburg TM, Kist-van Holthe J, Chinapaw MJM. Effectiveness of intervention strategies exclusively targeting reductions in children's sedentary time: a systematic review of the literature. Int J Behav Nutr Physical Act. 2016;13(1):65.
90. Kaur N, Gupta M, Malhi P, Grover S. Screen time in under-five children. Indian Pediatr. 2019;56(9):773–88.

91. Marsh S, Foley LS, Wilks DC, Maddison R. Family-based interventions for reducing sedentary time in youth: a systematic review of randomized controlled trials. Obes Rev. 2014;15(2):117–33.
92. Schmidt ME, Haines J, O'Brien A, McDonald J, Price S, Sherry B, et al. Systematic review of effective strategies for reducing screen time among young children. Obesity. 2012;20(7):1338–54.
93. Steeves JA, Thompson DL, Bassett DR, Fitzhugh EC, Raynor HA. A review of different behavior modification strategies designed to reduce sedentary screen behaviors in children. J Obes. 2012;2012:379215.
94. Blackburn NE, Wilson JJ, McMullan II, Caserotti P, Giné-Garriga M, Wirth K, et al. The effectiveness and complexity of interventions targeting sedentary behaviour across the lifespan: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2020;17(1):53.
95. Lam K, Baurecht H, Pahmeier K, Niemann A, Romberg C, Biermann-Stallwitz J, et al. How effective and how expensive are interventions to reduce sedentary behavior? An umbrella review and meta-analysis. Obes Rev. 2022;23(5):e13422.
96. dos Santos PC, Barbosa Filho VC, da Silva JA, AdS B, Minatto G, da Silva KS. What works in sedentary behavior interventions for youth: a review of reviews. Adoles Res Rev. 2019;4(3):267–92.
97. Minges KE, Chao AM, Irwin ML, Owen N, Park C, Whittemore R, et al. Classroom standing desks and sedentary behavior: a systematic review. Pediatrics. 2016;137(2):e20153087.
98. Hinckson E, Salmon J, Benden M, Clemes SA, Sudholz B, Barber SE, et al. Standing classrooms: research and lessons learned from around the world. Sports Med. 2016;46(7):977–87.
99. Guirado T, Chambonnière C, Chaput JP, Metz L, Thivel D, Duclos M. Effects of classroom active desks on children and adolescents' physical activity, sedentary behavior, academic achievements and overall health: a systematic review. Int J Environ Res Public Health. 2021;18(6):2828.
100. Sherry AP, Pearson N, Clemes SA. The effects of standing desks within the school classroom: a systematic review. Prev Med Rep. 2016;3:338–47.
101. McMichan L, Gibson AM, Rowe DA. Classroom-based physical activity and sedentary behavior interventions in adolescents: a systematic review and meta-analysis. J Phys Act Health. 2018;15(5):383–93.
102. Anselma M, Chinapaw MJM, Kornet-van der Aa DA, Altenburg TM. Effectiveness and promising behavior change techniques of interventions targeting energy balance related behaviors in children from lower socioeconomic environments: A systematic review. PLoS One. 2020;15(9):e0237969.
103. Nguyen P, Le LK-D, Nguyen D, Gao L, Dunstan DW, Moodie M. The effectiveness of sedentary behaviour interventions on sitting time and screen time in children and adults: an umbrella review of systematic reviews. Int J Behav Nutr Phys Act. 2020;17(1):117.
104. Wu L, Sun S, He Y, Jiang B. The effect of interventions targeting screen time reduction: A systematic review and meta-analysis. Medicine (Baltimore). 2016;95(27):e4029-e.
105. Gardner B, Smith L, Lorencatto F, Hamer M, Biddle SJ. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. Health Psychol Rev. 2016;10(1):89–112.
106. Ryde GC, Brown HE, Gilson ND, Brown WJ. Are we chained to our desks? Describing desk-based sitting using a novel measure of occupational sitting. J Phys Act Health. 2014;11(7):1318–23.
107. Shrestha N, Ijaz S, Kukkonen-Harjula KT, Kumar S, Nwankwo CP. Workplace interventions for reducing sitting at work. Cochrane Database Sys Rev. 2015;1:CD010912.
108. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Bhaumik S. Workplace interventions for reducing sitting at work. Cochrane Database Sys Rev. 2016;3:CD010912.
109. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Pedisic Z. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2018;6(6):Cd010912.

110. Straker L, Abbott RA, Heiden M, Mathiassen SE, Toomingas A. Sit-stand desks in call centres: associations of use and ergonomics awareness with sedentary behavior. Appl Ergon. 2013;44(4):517–22.
111. Neuhaus M, Eakin EG, Straker L, Owen N, Dunstan DW, Reid N, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. Obes Rev. 2014;15(10):822–38.
112. Commissaris D, Huysmans MA, Mathiassen SE, Srinivasan D, Koppes LLJ, Hendriksen IJM. Interventions to reduce sedentary behavior and increase physical activity during productive work: a systematic review. Scand J Work Environ Health. 2016;42(3):181–91.
113. Jancey JM, McGann S, Creagh R, Blackford KD, Howat P, Tye M. Workplace building design and office-based workers' activity: a study of a natural experiment. Aust N Z J Public Health. 2016;40(1):78–82.
114. Alkhajah TA, Reeves MM, Eakin EG, Winkler EAH, Owen N, Healy GN. Sit–stand workstations: a pilot intervention to reduce office sitting time. Am J Prev Med. 2012;43(3): 298–303.
115. Neuhaus M, Healy GN, Dunstan DW, Owen N, Eakin EG. Workplace sitting and height-adjustable workstations: a randomized controlled trial. Am J Prev Med. 2014;46(1):30–40.
116. Neuhaus M, Healy GN, Fjeldsoe BS, Lawler S, Owen N, Dunstan DW, et al. Iterative development of stand up Australia: a multi-component intervention to reduce workplace sitting. Int J Behav Nutr Phys Act. 2014;11:21.
117. Healy GN, Eakin EG, Lamontagne AD, Owen N, Winkler EA, Wiesner G, et al. Reducing sitting time in office workers: short-term efficacy of a multicomponent intervention. Prev Med. 2013;57(1):43–8.
118. Peachey MM, Richardson J, Tang AV, Dal-Bello Haas V, Gravesande J. Environmental, behavioural and multicomponent interventions to reduce adults' sitting time: a systematic review and meta-analysis. Br J Sports Med. 2020;54(6):315.
119. Aunger JA, Doody P, Greig CA. Interventions targeting sedentary behavior in non-working older adults: a systematic review. Maturitas. 2018;116:89–99.
120. Schoeppe S, Alley S, Van Lippevelde W, Bray NA, Williams SL, Duncan MJ, et al. Efficacy of interventions that use apps to improve diet, physical activity and sedentary behaviour: a systematic review. Int J Behav Nutr Phys Act. 2016;13(1):127.
121. Khoo S, Mohbin N, Ansari P, Al-Kitani M, Müller AM. mHealth interventions to address physical activity and sedentary behavior in cancer survivors: a systematic review. Int J Environ Res Public Health. 2021;18(11):5798.
122. Shrestha N, Grgic J, Wiesner G, Parker A, Podnar H, Bennie JA, et al. Effectiveness of interventions for reducing non-occupational sedentary behaviour in adults and older adults: a systematic review and meta-analysis. Br J Sports Med. 2019;53(19):1206.
123. Chastin S, Gardiner PA, Harvey JA, Leask CF, Jerez-Roig J, Rosenberg D, et al. Interventions for reducing sedentary behaviour in community-dwelling older adults. Cochrane Database Syst Rev. 2021;6(6):Cd012784.

Chapter 25
Targeting Sedentary Behaviour at the Policy Level

Anthony D. Okely, Megan Hammersley, and Salomé Aubert

Abstract Policy-level approaches are a promising and potentially powerful way to reduce sedentary behaviour at a population level. Ecological models have typically been used to reduce sedentary behaviour at a policy level. These focus on specific settings where policies may be present. This chapter examines home, workplace, education, transportation, healthcare, and nonhome-based leisure settings where sedentary behaviour reduction can be targeted at a policy level and the accompanying evidence for such policies along with important supporting factors. For policies to be effective in these settings, they also require shifting strong social norms to sit and should focus on benefits broader than health, such as increased productivity and academic learning and reduced traffic congestion. Government guidelines are a key policy component, as are recommendations from non-government organizations. Current sedentary behaviour guidelines and stakeholder recommendations are summarized. A description of the national physical activity report cards is provided as an example of a successful policy initiative driving sedentary behaviour reduction in many countries. Limitations of the existing evidence and recommendations for future research are also included.

A. D. Okely (✉)
School of Health and Society, University of Wollongong, Wollongong, NSW, Australia
e-mail: tokely@uow.edu.au

M. Hammersley
University of Wollongong, Wollongong, NSW, Australia
e-mail: mhammers@uow.edu.au

S. Aubert
Children's Hospital of Eastern (CHEO), Ontario Research Institute, Ottawa, Canada
e-mail: saubert@cheo.on.ca

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_25

What Is New?

- The recent Guidelines on Physical Activity and Sedentary Behaviour published by the World Health Organization (WHO) in 2020 for the first time include recommendations on sedentary behaviour and address all age groups as well as population subgroups, such as pregnant women or adults living with chronic conditions (see Chap. 1).
- The first setting-specific recommendations for school-related sedentary behaviours were published (see Chap. 1).
- The WHO Global Action Plan on Physical Activity 2018–2030 provides the basis for global policy action to reduce sedentary behaviour considering aspects of environmental health and sustainability (see Chap. 27).

25.1 Introduction

In this chapter, policies are defined as laws, regulations, formal rules, informal rules, or understandings that are adopted on a collected basis to guide individual and collective behaviour [1]. Policy changes are designed to affect large groups and populations and establish settings and incentives that can persist in sustaining behaviour change [2]. As such, policy-level interventions and strategies represent arguably the most powerful means for changing sedentary behaviour at a population level. While it is known that the health consequences of sedentary behaviour are somewhat independent of physical inactivity [3] and that the correlates of sedentary behaviour are different from physical inactivity and moderate- to vigorous-intensity physical activity [2], with the exception of television viewing in children, only recently have researchers started to examine interventions to specifically reduce sedentary behaviour. Policy-level interventions to reduce sedentary behaviour are even less advanced.

The policy environment is a feature of most ecological models of behaviour, but it is often the least developed and tested. National and international organizations (e.g. World Health Organization, Institute of Medicine, US Department of Health and Human Services) have recognized the importance of policy in changing health behaviours. For example, the World Health Organization in their 2016 Ending Childhood Obesity Report [4] sought to use policy recommendations to address three strategic objectives and saw targeting policy as the key to reducing the prevalence of childhood obesity. Over the past 30 years, there has been mention of the role of policy in models designed to guide behavioural interventions. The sedentary behaviour field is still in the early stages of developing and testing specific multilevel ecological models that include targeting policy-level influences [2].

This chapter first describes major models for targeting sedentary behaviour that incorporate policy-level initiatives. It then examines the specific settings in which reducing sedentary behaviour can be targeted at a policy level and evidence of the effect of interventions in such settings. The factors important to supporting policies are then described. Finally, recommendations for future research targeting policy-level change are also provided.

25.2 Models for Targeting Sedentary Behaviour Reduction at a Policy Level

There is good evidence that changing health behaviours at a policy level has more chance of success if theoretical models or frameworks are used [5]. The behavioural epidemiology framework is especially useful in describing phases of research upon which policy-level changes should be built [6]. In the context of policy research, this would include Phase 1 (identifying the health consequences of prolonged sitting and other sedentary behaviours such as television viewing) and Phase 3 (examining factors that influence sedentary behaviour). This will strengthen the evidence base for the development, testing, and evaluation of policy-level interventions (Phase 4) and the dissemination of successful interventions into broader public policy (Phase 5).

While there is little doubt that the need to identify policy correlates and determinants of sedentary behaviour is important [2], there has been some debate around how much evidence is needed in Phase 3 before Phases 4 and 5 can be commenced. That is, are observational studies needed to determine correlates or health consequences first, before testing policy interventions to reduce sedentary behaviour? Robinson's solution-oriented approaches have been recommended to more rapidly advance behaviour change at a policy level by focusing on interventions that are directly applicable to policy [7]. In a solution-oriented approach, experimental or quasi-experimental research designs are emphasized to identify the cause of high levels of sedentary behaviour [8].

For example, observational research shows that policies relating to limiting sedentary behaviour are only weakly associated with sedentary behaviour in childcare settings [9]. From this, it may be concluded that policy-level variables are not important in relation to reducing sedentary behaviour in childcare. Alternatively, the poor relationships could be explained by the difficulty in accurately measuring screen-based sedentary behaviour and policy-level variables in these settings (predominantly self-report) or incomplete implementation of the policies. But intervention studies have shown that targeting sedentary behaviour policies in this setting have had a significant effect on reducing sedentary behaviour among children [10, 11]. To overcome this limitation, a quasi-experimental design must be applied where the exposure (policies to reduce sedentary behaviour) is manipulated. Under a solution-oriented paradigm, the effects of a policy to reduce sedentary behaviour on time spent in sedentary behaviour would be tested. The results would then be able to directly answer questions of causality and indicate methods that are successful or not successful in reducing sedentary behaviour in this setting [8].

While quasi-experimental studies are able to address issues of causality, the ability to prepare and plan policy-level interventions using experimental research designs is often difficult or unauthentic. In such circumstances, observational "natural experiments" may be more feasible and have increased external validity. At the policy level, initiatives are often informed by both evidence-based practice and practice-based evidence.

Ecological models of behaviour are the ones in which the policy environment is specifically identified. Ecological models put the behaviour at the centre and then group the factors that influence the behaviour into levels or domains [12]. Owen et al. [2] have developed an ecological model of sedentary behaviour, which includes the policy environment grouped according to specific settings in which sedentary behaviour typically occurs. A figure of this model, with the policy environment represented in the most outer concentric circle, can be found in Chap. 15.

25.3 Specific Settings for Reducing Sedentary Behaviour at a Policy Level

Ecological models propose that research at a policy level should focus on the behavioural settings within which policies may operate. As such, there is a need to identify the specific settings in which sedentary behaviours occur and then target specific policies for these settings. In this chapter, we have focused on the domestic or home environment, workplace, education (school and early childhood education and care), transportation and urban design, healthcare, and nonhome-based leisure settings. In addition, we have included government guidelines or recommendations under the public health and non-government organization sectors. Many of the policy strategies to reduce sedentary behaviour could also accompany messages about increasing physical activity. Documents such as the US National Physical Activity Plan (involving 19 organizational partners) [13] and the National Heart Foundation's Blueprint for an Active Australia [14] lay out specific strategies to influence change at a policy level. In these documents, although the focus is promoting physical activity, many of the strategies could be modified to be tested in order to reduce sedentary behaviour.

25.3.1 Domestic or Home Environments

In the context of this chapter, this environment encompasses sedentary behaviours undertaken in the home. These behaviours are largely recreational or domestic in nature. Policy options for reducing sedentary behaviour in the home environment are limited [2], and we are unaware of any policy interventions to reduce sedentary behaviour that have been conducted in this environment. In the absence of this evidence, we have provided examples of successful strategies that could be used to develop policy-level interventions and how this might be done.

Strategies that have been shown to be efficacious in reducing sedentary behaviour in the home environment include decreasing the number of hours of screen media use through removing televisions from bedrooms, budgeting the amount of time spent in screen use each week, and setting rules to limit the content, timing, and location of screen use in the house [15–18]. These strategies are often provided as part of policy documents such as national sedentary behaviour guidelines or recommendations. Strategies that probably will reduce sedentary behaviour, but for which the only evidence we have is that targeting them can result in a change in behaviour, including increasing non-labour saving behaviours such as hanging clothes on a line (instead of using a dryer) [19] and hand washing a car instead of using an automatic car wash. An added advantage of these strategies is the increased motivation that may come from reducing greenhouse gases and saving money through more energy-efficient behaviours.

Modifying the interior (and exterior) design of homes is another potential strategy for decreasing sedentary behaviour in the home environment. It has been shown in other environments such as schools and workplaces that providing spaces that are less cluttered and more flexible in how they can be used can reduce sitting time [20, 21]. Additional ideas in the home environment could include rearranging furniture so that the television is not the centre of attention in a room, removing stools at benches, and having more tables and desks that could be used while standing. While it is difficult to target these changes at a policy level, incentives such as introducing a policy whereby tax incentives can be claimed on height-adjustable tables and desks and using interior designers who follow these guidelines may provide a financial impetus for behaviour change.

Perhaps the greatest scope for change in the home environment as a result of policy is through ensuring sedentary behaviour reduction is included in national and jurisdictional guidelines [22]. Table 25.1 shows current policy examples listed by country. Many of the guidelines specific to sedentary behaviour reduction include a focus on the home environment. For example, the Canadian Sedentary Behaviour Guidelines for children 0–4 years recommend limiting prolonged sitting or being restrained for more than 1 h at a time [23]. The UK Guidelines for Physical Activity for Adults recommend minimising the amount of time spent being sedentary for extended periods in the home environment [24]. Guidelines for recreational (noneducational) screen-based time for children and adolescents also predominantly target the home environment, as this is where most of this type of sedentary behaviour occurs (see Sect. 1.3 for more details on existing recommendations targeting sedentary behaviour).

Table 25.1 Government and organizational policies and guidelines on sedentary behaviour

Country	Title/organization	Year	Sector	Description
Australia and New Zealand				
Australia	Australian Government "Australia's Physical Activity and Sedentary Behaviour Guidelines"[a]	2014	Government	Comprises a series of physical activity guidelines focusing on different age groups (0–5 years, 5–12 years, 13–18 years, and adults). Sedentary time recommendations form part of each of these guidelines. Information on the benefits of sitting less is provided, followed by tips on how to reduce sitting and break up long periods of sitting. Screen time is specifically targeted.
Australia	National Heart Foundation of Australia "Blueprint for an Active Australia"[b]	2014	Non-government organization	Provides specific suggestions for 13 key action areas, including prolonged sitting/sedentary behaviour in schools, workplaces, aged care, and other settings
Australia	National Heart Foundation of Australia "Sit Less" resources[c]	2011–2013	Non-government organization	Resources include a fact sheet, posters, and "sitting less for adults" guide and "sitting less for children" guide, which discuss the benefits of sitting less, the recommendations, and some suggestions on how to sit less
Australia	Exercise and Sports Science Australia "Physical Activity in the Workplace: A Guide"[d]	2013	Health professional organization	Advises how organizations can encourage employees to sit less in the workplace. It is recommended that organizations include prolonged sitting in their occupational health and safety policies, conduct audits to determine employee sitting time while at work, and consider implementing

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				interventions to reduce sitting time such as breaking up sitting every 30 min, providing height-adjustable desks, and utilizing standing or walking meetings
Australia	Baker IDI Heart and Diabetes Institute, Cancer Prevention Research Centre UQ and Medibank Private "Stand Up Australia: Sedentary Behaviour in Workers"[e]	2009	Non-government organization	Recommends inclusion of prolonged sitting in occupational health and safety policies, investigation of the level of prolonged sitting occurring in the workplace, and the use of interventions to assist employees in replacing sedentary time with light physical activity, such as standing while making telephone calls, breaks during long meetings, or reorganizing work tasks so that employees can sit or stand
Australia	Public Health Association of Australia "Physical Activity Policy"[f]	2014	Non-government organization	Supports the use of the Australian Physical Activity Guidelines, specifically noting the sedentary behaviour component of the guidelines
Australia	Royal Australian College of General Practitioners "Smoking, nutrition, alcohol, physical activity (SNAP): a population health guide to behavioural risk factors in general practice"[g]	2015	Health professional organization	Supports the use of the Australian Physical Activity Guidelines, specifically noting the sedentary behaviour component of the guidelines. Provides recommendations on providing advice on reducing sedentary behaviour to relevant patients
Australia	Australian Government Comcare "Sedentary work practices toolkit"[h]	2014	Government	Comcare has a range of resources to assist organizations in reducing sedentary behaviour in the workplace. These include "implementing a

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				program to reduce sedentary work practices: a checklist", posters, and fact sheets
Australia	Worksafe Tasmania "Healthy Workplace Resource Toolkit"[i]		Government	The Healthy Workplace Resource Toolkit features a section on sedentary behaviour, which provides background information and advice on how to encourage employees to sit less while at work. Provides a template to develop a physical activity policy
Australia	Department of Education, Queensland "Physical activity in state schools"[j]		Government	Provides recommendations to minimize and break up long periods of sitting. It also advises educating students on limiting the use of electronic devices
Australia	NSW Ministry of Health, "Healthy kids—eat well, get active" website[k]		Government	Provides advice on developing a physical activity policy for early childhood centres. Sedentary time is specifically addressed. It is recommended to limit prolonged sitting, with particular mention of limiting the use of electronic media
Australia	Active Healthy Kids Australia "Is Sport Enough? 2014 Report Card on Physical Activity for Children & Young People"[l]	2014	Non-government organization	Reports on compliance with the Australian Sedentary Behaviour Guidelines for Children and Youth. Discusses the importance of parent education and encourages parents to minimize sedentary and screen time. Recommends that schools work to break up long periods of sitting throughout the day and that guidelines for sedentary behaviour are updated as evidence of

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				dose–response relationships become available
Australia	VicHealth "Reducing prolonged sitting in the workplace"[m]	2012	Government	This evidence report summarizes findings from workplace sedentary behaviour studies. Strategies that have been used in studies include increasing breaks, changing posture, ergonomic changes, building design changes or a combination of these strategies. Overall, strategies to reduce sitting were effective, especially in improving musculoskeletal health. In some studies, there were improvements in productivity, absenteeism, and injury. It was also found that employees were more likely to reduce sitting time when specific guidelines were provided
New Zealand	Ministry of Health "Eating and Activity Guidelines for New Zealand Adults"[n]	2015	Government	The guidelines consist of five activity statements—the first being "Sit less, move more! Break up long periods of sitting." Provides background evidence and recommendations for the general public on how to reduce sitting time in work, travel, and leisure-time settings
New Zealand	Ministry of Education "Physical activity for healthy confident kids"[o]	2007	Government	These guidelines do not discuss sedentary behaviour in general but do recommend that children limit time using computers, electronic games, and television to no more than 2 h outside of school hours

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
New Zealand	Ministry of Health "Physical activity guidelines"[p]	2015	Government	The guidelines for older people (65 years and over) discuss the increase in sedentary behaviour in this age group and the importance of limiting sedentary behaviour, specifically noting that maintaining activities of daily living can assist in reducing sedentary time
North America				
Canada	Active Canada 20/20[q]	2012	Non-government organization	Canada 20/20 proposes that a policy be developed which addresses sedentary behaviour. In workplaces, it is suggested that policies are developed and that the workplace environment is modified to allow for less sedentary behaviour. It is suggested that tax incentives are provided to employers to implement such changes. Additionally, it is recommended that schools provide opportunities to reduce sedentary behaviour
Canada	Canadian Society for Exercise Physiology "Canadian Physical Activity and Sedentary Behaviour Guidelines"[r]	2011	Health professional organization	The document consists of guidelines for different age groups. There is a recommendation for no screen time at all for children 0–2 years of age, no more than 1 h per day for children 2–4, and no more than 2 h per day for older children. For children aged 0–4, it is recommended to limit equipment that restricts movement, have screen time limits, and remove televisions and computers from bedrooms. For children aged 5–18,

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				it recommends providing active alternatives to screen time, such as play and family games
Canada	ParticipACTION[s]	Est 1971	Non-government organization	ParticipACTION is a non-profit organization that promotes sitting less and moving more. There are a series of resources on their website covering screen time, parental role-modelling, infographics, “unplug and play” pledge, and information on various partnership programs. Resources focus on both children and adults, and tips are provided to reduce sedentary time at home and in the workplace
Canada	The Conference Board of Canada “Moving Ahead: The Economic Impact of Reducing Physical Inactivity and Sedentary Behaviour”[t]	2014	Non-government organization	This document discusses the prevalence of sedentary behaviour in Canada and reports that Canadians sit for approximately 10 h per day. The impact on population health and subsequent effects on GDP, absenteeism, and healthcare expenditure are discussed. If just 10% of Canadians who are inactive were to become more active and less sedentary, this could result in an increase of around $1.6 billion in GDP by 2040. Additionally, healthcare expenditure could be reduced by $2.6 billion during the same period
USA	American College of Sports Medicine” Reducing Sedentary Behaviors:	2011	Health professional organization	Provides practical suggestions for reducing sedentary behaviour in the workplace and at

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
	Sitting Less and Moving More"[u]			home. Suggestions include both moderate-intensity activity and light-intensity activity alternatives to sitting. There are no specific screen time recommendations
USA	American Academy of Pediatrics "Active Healthy Living: Prevention of Childhood Obesity"[v]	2006	Health professional organization	Provides guidelines for specific age groups. It is recommended that infants and toddlers do not watch television at all. For older children, it is recommended that screen time should be limited to no more than 2 h per day. For preschool-aged children, it is recommended that sedentary transport via car or stroller be limited. It is recommended that healthcare professionals record the number of hours that children are sedentary and provide advice to reduce sedentary time
USA	American Academy of Pediatrics "The Role of the Pediatrician in Primary Prevention of Obesity"[w]	2015	Health professional organization	Discusses the increase in sedentary behaviour as children get older. The importance of parental influence in the development of behaviours is highlighted, with particular reference to screen time. Recommendations from 2006[v] are reinforced. It is recommended to limit the number of screens available, to remove televisions and other screens from a child's bedroom and from meal areas, and for parents to monitor their child's screen time

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
USA	Institute of Medicine "Early Childhood Obesity Prevention Policies"[x]	2011	Health professional organization	It is recommended that childcare providers reduce sedentary time in children by limiting the use of movement-restricting equipment (such as high chairs, strollers, and bouncers) to when they are needed only. It is also recommended that periods of sitting or standing are broken up at least every 30 min
USA	National Heart, Lung and Blood Institute "We Can!: Ways to Enhance Children's Activity and Nutrition"[y]		Government	We Can! website contains resources on reducing screen time, including a fact sheet/goal setting and screen time chart. A number of programs are available such as the "Energise Our Families" parent course, which has a large emphasis on reducing sedentary behaviour through limiting screen time. "SMART (Student Media Awareness to Reduce Television)" is aimed at third–fourth-grade students and "Media-Smart Youth" is aimed at 11–13 year olds
USA	Society of Behavioural Medicine "Position statement: early care and education (ECE) policies can impact obesity prevention among preschool-aged children"[z]	2015	Health professional organization	This position statement puts forward recommendations for policymakers which are based on Caring for Our Children, The Child and Adult Care Food Program and Let's Move! Child Care recommendations. The position statement recommendations include limiting sedentary behaviour to less than 30 min at a time and limiting screen time for

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				entertainment to less than 30 min per week
USA	Office of the President of the United States "Solving the problem of childhood obesity within a generation: White House Task Force on Childhood Obesity Report to the President"[aa]	2010	Government	Presents an action plan which outlines a number of recommendations to address childhood obesity. Sedentary behaviour is discussed, and reducing screen time is included in the recommendations
USA	USA Government "Let's Move!"[ab]	2010	Government	Program aims to improve healthy eating and physical activity and includes specific recommendations on reducing sedentary behaviour and screen time
Asia				
Korea	Ministry of Health and Welfare: "The physical activity guide for Koreans"[ac]	2013	Government	Sedentary behaviour forms part of the physical activity guidelines. It is recommended to reduce the amount of time sitting and limit the amount of time watching television to less than 2 h per day
Qatar	Aspetar Hospital "Qatar National Physical Activity Guidelines"[ad]	2014	Health service	For adults, it is recommended to limit "low-level activities" (television, computer, electronic games) to no more than 2 h per day for people with coronary artery disease and heart failure. For children and youth (up to 17 years of age), the guidelines recommend having no computers or TVs in bedrooms and limiting the amount of screen time to no more than 2 h per day. It is also recommended that sitting time be broken up every hour
Europe				

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
Belgium	WHO “Belgium Physical Activity Factsheet”[ae]	2015	Non-government organization	This document presents two projects [“10,000 steps” and “stand on your own two feet (BOEBS)”] which aim to limit sedentary behaviour among older adults in the Flemish region
Europe	HEPA (Health Enhancing Physical Activity) “EU Physical Activity Guidelines”[af]	2008	Non-government organization	Presents European Union Physical Activity Guidelines including sedentary behaviour guidelines. Policy guidelines and examples of good practices in Europe in various contexts (sport, health, education, transport working environment, services for senior) for different groups of actors are developed
Europe	European Heart Network “Children and young people—The importance of physical activity”[ag]	2001	Non-government organization	Evidence review resulting from the European Heart Health Initiative published with the intention of promoting physical activity measures as a way to reduce the burden of cardiovascular diseases. Policy recommendations on different domains of influence which also targets sedentary behaviour reduction are provided
France	Ministry of Work, Employment and Health “National Health and Nutrition Program (Programme National Nutrition Sante)“[ah]	2011	Government	This document contains health objectives for the French population and actions taken to target these objectives. General objective 2 is “increase physical activity and decrease sedentary behaviour for all ages.” Sub-objective 2.2 aims to, over the next 5 years, decrease by at least 10% the average daily screen

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				time among 3–17 children and teenagers
Greenland, Iceland, Norway, Sweden, Finland & Denmark	Norden Council of Ministers "Nordic Nutrition recommendation"[ai]	2012	Government	Present sedentary behaviour guidelines, for children, adolescents, and adults. For these age groups, there is a guideline to reduce sedentary behaviour
Ireland	National Association for Sport and Physical Education "Fact sheet for childcare providers"[aj]	2006	Professional organization	This one-page fact sheet is addressed to childcare providers and gives specific sedentary behaviour guidelines for children from birth to age 5
Spain	Ministry of Health, Social Services and Equity "Physical activity for health and sedentary behaviour reduction, guidelines for the population"[ak]		Government	This document presents complex guidelines for physical activity, sedentary behaviour, and screen time adapted for under 5 years old, 5–17 years old, adults, older adults (more than 65 years old), pregnant and post-partum women
Turkey	Republic of Turkey, Ministry of Health, Public Health Institution "Physical Activity Guidelines For Turkey"[al]	2014	Government	Present the physical activity guidelines for children, adolescents, families, teachers, adults, older adults, and disabled, and provide an example of games and tips for being more active. It includes sedentary behaviour guidelines (based on limiting screen time) for children and teenagers
UK	British Heart Foundation "Sedentary Behaviour: Evidence Briefing"[am]	2012	Non-government organization	Defines sedentary behaviour, its health consequences, and correlates. The UK guidelines are stated along with strategies to reduce sedentary behaviours for different age groups. Implications for practice, targeting the commissioners, the

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				policymakers, and the practitioners are provided
UK	Department of Health, Physical Activity, Health Improvement and Protection "Start Active, Stay Active—a report on physical activity for health from the four home countries' Chief Medical Officers"[an]	2011	Government	Gives physical activity and sedentary behaviour guidelines for different age groups (under 5 s, 5–18, 19–64, and 65þ years). Recommendations and examples of effective actions targeting sedentary behaviour reduction at multiple levels (environmental, organizational, community, and interpersonal) are presented
UK	Public Health England "Everybody Active, Every Day: An evidence-based approach to physical activity"[ao]	2014	Government	This paper presents the chief medical officer's guidelines for physical activity and sedentary behaviour that target early years (under 5 s), children and young people (5–18 years), adults, and older adults (65þ years). It also contains an overview of the physical inactivity problem and recommendations for reducing sedentary behaviour in various contexts
UK	British Heart Foundation "Physical Activity in the Early Years Evidence Briefing"[ap]	2014	Non-government organization	In this evidence briefing the role of sedentary behaviour in the health and well-being of children under five is examined. It presents the public health guidelines concerning sedentary behaviour for the early year's children and provides some potential actions for practitioners and parents that specifically target sedentary behaviour
UK		2014		

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
	British Heart Foundation "Physical activity for children and young people"[aq]		Non-government organization	The purpose of this evidence briefing is to provide an overview of the evidence relating to children and young people (aged 5–18 years) and sedentary behaviour to help commissioners, policymakers, and practitioners influence work in the field. It includes a presentation of sedentary behaviour guidelines and recommendations for multicomponent interventions
UK	British Heart Foundation "Economic Costs of Physical Inactivity Evidence Briefing"[ar]	2012	Non-government organization	This document reviews evidence on exergaming (screen-based activities which combine video game play with exercise), presents exergames as an alternative to sedentary behaviours, and gives some recommendations for designing interventions that incorporate exergaming
UK	British Heart Foundation "Children: Practical Strategies for Promoting Physical Activity"[as]	2013	Non-government organization	The purpose of this briefing is to provide commissioners, physical activity and health professionals, and school staff with evidence-based recommendations and practical strategies to consider when planning, developing, and delivering activities to reduce screen time in children (aged 6–11 years old)
UK	British Heart Foundation National Centre "Factors influencing sedentary behaviours"[at]	2012	Non-government organization	This fact sheet gives an overview of the factors that influence sedentary behaviour among adults and children and presents some recommendations addressed to

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				commissioners, policymakers, and practitioners
Worldwide				
Worldwide	Active Healthy Kids Global Alliance[au]	2014	Non-government organization	The Active Healthy Kids Report Card (now in 14 other countries) provides an overview of nine indicators, including sedentary behaviour. Gaps in research and availability of sedentary behaviour information/data have been identified
Worldwide	World Health Organization "Report of the commission on ending childhood obesity"[av]	2016	Non-government organization	Sedentary behaviour is specifically addressed in two of the recommendations, namely, provide guidance to children and adolescents, their parents, caregivers, teachers, and health professionals on healthy body size, physical activity, sleep behaviours, and appropriate use of screen-based entertainment and provide guidance on appropriate sleep time, sedentary or screen time, and physical activity or active play for the 2–5 years of age group. Responsibilities of the WHO, international organizations, governments, non-government organizations, private sector and philanthropic foundations, and academic institutions are outlined in regard to the implementation of the recommendations
Worldwide	Get. . .standing[aw]		Private	Self-described as a campaign to "increase awareness and education of the dangers of

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
				sedentary working and prolonged sitting time". The organization has websites for Britain, America, Australia, Canada, Europe, and Ireland. It appears to be privately funded with support from health professional organizations, produce suppliers, and professional services

Sources

[a]Australian Government Department of Health (2014) *Australia's Physical Activity and Sedentary Behaviour Guidelines*. http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-strateg-phys-act-guidelines Accessed 12/02/16

[b]Dunstan D, Healy G, Owen N, et al (2014). Action area 5: Prolonged sitting. In: Blueprint for an Active Australia. 2nd edn. Melbourne: National Heart Foundation of Australia

[c]Heart Foundation of Australia. *Sit Less*. http://heartfoundation.org.au/active-living/sit-less. Accessed 12/02/16

[d]Exercise and Sports Science Australia. Physical Activity in the Workplace: A Guide. http://exerciseismedicine.org.au/wp-content/uploads/2012/10/EIM_Workplace_PA_Guide.pdf. Accessed 12/02/16

[e]Thorp A, Dunstan D et al (2009). *Stand Up Australia: Sedentary Behaviour in Workers*. http://www.medibank.com.au/Client/Documents/pdfs/Stand_Up_Australia.pdf. Accessed 12/02/16

[f]Public Health Association of Australia (2014). *Physical Activity Policy*. https://www.phaa.net.au/documents/item/265. Accessed 12/02/16

[g]The Royal Australian College of General Practitioners (2015). Smoking, nutrition, alcohol, physical activity (SNAP): A population health guide to behavioural risk factors in general practice. 2nd edn. Melbourne: The Royal Australian College of General Practitioners

[h]Australian Government Comcare (2014). Sedentary Work Practices Toolkit. Australian Government https://www.comcare.gov.au/preventing/hazards/physical_hazards/sedentary_work/sedentary_work_practices_toolkit. Accessed 12/02/16

[i]Worksafe Tasmania. Sedentary Behaviour. In: *Healthy Workplace Resource Toolkit*. Worksafe Tasmania. http://worksafe.tas.gov.au/__data/assets/pdf_file/0008/288197/06C_Sedentary_behaviour.pdf. Accessed 12/02/16

[j]Queensland Government Department of Education. *Physical Activity in State Schools*. Brisbane: Queensland Government Department of Education. http://education.qld.gov.au/schools/healthy/wellbeing-guidelines/physical-activity.html. Accessed 18/02/16

[k]NSW Ministry of Health. *Developing a Physical Activity Policy*. Sydney: NSW Ministry of Health. https://www.healthykids.nsw.gov.au/teachers-childcare/physical-activity/service-policy.aspx Accessed 18/02/16

[l]Healthy Kids Australia (2014). Is Sport Enough? 2014 Report Card on Physical Activity for Children & Young People. Healthy Kids Australia http://www.activehealthykidsaustralia.com.au/siteassets/documents/ahka_reportcard_longform_web.pdf Accessed 22/02/16

[m]Healy GN, Lawler SP, Thorp A, Neuhaus M, Robson EL, Owen N & Dunstan DW (2012). *Reducing Prolonged Sitting in the Workplace (An evidence review: full report)*, Melbourne: Victorian Health Promotion Foundation. http://www.uq.edu.au/cprc/docs/Reducing_Sitting_Workplace_Full.pdf Accessed 22/02/16

(continued)

[n]Ministry of Health (2015). Eating and Activity Guidelines for New Zealand Adults. Wellington: Ministry of Health. http://www.health.govt.nz/system/files/documents/publications/eating-activity-guidelines-for-new-zealand-adults-oct15_0.pdf. Accessed 12/02/16
[o]Ministry of Education (2007). Physical Activity for Healthy Confident Kids: Guidelines for sustainable physical activity in school communities. NZ Ministry of Education http://www.education.govt.nz/assets/Documents/School/Running-a-school/Health-and-safety/Physical+activity+for+healthy+confident+kids-guidelines-1.pdf. Accessed 15/02/16
[p]Ministry of Health. *Sit Less, Move More*. Wellington: Ministry of Health. http://www.health.govt.nz/your-health/healthy-living/food-and-physical-activity/physical-activity/sit-less-move-more Accessed 15/02/16
[q]Active Canada 20/20 (2012). *Active Canada 20/20: A Physical Activity Strategy and Change Agenda for Canada*. Canada: Active Canada 20/20. http://www.activecanada2020.ca/sections-of-ac-20-20/download-pdf-document. Accessed 15/02/16
[r]The Canadian Society for Exercise Physiology (2011). Canadian Physical Activity and Sedentary Behaviour Guidelines. Ottawa: CSEP. http://www.csep.ca/CMFiles/Guidelines/CSEP_Guidelines_Handbook.pdf. Accessed 17/02/16
[s]ParticipACTION. ParticipACTION website. Toronto: ParticipACTION. http://www.participaction.com/. Accessed on 18/02/16
[t]The Conference Board of Canada (2014). *Moving Ahead: The Economic Impact of Reducing Physical Inactivity and Sedentary Behaviour*. Ottawa: The Conference Board of Canada. http://www.conferenceboard.ca/e-library/abstract.aspx?did=6436. Accessed 22/02/16
[u]American College of Sports Medicine (2011). Reducing Sedentary Behaviors: Sitting Less and Moving More. USA: ACSM. https://www.acsm.org/docs/brochures/reducing-sedentary-behaviors-sitting-less-and-moving-more.pdf. Accessed 18/02/16
[v]American Academy of Pediatrics (2006). Active healthy living: prevention of childhood obesity through physical activity. *Pediatrics*17(5): 1834–1841
[w]American Academy of Pediatrics (2015). The role of the Pediatrician in primary prevention of obesity. Pediatrics 136(1): e275-e292
[x]Institute of Medicine (IOM) (2011). Early Childhood Obesity Prevention Policies. Washington, DC: The National Academies Press. http://www.nap.edu/read/13124/chapter/1#ii. Accessed 18/02/16
[y]National Heart, Blood and Lung Institute. We Can! Website. Bethesda: National Heart, Blood and Lung Institute. http://www.nhlbi.nih.gov/health/educational/wecan/. Accessed 18/02/16
[z]Buscemi, J., Kanwischer, K., Becker, A., Ward, D., Fitzgibbon, M (2015). Society of Behavioral Medicine position statement: early care and education (ECE) policies can impact obesity prevention among preschool-aged children. TBM 5:122–125
[aa]Office of the President of the United States (2010). Solving the Problem of Childhood Obesity Within a Generation: White House Task Force on Childhood Obesity Report to the President. Washington DC: Office of the President of the United States. http://www.letsmove.gov/sites/letsmove.gov/files/TaskForce_on_Childhood_Obesity_May2010_FullReport.pdf. Accessed 05/04/16
[ab]USA Government (2010). *Let's Move* website. USA Government http://www.letsmove.gov/. Accessed on 05/04/16
[ac]Ministry of Health and Welfare health promotion and treatment (2013). *The Physical Activity Guide for Koreans*. Korea: Ministry of Health. http://download.mw.go.kr/front_new/modules/download.jsp?BOARD_ID=1250&CONT_SEQ=291924&FILE_SEQ=140114. Accessed 17/02/1
[ad]Aspetar (2014). Qatar National Physical Activity Guidelines. Qatar: Aspetar Hospital. http://www.namat.qa/NamatImages/Publications/75/QATAR%20PA%20GUIDLINE%20ENGLISH.PDF. Accessed 17/02/16
[ae]World Health Organisation (2015). Belgium Physical Activity Factsheet. Geneva: WHO. http://ec.europa.eu/sport/library/factsheets/belgium-factsheet_en.pdf. Accessed 05/04/2016

(continued)

[af]European Heart Network (2001). Children and Young People – The Importance of Physical Activity. Belgium: European Heart Network. http://ec.europa.eu/health/ph_projects/2000/promotion/fp_promotion_2000_frep_11_en.pdf. Accessed 05/04/2016
[ag]HEPA (Health Enhancing Physical activity) (2008). *EU Physical Activity Guidelines - Recommended Policy Actions in Support of Health-Enhancing Physical Activity*. EU: HEPA. http://ec.europa.eu/sport/library/policy_documents/eu-physical-activity-guidelines-2008_en.pdf. Accessed 05/04/2016
[ah]Ministry of Work, Employment and Health (2011). National Health and Nutrition Program (Programme National Nutrition Sante). France: Ministry of Work, Employment and Health. http://www.mangerbouger.fr/PNNS. Accessed 05/04/2016
[ai]Norden Council of Ministers (2012). Nordic Nutrition recommendation: Integrating Nutrition and Physical Activity. Copenhagen: Norden Council of Ministers. http://norden.diva-portal.org/smash/get/diva2:704251/FULLTEXT01.pdf. Accessed 05/04/2016
[aj]National Association for Sport and Physical Education (2006). *Fact sheet for Childcare Providers*. http://www.getirelandactive.ie/Preschoolers/Resources/Fact-sheet-for-Childcare-Providers.pdf. Accessed 05/04/2016
[ak]Ministry of Health, Social Services and Equity. Physical Activity for Health and Sedentary Behaviour Reduction, Guidelines for the Population (Plain document and summary table). Spain: Ministry of Health, Social Services and Equity
[al]Republic Of Turkey, Ministry of Health, Public Health Institution (2014). *Physical Activity Guidelines for Turkey*. Turkey: Ministry of Health, Public Health Institution
[am]British Heart Foundation National Centre (2012). *Sedentary Behaviour: Evidence Briefing*. Loughborough: British Heart Foundation National Centre. http://www.bhfactive.org.uk/resources-and-publications-item/40/328/index.html. Accessed 05/04/2016
[an]Department of Health, Physical Activity, Health Improvement and Protection (2011). *Start Active, Stay Active-A report on physical activity for health from the four home countries' Chief Medical Officers*. UK: Department of Health, Physical Activity, Health Improvement and Protection. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/216370/dh_128210.pdf. Accessed 05/04/2016
[ao]Public Health England (2014). *Everybody Active, Every Day An Evidence-based Approach to Physical Activity*. London: Public Health England. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/353384/Everybody_Active__Every_Day_evidence_based_approach_CONSULTATION_VERSION.pdf. Accessed 05/04/2016
[ap]British Heart Foundation National Centre (2014). *Physical Activity in the Early Years Evidence Briefing*. Loughborough: British Heart Foundation National Centre. http://www.bhfactive.org.uk/early-years-resources-and-publications-item/40/278/index.html. Accessed 05/04/2016
[aq]British Heart Foundation National Centre (2014). *Physical Activity for Children and Young People Evidence Briefing*. Loughborough: British Heart Foundation National Centre. http://www.bhfactive.org.uk/resources-and-publications-item/40/475/index.html. Accessed 05/04/2016
[ar]British Heart Foundation National Centre (2012). *Economic Costs of Physical Inactivity Evidence Briefing*. Loughborough: British Heart Foundation National Centre. http://www.bhfactive.org.uk/userfiles/Documents/eonomiccosts.pdf. Accessed 05/04/2016
[as]British Heart Foundation National Centre (2013). *Children: Practical Strategies for Promoting Physical Activity Practice Briefing*. Loughborough: British Heart Foundation National Centre. http://www.bhfactive.org.uk/resources-and-publications-item/38/417/index.html. Accessed 05/04/2016
[at]British Heart Foundation National Centre (2012). *Factors Influencing Sedentary Behaviours – Fact Sheet.* Loughborough:British Heart Foundation National Centre. http://www.bhfactive.org.uk/resources-and-publications-item/18/416/index.html. Accessed 05/04/2016
[au]Tremblay MS, et al. (2014). Physical activity of children: A global matrix of grades comparing 15 countries. *Journal of Physical Activity and Health*. 11 (Suppl 1): S113-S125

(continued)

[av]World Health Organization (2016). R*eport of the Commission on Ending Childhood Obesity*. Geneva: WHO. http://apps.who.int/iris/bitstream/10665/204176/1/9789241510066_eng.pdf?ua=1 Accessed 22/02/16

[aw]http://getamericastanding.org/; http://getbritainstanding.org/; http://getaustraliastanding.org/; http://getcanadastanding.org/; http://geteuropestanding.org/; and http://getirelandstanding.com/. Accessed 18/04/2016

25.3.2 Workplace

This environment encompasses the work or study environments for adults. The sedentary behaviour is occupational in nature, and examples include sitting at a desk or in meetings, operating equipment, and driving a vehicle. Given that the typical contemporary workplace is a highly sedentary environment and that employees and organizations have the authority to implement their own policies, this setting is ideal for targeting policy-level change. Employees expect their employers to provide a healthy workplace, and many regulatory agencies require this, making it easier for policy-level change to be encouraged and supported. It will also be beneficial to employers in terms of increased productivity, reduced absenteeism, and improved presenteeism, and may enhance employer/employee relationships [14, 25].

Observational studies have shown that promotion of active workplace policies has been associated with significantly less sedentary time in the workplace [26]. Examples exist of workplace policies that have specifically targeted sedentary behaviour reduction. The most widely used strategy has been providing office workers with height-adjustable or standing desks. A recent systematic review of nine studies showed that these desks, compared with traditional desks, reduced sitting time by 30–120 min/day [27]. The same review examined the effect of policies to promote walking meetings and walking during lunch breaks. Two studies involving 443 participants found that these strategies, compared with a no-strategy control group, reduced sitting by just over 15 min/day, although the differences were not statistically significant. Another study investigated as a natural experiment the impact of relocation of office workers from a 30-year-old building to a new purpose-built building specifically designed with a central staircase on their sedentariness and level of physical activity. The 42 office-based workers significantly decreased their percentage of daily sitting time from 85 to 80% in the new building [20].

Other policies that could be tested to reduce sedentary behaviour in the work environment include:

- Governments providing a tax incentive to reduce the cost of standing desks for employees if employers are unable to provide them.
- Discounted health insurance premiums for those who sit for less than a prescribed level per day. This policy would be easier to implement in countries where it would not require significant changes to the Health Insurance Act due to current community rating requirements.

- Allowing or prompting office workers to break after 30 min of sitting and to stand during meetings.
- Changing workplace health and safety policies around office design that may stipulate all employees need a seated desk or that people are not allowed to stand in public spaces (e.g. lecture theatres in universities).
- For those employees whose occupation involves driving (e.g. truck, bus, and taxi drivers), examining—and where relevant changing—policies that discourage them to take more frequent breaks (say every hour) during their work.

25.3.3 Education

The school and early childhood education and care environments encompass primary and secondary school and early childhood settings as well as structured out-of-school settings such as after-school programmes. These are the environments where the largest amount of evidence exists for targeting sedentary behaviour reduction at a policy level.

In primary schools, it has been shown that the presence of policies such as Park and Stride was associated with less time spent in sedentary behaviour [28]. This scheme involves the provision of a pickup/drop-off point 5–10-min walk from the school, encouraging children to walk part of the way to school. Similar to the workplace environment, providing standing desks to students has been a popular strategy. Hinckson et al. [29] reviewed 13 studies that examined the impact of standing desks in schools. All but one of these studies were in primary school settings. They found that, compared with traditional desks, sitting time was reduced by between 44 and 60 min/day at school. Minges et al. [30] reviewed eight studies conducted in school settings and found that time spent sitting decreased by approximately 60 min/day. Although these studies were not targeting policies, they do provide evidence to support a change in policy, especially given there does not appear to be any detrimental effect on academic learning outcomes or concentration levels, which are important considerations for teachers and schools.

Among secondary school students, Parrish and colleagues [31] provided five standing desks in a classroom in two secondary intervention schools. When combined with educational activities and changes in school assembly and recess policies to promote less sitting, there was 30 min/day greater reduction in sitting in these schools compared with their control schools.

In schools, there have been a number of studies that have examined the impact of policy changes, delivered through the formal curriculum, on sedentary behaviour. These have been reviewed in Chap. 17 and generally result in a significant decrease in screen time and time spent sitting. In addition, Morton et al. [32] reviewed this evidence among adolescents. They investigated factors related to the whole school's policy environment and found that school policies appear to influence sedentary behaviours indirectly, mostly via the school's social environment. According to the authors, findings from these studies indicate a lack of independence and empowerment of the students, which is both encouraged by the school and negatively perceived by the students, impacting upon their sedentary behaviour within school.

Parrish et al. [33] conducted a randomized controlled trial in four Australian primary schools to examine the impact of policy-level changes to promote physical activity and reduce sitting time. These included allowing children with no hat to play in the shade (under the previous policy, they were not allowed to play outside), reducing the mandatory time children had to sit to eat their food at recess and lunch before they could play, and maximizing access to sporting fields during break times for all students. Results showed that children in intervention schools spent significantly less time being sedentary at recess.

Other changes to the school policy environment that could reduce sedentary behaviour include allowing children to stand in assemblies and in classes where there are no standing desks available. In some classes such as science, art, and music, which are often held in non-traditional classrooms, this would only require modifications such as removing stools to allow children to stand. In other classes such as physical education, school policies often stipulate that children should sit at the start of class while attendance is taken. These policies could be modified by allowing students to stand or participate in a more active way (e.g. during a warm-up game) while attendance is taken. It would be of interest to examine if reduced sitting could be achieved through policies that simply allow students to stand (to read, study, or have group meetings) irrespective of the presence of standing desks. That is, create a culture of standing rather than the structural presence of standing desks. A benefit of such an approach would be the negligible cost of implementing such policies. In the United States, school sports policies have also been shown to be related to sedentary behaviour in middle school children. Bocarro et al. [34] found that children who attended schools with an intramural sports policy spent 46.5% of their sport time sedentary compared with 54.2% in schools with a varsity policy.

The area of active design is an emerging field in sedentary behaviour research. It is defined as designing the built environment to promote or at least facilitate less sedentary behaviour [21]. This incorporates aspects such as introducing standing desks and broader environmental changes such as modifying the setup of classrooms and the general internal school environment by increasing the distances between classrooms and activity-generating locations (canteens and lockers). Lanningham-Foster et al. [35] compared both a traditional school environment (sitting only) and a sitting and standing desk environment with an activity-permissive environment that was specifically designed to facilitate active learning. It comprised a hockey rink as a classroom which included standing desks and whiteboards, sports equipment, and policies that allowed the children to freely move around during lessons. It was found that the children in the active-permissive environment spent significantly more time in physical activity compared with the other two classrooms; however, changes in sedentary behaviour were not reported.

In Australia, the New South Wales state Education Department is evaluating the implementation of flexible learning spaces in their schools. This project allows schools to develop and implement their own policies around modifying space and furniture to enable the use of alternative pedagogies to achieve the desired modes of learning. From the schools' perspective, they are interested in the impact of these modifications on student learning, engagement, classroom behaviour, and, to a lesser extent, student well-being. From a public health perspective, it is hypothesized that these modifications in the school policy and physical environment should result in less sitting. Such approaches are likely to be more sustainable as they are being driven by schools and for outcomes that are seen as more important to the role of schools than health promotion.

Although a systematic review of correlates of sedentary behaviour in early childhood education and care settings found no consistent association between the quality of the centre and time spent in objectively measured sedentary behaviour, children were less sedentary in centres that had policies that provided more opportunities for physical activity indoors and outdoors [9]. Observational studies have also found that screen time policies were associated with screen time practices [36] and children's sedentary behaviour [37]. Childcare settings are among the most highly regulated in society. There are many policies or standards that exist to provide services with a guide to what constitutes a high-quality environment. Policy recommendations or standards exist around sedentary behaviour (see, e.g. the Institute of Medicine 2011 and Society for Behavioural Medicine 2015 in Table 25.1), and in some cases, these have been implemented and evaluated at a state or provincial level. Interventions have been conducted in several countries, but most have targeted improving physical activity or active play, not reducing sedentary behaviour. These interventions have involved professional development for educators and have typically included a measure of sedentary behaviour (usually screen time) as an outcome. The findings are inconsistent. Two studies that assessed change in screen time policies in the childcare environment found significant improvements [38, 39]. Of the three studies that examined change in children's television viewing [38, 40, 41], only one found a statistically significant difference between intervention and control groups. The only study that examined changes in prolonged sitting in childcare found no difference between intervention and control centres [38].

Carson et al. [42] examined the impact of a revision to the standards for physical activity and sedentary behaviour in the province of Alberta, Canada, in 2013. This had a specific focus on promoting physical activity and minimizing sedentary time in children. The authors found a small but statistically significant decrease in sedentary time of 3.1 min/h among toddlers from eight centres. This demonstrates the power of a government-led policy initiative in changing sedentary behaviour at a population level.

Similar policy strategies to reduce sedentary behaviour that have been employed in schools could also be tested in childcare settings. These include allowing children to stand during table-based activities and meal times instead of requiring them to sit, moving scrap bins off tables during meal times which would require children to get up to put their food scraps in the bin, and breaking up prolonged sitting (>20 min) with short activity breaks (3–4-min duration) of moderate-to-vigorous activity 3–4 times per day. Data we have collected from a single group study showed that this strategy reduced sedentary time by 15 min/day. In a current study being completed by the authors, educators are finding this policy a highly effective strategy for managing child self-regulation and helping children more effectively transition between activities during the day.

An area in childcare where further reductions in sedentary behaviour could be achieved through policy change is nap time. It has been shown that despite the majority of 3–5-year-old children not needing to nap, many centres still have a "sleep" time where children are required to lie quietly for up to 90 min [43], further adding to their excessive levels of sedentary time. Such practices are associated with a poorer emotional climate and behaviour management in services [44]. Sedentary behaviour could be reduced by training educators to allow children who do not fall asleep after 30 min to leave the sleep area.

The after-school environment includes formal after-school programmes that are typically attended for a 2–3-h period on weekdays during school terms. These programmes are attended by approximately 10% of children aged 5–12 years in countries such as the United States, Australia, Canada, and the United Kingdom. Beets et al. [45] reviewed the effect of after-school programmes on a range of outcomes, including sedentary behaviour. Four studies were included with measures relating to television, computer, and video game use. The pooled effect size was 0.20 (95% CI ¼ −0.04 to 0.44) with only one showing a statistically significant effect on reducing screen-based sedentary behaviour [46]. Two observational studies have examined the relationship between policy factors and sedentary behaviour. Ajja et al. [47] audited 20 after-school programmes and found that sedentary behaviour was not related to the presence of a policy. Beets et al. [48] audited 18 after-school programmes and found that, counter-intuitively, having a physical activity policy was associated with more time in sedentary behaviour. It was suggested that this may be due to the implementation of policies being voluntary in after-school programmes, and the sedentary behaviour observed may be a result of lack of policy implementation rather than policy ineffectiveness. It was recommended that improved support be provided to after-school programmes to assist with policy implementation. It was also noted that none of the policies reviewed contained specific recommendations quantifying the amount of sedentary behaviour. More specific policies which outline the number of minutes which should be spent in sedentary activities are likely to be more successful.

In a study that examined the effect of targeting policy, Beets et al. [49] examined the effect of implementing the Californian After School Physical Activity Guidelines [50]. These guidelines recommend children participate in 60 min of physical activity, 30 min of which should be moderate-to-vigorous in intensity, while attending after-school programmes. Twenty after-school programmes were randomized into intervention or control groups. The intervention involved working with after-school programmes to support their adoption and maintenance of the policy. After 1 year, intervention boys and girls showed significantly greater reductions in sedentary time of around 5 min/day and 3 min/day, respectively.

25.3.4 Transportation and Urban Design

This environment encompasses travel for work, school, household, and recreation activities. It is well known that transportation systems (including land use and community design) are an important influence on sedentary behaviour and that individuals can be less sedentary if communities are designed and built to support safe walking, cycling, and the use of public transport [13]. For instance, Koohsari et al. [51] found that lower overall walkability, lower residential density, and lower intersection density were significantly associated with prolonged sitting in cars. In a review that synthesized current evidence on associations of neighbourhood environmental attributes with adults' sedentary behaviours, Koohsari et al. [52] showed that living in a rural area was recurrently and significantly associated with higher sedentary behaviours, while higher walkability-related measures, better social and safety issues, better neighbourhood aesthetics, having better access to destinations, and better route attributes were associated with less time spent sitting. However, some studies also observed a significant association in the unexpected direction for sedentary behaviour with these last five environmental attributes. Given that the alternative (passive transportation such as car travel) is sedentary, any increase in active transportation is likely to result in an overall reduction in sedentary behaviour.

Providing better public transport infrastructure such as park and ride (bus or train) or park and cycle for those who commute from the outer suburbs of cities is important as it has been shown that prolonged sitting time in cars was higher among those living in outer suburbs [53]. Other policy initiatives could include:

- Providing incentives for adopting policies that support "complete streets" standards in the planning and development of transportation networks [54]. This includes improving street lighting, ensuring footpath continuity, introducing traffic calming devices, and landscaping street areas to improve aesthetics [55].
- Appointing at both state/provincial and federal levels, ministers who are responsible for urban development and who provide policy leadership that incorporates aspects of active transportation and community design.
- Ensuring appropriate funding for improving the infrastructure to support public transport, including providing subsidies to encourage greater use among individuals.
- Providing tax incentives for employers and owners of buildings to provide workplace facilities that support active commuting such as showers, lockers, and bike racks. Tax or financial benefits could also be provided for establishing bicycle-sharing programmes in communities.
- Providing greater infrastructure to increase active transport to reduce sitting time in cars. Urban design variables that have been found to be associated with reduced sitting in cars include a more walkable neighbourhood and, more specifically, a higher net retail area (which indicates more tightly spaced commercial outlets) [51].
- Providing support for schools and employers to implement policy initiatives to make travel to school and work safer. For example, "no car" zones 100 m around

schools forcing parents and children to break up their sitting in cars by having to park and walk.

- Restricting motor vehicle access and the availability of parking at town centres, universities, airports, and other highly congested environments by implementing congestion pricing or other comparable pricing schemes and by providing high-quality public transport access, reclaiming streets in these locations for public transport, designated pedestrian areas, and shared space [54]. Bergman et al. [56] studied the effects of the Stockholm congestion charge trial, which was inconclusive. Although it was found that sitting time was reduced after the introduction of the congestion charge, there was no difference compared to other regions (G €oteborg/Malm€o) where the charge was not introduced. Other studies which have looked at physical activity outcomes of congestion pricing schemes have been of low quality and have not specifically focused on sedentary time [57].

25.3.5 Healthcare

It is important to equip healthcare professionals with the resources and training needed to reduce sedentary behaviour. Coombes et al. [58] reported on an Australian implementation of the global initiative "Exercise is Medicine" (http://exerciseismedicine.org/) that encourages primary care providers to discuss sedentary behaviour reduction with their patients and provides them with resources and referral options. If efficacious, initiatives such as this can hopefully lead to policy changes that provide greater support for sedentary behaviour reduction counselling and referrals in healthcare settings.

Many national societies of healthcare professionals have issued position statements supporting sedentary behaviour reduction policies and programmes and encouraging their members to promote sedentary behaviour reduction in their communities. Examples of these are summarized in Table 25.1. In addition, some such as the Canadian Society for Exercise Physiology (CSEP) have developed sedentary behaviour guidelines which have been endorsed at a national level and driven much of the policy change in this area in Canada.

25.3.6 Nonhome-Based Leisure Settings

This environment includes sedentary recreational activities that are participated in outside the home environment. Examples include spectating at sporting events and going to the movies, concert, or theatre. There are very few studies that have examined the association of policies in these settings with sedentary behaviour. We are also unaware of any policy-level interventions that have been conducted in these settings.

In the absence of such evidence, we suggest that policy-level changes could include examining how occupational health and safety regulations could be modified to allow people to stand in public venues and encourage community entertainment venues to provide non-sitting alternatives.

We can learn from smoking that policy interventions such as promoting sitting-reduced environments (through design, tax incentives), benefits to productivity (workplace) and learning (schools and childcare), limiting access to sitting (having standing meeting rooms), and providing appealing alternatives (walking meetings) could be attractive targets for policy interventions, and similar policy level interventions have been successful in decreasing the prevalence of smoking in the United States.

25.3.7 Public Health

This sector includes government guidelines or recommendations that have been developed to target sedentary behaviour reduction (see Table 25.1 and Sect. 21.3 of this book for a summary of these guidelines). Ideally, governments must commit to and lead a multisectoral effort if we are to see the health and economic benefits of reductions in sedentary behaviour fully realized. Sedentary behaviour guidelines have evolved from television viewing to broader screen use and more recently in countries such as Australia, Canada, Spain, and the United Kingdom to include specific guidance on reducing prolonged sitting (see Table 25.1). Little research has examined the impact of national guidelines on sedentary behaviour reduction, but policy-level strategies that could be targeted to reduce sedentary behaviour include using mass media to promote the guidelines at a population level [2]. This would include using social media and social marketing principles [13].

In addition, policymakers should ensure that sedentary behaviour guidelines are updated every 5 years [59], and health organizations at all levels of government should work together to engage in policy development and advocacy and tailor policy messages to support compliance with the guidelines among diverse settings and populations [13].

25.3.8 Non-government Organizations

In some countries, the absence of strong policy leadership from governments has resulted in key stakeholder organizations "stepping up to the plate" to provide recommendations for how sedentary behaviour can be reduced at a policy level. Examples of these are found in Table 25.1 and include the National Heart Foundation of Australia (Blueprint for an Active Australia and reducing sitting information sheets for children and adults), ParticipACTION, Active Healthy Kids Canada, and the British Heart Foundation (sedentary behaviour evidence brief).

A policy initiative that has been highly successful in driving change in sedentary behaviour reduction has been the National Physical Activity Report Cards coordinated through the Active Healthy Kids Global Alliance. The first "Global Matrix" of grades compared 15 countries from around the world [60] and observed higher levels of sedentary behaviour in high-income countries than low-middle-income countries. In general, it seemed like more policies, structure, and infrastructure were associated with more sedentary behaviour. Counter to the general tone of this chapter, these findings suggest that the best way to decrease sedentary behaviour among children and adolescents is to simply allow them the freedom (permission) to move, roam, and stand at their own free will. The Global Matrix 2.0 will compare 39 countries and will be released in November 2016, providing unprecedented comparisons in sedentary behaviours of children and adolescents from around the world (see www.activehealthykids.org). Organizations and individuals can use these findings and comparisons to advocate for policy-level changes in sedentary behaviours.

25.4 Factors Important to Supporting Policies

While this chapter focuses on the policy level, it is important to note that most effective interventions to reduce sedentary behaviour will incorporate multiple levels of the ecological model [61]. Any policies will also need to overcome the strong social norms to sit in meetings, classes, childcare, cinemas, on public transport (or to avoid public transport if one perceives they will not be able to get a seat), sporting events, and at home while relaxing. These norms are reinforced socially (e.g. questioning why someone is standing in a meeting) and reinforced by environmental manipulations (providing chairs and policies that prohibit standing in a class or cinema). It is also important to have role models in the media where standing is the norm. An example of this in recent years is the trend for newsreaders and those presenting sports and weather on the news to do so standing rather than sitting behind a table.

A challenge for sedentary behaviour research is examining how policy-level influences interact with other levels of influence. For example, policies supporting a reduction in sedentary behaviour in school environments such as standing assemblies or providing a number of standing desks for each classroom will work better when combined with teacher professional development in this area.

Policy level changes to reduce sitting may be motivated by outcomes other than health ones. It may be for increased productivity (work), learning or academic outcomes (school/childcare), transport efficiency (fewer seats on buses or trains), and reduced traffic congestion (fewer cars). These factors need to be considered when developing policy-level initiatives to reduce sedentary behaviour.

25.5 Recommendations and Future Research Directions

On the basis of the evidence summarized in this chapter, the following recommendations are made:

1. Efforts to improve public policies to reduce sedentary behaviour should be evaluated to determine if there is an impact on health behaviour. Reasons for a change in policy not equalling a change in behaviour are the policy being too weak, short lived, incompletely implemented, or only for a limited determinant of sedentary behaviour.
2. Researchers should attempt to disentangle the policy environment from other environments and strategies. For example, in schools, a strategy may be to reduce sitting by having standing-only assemblies. Attention needs to be given to determining when this becomes a policy-level initiative.
3. To more effectively target reducing sedentary behaviour at a policy level, better monitoring and surveillance systems are needed. This would include the correlates and determinants of sedentary behaviour and evaluation of policy approaches to reduce sedentary behaviour. More funding for policy research in these areas is also needed. Investing in the appropriate infrastructure to support policy initiatives (such as monitoring and surveillance systems) will allow stakeholders to measure the impact of any policy-level sedentary behaviour strategies and to track any legislation efforts. Policymakers and researchers also need to work closely to respond promptly to changes in legislation that could be used opportunistically in natural experiments. For example, the work of Carson et al. [42] in Alberta, Canada, responding to changes in legislation in sedentary behaviour in early childhood education and care settings.
4. As policy-level variables are also difficult to manipulate experimentally, new methods are needed to determine how to best test the effect of policy-level change on sedentary behaviour reduction.

25.6 Summary

It is the responsibility of all stakeholders to advocate and engage in policy development to raise the priority of sedentary behaviour reduction in research, policy, and practice. Policy approaches have significant potential in reducing sedentary behaviour, especially at the population level. For them to work, there needs to be a coordinated effort involving individuals, non-government agencies, and all levels of government. Investment in evidence-guided initiatives is crucial, and researchers need to work with other stakeholders to demonstrate that such changes are cost-effective and, in the case of education and workplace environments, do not adversely affect productivity or learning outcomes. For the population, the most effective policy interventions will use theoretical models and involve multilevel, multicomponent strategies in each of the settings described in this chapter. Such approaches are likely required to make demonstrable and sustained changes to engrained social norms that are sedentary-centric and provide the best chance to reduce sedentary behaviour at a national and international level.

References

1. Schmid TL, Pratt M, Howze E. Policy as intervention: environmental and policy approaches to the prevention of cardiovascular disease. Am J Public Health. 1995;85(9):1207–11.
2. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. Am J Prev Med. 2011;41(2):189–96.
3. Owen N, Healy GN, Matthews CE, Dunstan D. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105–13.
4. World Health Organization. Report of the commission on ending childhood obesity. Geneva: WHO; 2016.
5. Glanz K, Rimer BK, Viswanath K. Health behavior and health education: theory, research, and practice. 4th ed. Hoboken: John Wiley & Sons; 2008.
6. Sallis JF, Owen N. Physical activity and behavioural medicine. Thousand Oaks, CA: Sage; 1999.
7. Manini TM, Carr LJ, King AC, Marshall S, Robinson TN, Rejeski WJ. Interventions to reduce sedentary behavior. Med Sci Sports Exerc. 2015;47(6):1306–10.
8. Robinson TN, Sirard JR. Preventing childhood obesity: a solution-oriented research paradigm. Am J Prev Med. 2005;28(2 Suppl 2):194–201.
9. Tonge KL, Jones RA, Okely AD. Correlates of children's objectively measured physical activity and sedentary behavior in early childhood education and care services: A systematic review. Prev Med. 2016;89:129–39.
10. Neelon SEB, Taveras EM, Østbye T, Gillman MW. Preventing obesity in infants and toddlers in child care: results from a pilot randomized controlled trial. Matern Child Health J. 2014;18(5): 1246–57.
11. Puder J, Marques-Vidal P, Schindler C, Zahner L, Niederer I, Bürgi J, et al. Effect of multidimensional lifestyle intervention on fitness and adiposity in predominantly migrant preschool children (Ballabeina): Cluster randomised controlled trial. BMJ. 2011;343:1–11.
12. Sallis JF, Owen N. Ecological models of health behavior. In: Glanz K, Rimer BK, Lewis FM, editors. Health behavior and health education: theory, research, and practice. San Francisco: Jossey-Bass; 2002. p. 462–84.
13. US National Physical Activity Plan Coordinating Committee. National Physical Activity Plan for the United States 2010.
14. National Heart Foundation of Australia. Blueprint for an active Australia. Melbourne, Australia: National Heart Foundation of Australia; 2014.
15. Dietz WH, Gortmaker SL. Preventing obesity in children and adolescents. Annu Rev Public Health. 2001;22:337–53.
16. Gortmaker SL, Cheung LWY, Peterson KE, Chomitz G, Cradle JH, Dart H, et al. Impact of a school-based interdisciplinary intervention on diet and physical activity among urban primary school children. Arch Pediatr Adolesc Med. 1999;153:975–83.
17. Hinkley T, Cliff DP, Okely AD. Reducing electronic media use in 2–3 year-old children: feasibility and efficacy of the Family@ play pilot randomised controlled trial. BMC Public Health. 2015;15:779.
18. Robinson TN, Borzekowski DLG. Effects of the SMART classroom curriculum to reduce child and family screen time. J Commun. 2006;56(1):1–26.

19. Cornelius M, Carrie Armel K, Hoffman K, Allen L, Bryson SW, Desai M, et al. Increasing energy- and greenhouse gas-saving behaviors among adolescents: a school-based cluster-randomized controlled trial. Energ Effic. 2014;7:217–42.
20. Jancey JM, McGann S, Creagh R, Blackford KD, Howat P, Tye M. Workplace building design and office-based workers' activity: a study of a natural experiment. Aust N Z J Public Health. 2016;40(1):78–82.
21. Ucci M, Law S, Andrews R, Fisher A, Smith L, Sawyer A, et al. Indoor school environments, physical activity, sitting behaviour and pedagogy: a scoping review. Build Res Inf. 2015;43(5): 566–81.
22. British Heart Foundation National Centre. Sedentary behaviour: evidence briefing. Loughborough: Loughborough University: British Heart Foundation National Centre; 2012.
23. Tremblay MS, LeBlanc AG, Carson V, Choquette L, Connor Gorber S, Dillman C, et al. Canadian sedentary behaviour guidelines for the early years (aged 0–4 years). Appl Physiol Nutr Metab. 2012;37(2):370–80.
24. Department of Health PA, Health Improvement and Protection. Start active, stay active - A report on physical activity for health from the four home countries' Chief Medical Officers. London, UK; 2011.
25. Thorp A, Dunstan D, Clark B, Gardiner P, Healy G, Keegel T, et al. Stand Up Australia: Sedentary Behaviour in Workers. Melbourne: Medibank; 2009.
26. Crespo NC, Sallis JF, Conway TL, Saelens BE, Frank LD. Worksite physical activity policies and environments in relation to employee physical activity. Am J Health Promot. 2011;25(4): 264–71.
27. Shrestha N, Kukkonen-Harjula KT, Verbeek JH, Ijaz S, Hermans V, Bhaumik S. Workplace interventions for reducing sitting at work. Cochrane Database Syst Rev. 2016;3:CD010912.
28. Van Sluijs EM, Jones NR, Jones AP, Sharp SJ, Harrison F, Griffin SJ. School-level correlates of physical activity intensity in 10-year-old children. Int J Pediatr Obes: IJPO: an official journal of the International Association for the Study of Obesity. 2011;6(2–2):e574–81.
29. Hinckson E, Salmon J, Benden M, Clemes SA, Sudholz B, Barber SE, et al. Standing classrooms: research and lessons learned from around the world. Sports Med. 2015;1-11:977.
30. Minges KE, Chao AM, Irwin ML, Owen N, Park C, Whittemore R, et al. Classroom Standing Desks and Sedentary Behavior: A Systematic Review. Pediatrics. 2016;137(2):e20153087.
31. Parrish AM, Cliff DP, Salmon J, Trost SG, Batterham M, Okely AD. Breaking up prolonged sitting among secondary school students: The Stand Up for Health cluster randomized controlled trial. 2016 (under review).
32. Morton KL, Atkin AJ, Corder K, Suhrcke M, van Sluijs EM. The school environment and adolescent physical activity and sedentary behaviour: a mixed-studies systematic review. Obes Rev. 2016;17(2):142–58.
33. Parrish AM, Okely AD, Batterham M, Cliff D, Magee C. PACE: A group randomised controlled trial to increase children's break-time playground physical activity. J Sci Med Sport/Sports Medicine Australia. 2016;19(5):413–8.
34. Bocarro JN, Kanters MA, Cerin E, Floyd MF, Casper JM, Suau LJ, et al. School sport policy and school-based physical activity environments and their association with observed physical activity in middle school children. Health Place. 2012;18(1):31–8.
35. Lanningham-Foster L, Foster RC, McCrady SK, Manohar CU, Jensen TB, Mitre NG, et al. Changing the school environment to increase physical activity in children. Obesity. 2008;16(8): 1849–53.
36. Erinosho T, Hales D, Vaughn A, Mazzucca S, Ward DS. Impact of Policies on Physical Activity and Screen Time Practices in 50 Child-Care Centers in North Carolina. J Phys Act Health. 2016;13(1):59–66.
37. Hesketh KR, van Sluijs EM. Features of the UK childcare environment and associations with preschooler's in-care physical activity. Prev Med Rep. 2016;3:53–7.
38. Finch M, Wolfenden L, Falkiner M, Edenden D, Pond N, Hardy LL, et al. Impact of a population based intervention to increase the adoption of multiple physical activity practices

in centre based childcare services: a quasi experimental, effectiveness study. Int J Behav Nutr Phys Act. 2012;9:101.
39. Lyn R, Maalouf J, Evers S, Davis J, Griffin M. Nutrition and physical activity in child care centers: the impact of a wellness policy initiative on environment and policy assessment and observation outcomes, 2011. Prev Chronic Dis. 2013;10:E83.
40. De Silva-Sanigorski A, Elea D, Bell C, Kremer P, Carpenter L, Nichols M, et al. Obesity prevention in the family day care setting: impact of the Romp & Chomp intervention on opportunities for children's physical activity and healthy eating. Child Care Health Dev. 2011;37(3):385–93.
41. Jones J, Wyse R, Finch M, Lecathelinais C, Wiggers J, Marshall J, et al. Effectiveness of an intervention to facilitate the implementation of healthy eating and physical activity policies and practices in childcare services: a randomised controlled trial. Implement Sci: IS. 2015;10:147.
42. Carson V, Clark D, Ogden N, Harber V, Kuzik N. Short-term influence of revised provincial accreditation standards on physical activity, sedentary behavior, and weight status in Alberta, Canada child care centers. Early Childhood Educ J. 2015;43(6):459–65.
43. Staton S, Smith S, Pattinson C, Thorpe K. Mandatory naptimes and group napping trajectories in childcare: An observational study. Unpublished manuscript. 2014;
44. Pattinson CL, Staton SL, Smith SS, Sinclair DM, Thorpe KJ. Emotional climate and behavioral management during sleep time in early childhood education settings. Early Child Res Q. 2015;29:660–8.
45. Beets MW, Beighle A, Erwin HE, Huberty JL. After-school program impact on physical activity and fitness: a meta-analysis. Am J Prev Med. 2009;36(6):527–37.
46. Robinson TN, Killen JD, Kraemer HC, Wilson DM, Matheson DM. Dance and reducing television viewing to prevent weight gain in African-American girls: the Stanford GEMS pilot study. Ethn Dis. 2003;13(Suppl 1):S165–77.
47. Ajja R, Clennin MN, Weaver RG, Moore JB, Huberty JL, Ward DS, et al. Association of environment and policy characteristics on children's moderate-to-vigorous physical activity and time spent sedentary in afterschool programs. Prev Med. 2014;69(Suppl 1):S49–54.
48. Beets MW, Huberty J, Beighle A, Moore JB, Webster C, Ajja R, et al. Impact of policy environment characteristics on physical activity and sedentary behaviors of children attending afterschool programs. Health Education & Behavior: the official publication of the Society for Public Health Education. 2013;40(3):296–304.
49. Beets MW, Weaver RG, Turner-McGrievy G, Huberty J, Ward DS, Pate RR, et al. Making Policy Practice in Afterschool Programs: A Randomized Controlled Trial on Physical Activity Changes. Am J Prev Med. 2015;48(6):694–706.
50. Education CDo. California after school physical activity guidelines. Sacramento, CA: California Department of Education; 2009.
51. Koohsari MJ, Sugiyama T, Kaczynski AT, Owen N. Associations of leisure-time sitting in cars with neighborhood walkability. J Phys Act Health. 2014;11(6):1129–32.
52. Koohsari MJ, Sugiyama T, Sahlqvist S, Mavoa S, Hadgraft N, Owen N. Neighborhood environmental attributes and adults' sedentary behaviors: Review and research agenda. Prev Med. 2015;77:141–9.
53. Sugiyama T, Merom D, van der Ploeg HP, Corpuz G, Bauman A, Owen N. Prolonged sitting in cars: prevalence, socio-demographic variations, and trends. Prev Med. 2012;55(4):315–8.
54. Heath GW, Brownson RC, Kruger J, Miles R, Powell KE, Ramsey LT, et al. The effectiveness of urban design and land use and transport policies and practices to increase physical activity: a systematic review. J Phys Act Health. 2006;3:S55.
55. Heath GW, Parra DC, Sarmiento OL, Andersen LB, Owen N, Goenka S, et al. Evidence-based intervention in physical activity: lessons from around the world. Lancet. 2012;380(9838): 272–81.
56. Bergman P, Grjibovski AM, Hagströmer M, Patterson E, Sjöström M. Congestion road tax and physical activity. Am J Prev Med. 2010;38(2):171–7.

57. Brown V, Moodie M, Carter R. Congestion pricing and active transport - evidence from five opportunities for natural experiment. J Transp Health. 2015;2(4):568–79.
58. Coombes JS, Law J, Lancashire B, Fassett RG. “Exercise is Medicine”: curbing the burden of chronic disease and physical inactivity. Asia Pac J Public Health. 2015;27(2):NP600-5.
59. Tremblay MS, Haskell WL. From science to physical activity guidelines. In: Bouchard C, Blair SN, Haskell WL, editors. Physical activity and health. 2nd ed. Champaign, IL: Human Kinetics; 2012. p. 359–78.
60. Tremblay MS, Gray CE, Akinroye K, Harrington DM, Katzmarzyk PT, Lambert EV, et al. Physical activity of children: a global matrix of grades comparing 15 countries. J Phys Act Health. 2014;11(Suppl 1):S113–25.
61. Sallis JF, Owen N, Fisher EB. Ecological models of health behavior. Health behavior and Health Education: Theory, Research, and Practice. 2008;4:465–86.

Chapter 26
Dynamics of Sedentary Behaviours and System-Based Approach: Future Challenges and Opportunities in the Life-Course Epidemiology of Sedentary Behaviours

Sebastien F. M. Chastin, Sofie Compernolle, Marieke De Craemer, Jean-Michel Oppert, and Greet Cardon

Abstract This chapter challenges our current thinking about sedentary behaviour and offers new paradigms to move forward to understand the complex nature of sedentary behaviours and their determinants. Sedentary behaviours are ubiquitous and changing in nature over time: with advances in media and IT technology, television (TV) time is decreasing, but overall screen time is growing. Understanding the non-linear temporal dynamics of sedentary behaviours and how people accumulate, or break, sitting time appears a crucial step to design innovative strategies. Since multiple factors at different levels (proximal, distal) are interacting to drive sedentary time, new perspectives combining a life-course perspective and

S. F. M. Chastin (✉)
School of Health and Life Science, Glasgow Caledonian University, Glasgow, UK and Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium
e-mail: Sebastien.Chastin@gcu.ac.uk

S. Compernolle
Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium and Flemish Research Foundation, Brussels, Belgium
e-mail: Sofie.Compernolle@ugent.be

M. De Craemer
Department of Rehabilitation Sciences, Ghent University, Ghent, Belgium and Flemish Research Foundation, Brussels, Belgium
e-mail: Marieke.DeCraemer@ugent.be

J.-M. Oppert
Department of Nutrition, Pitié-Salpêtrière Hospital, Assistance Publique-Hôpitaux de Paris (AP-HP), Sorbonne Université Institute of Cardiometabolism and Nutrition (ICAN), Paris, France
e-mail: Jean-Michel.Oppert@aphp.fr

G. Cardon
Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium
e-mail: Greet.Cardon@ugent.be

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_26

complexity science are needed. System-based approach and adaptive dynamical systems modelling will help model the interaction between factors and feedback loops. A system-based framework for the study of sedentary behaviours called SOS (Systems of Sedentary behaviours) has been established by a transdisciplinary research group within the framework of the European DEDIPAC Knowledge Hub. Novel methods of enquiry are required to progress the field, including methodologies for analysis such as probabilistic modelling techniques (Bayesian Networks), simulation studies investigating different scenarios of possible societal changes and their effect on sedentary behaviours, and innovations in measuring accurately other dimensions such as context and type of sedentary behaviours. Finally, future opportunities for innovative data collection (e.g., ecological momentary assessment) and analysis (big data) and innovative interventions (natural experiments, just-in-time adaptive interventions, solutionist, and participatory approach) are highlighted for their potential to benefit sedentary behaviours research and work more efficiently towards public health solutions to tackle this new threat of modern life.

What Is New?

- A realist perspective was added as a suitable approach to deal with complex behaviours—such as sedentary behaviour.
- Ecological momentary assessment has been introduced as a promising alternative to acquire context-specific sedentary behaviour data.
- The development and implementation of just-in-time adaptive interventions to reduce sedentary behaviour was included as a result of IoT.

26.1 Introduction: Sedentary Behaviours—the Need for a Comprehensive Perspective

Societal changes have made sitting the dominant posture during most activities of daily life; learning, working, travelling, caring, and taking leisure time. Sedentary behaviours are ubiquitous throughout the day, and they concern everybody **from** infants to older adults. These changes have been crept up on us almost unnoticed until very recently. Devising solutions to tackle this issue in a world likely to change at a faster pace will require that we understand the dynamics of sedentary behaviours throughout the day, throughout the life-course, and also across regions of the world. It will also require that we understand the very complex interplay between biological, environmental, and societal processes that drive these dynamics. This clearly needs a more comprehensive perspective, a change in our thinking, and updating the paradigms we use.

In the last twenty years, the epidemiology of sedentary behaviours has evolved very rapidly since its first definition by [1] (see also Chap. 1 for the definition of sedentary behaviour and Chap. 2 for the descriptive epidemiology of sedentary behaviour). Chapters 7–14 of this book give a summary of the current evidence base on the relationship between sedentary behaviours and a variety of health outcomes including increased adiposity, cardiovascular disease, metabolic syndrome and diabetes, some cancers, other chronic diseases, and mortality. This first phase of the sedentary behaviours' research agenda, as described by [2], has provided consistent convincing evidence identifying "too much sitting" as a distinct health risk, and the field is ready to move towards finding effective solutions to address this public health concern.

The next phase of the research agenda will have to focus on gaining a deeper understanding of sedentary behaviours themselves and their determinants in order to inform public health interventions and policies [3]. Chaps. 2, 15, 16, and 28 of this book provide accounts of early research in this phase, guided by the behavioural epidemiology framework [4] and research recommendations [2, 3] inspired by the physical activity literature. In this chapter, we examine how the complex nature of sedentary behaviours challenges our current thinking and paradigms in moving forward. To date, we have mainly either considered sedentary behaviours in a global way/as a whole or considered sedentary behaviours to be equal. We studied them in isolation from other behaviours occurring throughout the day, using mostly linear methods and with a deterministic causal paradigm. However, sedentary behaviours are extremely diverse, changing, pervasive, and non-linear [5]. As much as there is a host of health consequences of sedentary behaviours, the determinants of sedentary behaviours are numerous, heterogeneous, dynamic, and with varying impact.

New perspectives, combining life-course and complex dynamics systems approaches might enable us to meet these challenges in this new phase of research. Finally, we look at how future opportunities for innovative data collection (e.g., ecological momentary assessment) and analysis (e.g., functional data analysis, compositional data analysis, machine learning) and innovative interventions (e.g., natural experiments, just-in-time adaptive interventions, solutionist approach) might benefit sedentary behaviours research.

26.1.1 Heterogeneous Behaviours

The reader will note that throughout this chapter we use the plural for sedentary behaviours, while most of the literature refers to the singular sedentary behaviour. This is to reflect the emerging notion that sedentary behaviours are heterogeneous, which is already present in the most widely accepted definition [6]. It is actually an umbrella term for a very wide array of daily activities which are performed in sitting or reclining postures. While most research has considered sedentary behaviours as a single collective behaviour, some research has emerged showing that not all sedentary behaviours have the same effect on health or are equally modifiable. For example, different associations have been found for different types of sedentary behaviours. In comparative studies, screen-based sedentary behaviours were found to be negatively associated with cardiovascular health outcomes, while this was not the case for non-screen-based sedentary behaviours [7, 8]. It is also conceivable that some sedentary behaviours might have health-enhancing effects (we all need to rest and relax sometimes, and this might have salutogenic effects).

While it is convenient in epidemiology to think collectively about sedentary behaviours as a single homogenous behaviour because it is easier to deal with in statistical modelling, some authors have argued that this could lead to unwanted demonizing of sitting. Indeed, some but not all sedentary behaviours might warrant changing or reducing. For example, Leask et al. [9] argued that some sedentary behaviours, such as reading or doing cross-words, contribute little to the total amount of time older adults spend sitting and might have health benefits in terms of cognition which outweigh potential other health risk [10]. Similarly, in children, there is reticence in modifying study time, and some classroom sitting time might be much harder to modify [11, 12], while targeting screen-based behaviours show more promises for obesity prevention [13].

Most interventions to reduce sedentary behaviours have tackled all sitting time homogeneously [14, 15], so there is a real dearth of information about which type of behaviour is more modifiable. However, it is clear from both quantitative and qualitative research that determinants differ between sedentary behaviours [16–19].

It is clear that in the future we will need to engage with the heterogeneity of sedentary behaviours to more precisely target those that are negative to health and modifiable. In the next sections, we look at technical advances, methodological investments, and opportunities that can contribute to achieving this.

26.1.2 The Changing Nature of Sedentary Behaviours

Early research in sedentary behaviours was prompted by concern about the health consequences of television (TV) and videocassette recorder (VCR) technology becoming more widely available and used [20]. Advances in media and IT technology are now very swift and so sweeping that it is fundamentally changing how and why we are sedentary.

Recent international surveys reveal that screen time sedentary behaviours are growing [21]. For example, with the rise of online media services such as Netflix, Hulu, and Amazon Video, with which the viewer can watch TV shows and movies on-demand, binge-watching is becoming a popular cultural phenomenon. Binge-watching, also called binge-viewing or marathon-viewing, is the practice of watching TV for a long time span, usually watching between 2 and 6 episodes of the same TV show in one sitting [22]. Furthermore, media multitasking like being on Facebook while watching TV has become very common [23, 24].

It was shown in many studies that having a TV in the bedroom was detrimental for excessive amounts of TV viewing, mainly in children and adolescents [18]. However, this seems no longer relevant as nowadays TV viewing is increasingly getting replaced by using a computer, tablet, or smartphone to watch TV or to chat, be on the internet, email.

So younger generations might be exposed to more sedentary behaviours of a very different nature compared to the generations we have built our evidence from. This also affects other generations as work practices for adults are changing and the "new" older adults from the Baby Boomer generation are some of the highest consumers of screen technology [25].

Future research needs to take into account the changing sedentary behaviours as its impact and implications are currently hard to predict and grasp.

26.1.3 Pattern of Accumulation of Sedentary Time

Understanding the temporal dynamics of sedentary behaviours and how people accumulate sitting time is crucial if we seek to modify it [26] and measure it accurately. This is one area where the complexity of sedentary behaviours is the most striking. Yet the way in which we measure, analyse sedentary behaviours, and conceptualize how we could modify them has to date mostly been based on linear assumption. Indeed, often by analogy to the FITT principle of physical activity (frequency, intensity, time, and type), we consider that the time spent sedentary is simply how often we sit times how long we sit for on average. However, the accumulation of sedentary time is a highly non-linear process and follow power law distributions [5, 27], which is the hallmark of complex systems dynamics present in numerous aspect of human physiology and behaviour [28, 29]. This means that people do not sit following regular and predictable patterns in time and do not have preferred or average sitting bout duration. Instead, sitting is accumulated in many frequent short bouts and very few long ones, which however contribute substantially more time to the total sitting time [5]. This is easy to understand, during the day, it can theoretically fit many short one-minute bouts of sitting but only eight four-hour long bouts. Yet a single four-hour bout contributes much more time to the total sitting time compared to numerous one-minute bouts. It would actually take 480 one-minute bouts to accumulate as much sedentary time as a 4 hour long box-set binge-watching session!

One of the important consequences of this non-linear dynamics is that it makes sedentary time extremely variable over time [30]. In turn, this has consequences in epidemiological modelling and for measurement and assessing behaviour change in the intervention [31]. More importantly, this non-linear dynamics drives the total sitting time, which is associated with poor health outcomes, and the way in which people accumulate sitting time might be a contributing factor in this relationship [32], as illustrated by the concept of breaks in sedentary time [33].

26.1.4 Interdependence

To date, the health consequences and determinants of sedentary behaviours have been largely studied in isolation of other health behaviours, such as physical activity and sleep or nutrition. In part, this is due to the fact that initially scientists struggled to delineate the specificity of sedentary behaviours. A substantial body of work has attempted to establish that the effect or association between sedentary behaviours and health are independent of time spent in physical activities in order to convince the scientific community that sedentary behaviours are not just seen as inactivity but as a different concept and class of behaviour worth of public health attention. In part, it is also due to the prevailing deterministic and causal paradigm that requires variables of interest to be independent. This assumption of independence is now being revisited as it is seen as a limitation in advancing the epidemiology of sedentary behaviours [34, 35]. Several authors have argued that sedentary behaviours need to be studied in conjunction with the rest of the 24-hour daily activity [36] and that patterns including physical activity could be delineated [37]. Others have examined the assumption of independence and suggested that it does not reflect the fact that time is limited during the day and that time spent in different behaviours are necessarily co-dependent [35, 38]. Finally, there is also evidence that nutrition and sedentary behaviours interact and that this might be one of the mechanisms by which time spent sedentary influences health [39–43].

26.1.5 Determinants of Sedentary Behaviours

The most recent systematic reviews [18, 44, 45] show that the current evidence on the determinants and factors influencing sedentary behaviours is limited, but that it is clear that multiple factors at different levels are interacting to drive sedentary time. The complexity of the web of influence acting on sedentary behaviours is already present in the current socio-ecological model of sedentary behaviour [3]. However, this neglects how determinants change within a day, from day to day, from week to week, as well as over the life course. In addition, research has focused largely on proximal factors and studied them as independent, not sufficiently taking into account feedback loops and interactions. We have barely attempted to understand more distal factors and how those interact. Consequently, we cannot predict or spot population secular trends in sitting time, which are non-linear [46–48] and see sudden changes and discontinuities. A good example is the emergence of binge-watching series (also known as box sets). In Sect. 26.1, we discussed how technological advances are changing the nature of sedentary behaviours, but this is also accompanied with a non-linear change in sitting time. However, the technology is not enough to explain these changes. Actually, a combination of technological advances (DVD, video on demand), increased piracy, and consequent drive by production houses to produce better material to fight piracy and retain economical gains has greatly enhanced the viewing experience. In turn, this has led to an explosion and social normalization of binge-watching, which several years ago would have been neither technically possible nor socially acceptable.

To date, there are no anthropological, historical, or economic studies that could help us understand these trends and identify the most powerful key macrolevel drivers. We often blame technology, industrialization, urbanization, and automation but without solid evidence or understanding of how these interact. More careful and multidisciplinary investigation is required to understand the complexity of influence driving sedentary time if we want to design innovative solutions to counter these global trends linked to technological and societal progress.

26.2 Tackling the Complexity of Sedentary Behaviours

In view of the characteristics of sedentary behaviours highlighted above, it is difficult to fathom how we could make efficient progress without engaging with complexity and change in part the way we conceptualize sedentary behaviours, the methods and models we use. In addition, it seems clear that new scientific disciplines need to engage in sedentary behaviours' research. In the following sections, we highlight some of the key concepts, methods, and recent developments that might enable us to tackle the complexity of sedentary behaviours and work more efficiently towards public health solutions.

26.2.1 Dynamic Complex Systems Approach: Application to Sedentary Behaviours

As most public health research and practice, the understanding and modification of sedentary behaviours generally has been guided by a linear and reductionist paradigm. This dominant conceptual thinking and epistemology posits that a problem can be fully described and explained by causal pathways that predict the problem at any point in time and under any circumstances [49]. The approach assumes that cause and effect are proportionally linked either directly or through a more complicated cascading pathway. Finding causal pathways can identify mechanisms explaining the consequence of sedentary behaviours on health and inform about possibilities for intervention.

This approach has been very useful in informing public health research and policy when dealing with communicable diseases and enabled to establish the current evidence base on the association between sedentary behaviours and health. However, limitations of this paradigm have come to the fore when dealing with problems such as chronic diseases, which involve endogenous effects, feedback loops, and

Table 26.1 Characteristics of complex systems and problems

Domain	Simple or complicated problems	Complex systems and problems
Relationships	Linear	Non-linear
Common statistical distributions	Normality	Non-normal, power law, log-normal
Perspective	Reductionist	Holistic
Factors	Independent	Interdependent, with feedback
Paradigm	Deterministic	Stochastic, probabilistic
Temporality	Static or discretely longitudinal	Dynamic, adaptive, self-organizing
Behaviour	Homogeneous	Heterogeneous

non-linear dynamics resulting from the interactions of multiple heterogeneous factors [50].

In the past decade, the exciting, interdisciplinary field of "complexity science" has emerged as an alternative perspective [51]. The science of complexity is not a single theory but rather a different epistemology coming from an array of disciplines that provide a collection of important concepts and tools for responding to these challenges. Amongst those, system-based approach and adaptive dynamical systems modelling are increasingly used to address particularly persistent and complex issues in health care and public health [52–54]. One of the most famous applications of complexity science in public health is probably the FORESIGHT model of obesity [55].

A complex system or problem must be distinguished from a complicated problem and is characterized by the features in Table 26.1.

In the following section, we explore how this applies to the epidemiology of sedentary behaviours and discuss some recent advances that engage with the complexity of these behaviours and how future developments might contribute to finding solutions.

26.2.2 System-Based Approach to the Determinants of Sedentary Behaviours, Intervention, and Policy

Dealing with sedentary behaviours as a complex adaptive system, as it has been done in other public health problems [52–54] might provide the next step of change and address some of the limitations of current socio-ecological models that inform sedentary behaviours research [56]. While these models consider that sedentary behaviours are driven by multiple factors from different spheres of influence, they still assume that there is a hierarchical and linear structure of causation. We need to explore new paradigms and invest in developing models that implicitly recognize the

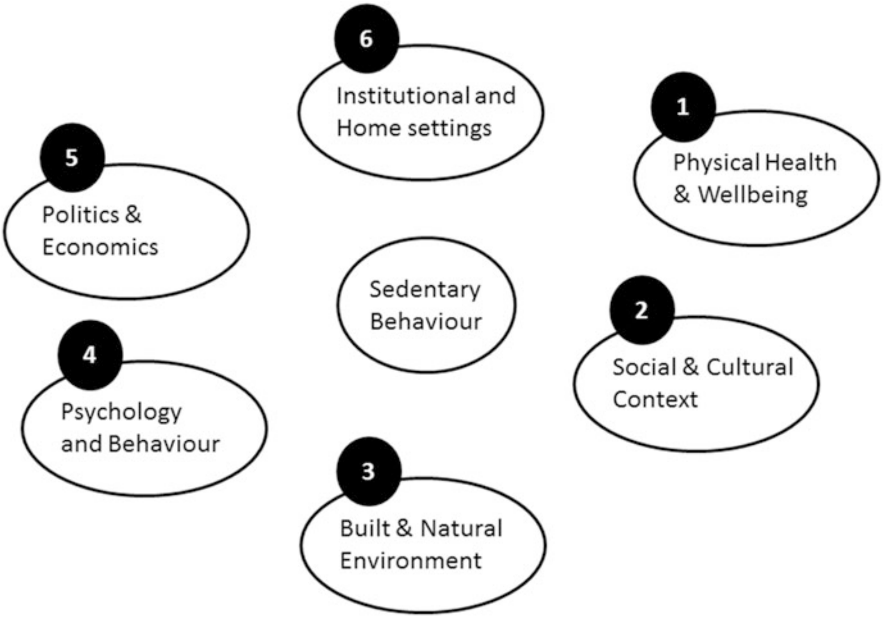

Fig. 26.1 SOS framework: Systems of sedentary behaviour with six cluster of determinant influencing sedentary behaviour

interaction between factors and feedback loops. A system-based approach enables this and also has the added benefit of focusing on systems rather than the individual.

Recently the Determinants of Diet and Physical Activity (DEDIPAC) Knowledge Hub [57] developed a transdisciplinary system-based framework for the study of sedentary behaviours called SOS (Systems Of Sedentary behaviours) [58] (Fig. 26.1.) This framework was developed by merging evidence and eminence in an international consensus process with the most multidisciplinary panel ever assembled on sedentary behaviours. This framework considers sedentary behaviours as a system of six interacting clusters of factors. The clusters are:

- Physical Health and Wellbeing: Cluster encompassing everything related to an individual/groups health and wellbeing, including (but not limited) to their personal health status. For example, this cluster also covers systems for the provision of health care or health enhancing facilities.
- Social and Cultural Context: Cluster referring to the social environment individuals/groups live in, the culture they were educated in and interact with.
- Built and Natural Environment: Cluster referring to the physical environment individuals/groups live in and interact with. This includes the natural environment factors such as weather or built environment such as the physical layout of towns.
- Psychology and Behaviour: Cluster referring to individuals/groups psychological and behavioural traits such as motivations and attitudes.

- Politics and Economics: Cluster encompassing political and economic factors that influence the civic life of individuals/groups at international, national, regional, and individual scales.
- Institutional and Home Settings: Cluster encompassing all factors influencing the physical and human organization of institutions (e.g., the home, schools, workplace, care homes) individuals/groups live in or interact with.

The framework has been used to guide secondary analyses of European cohort studies and set research priorities. The framework also forms the base for modelling and simulation studies, identifying tipping points, and developing strategies to reduce sedentary behaviours.

26.2.3 Novel Analytical Methods

In addition to the basic description of sedentary behaviour data analysis in Chap. 4 of this book, there are a host of novel analytical approaches that are yet to be used in order to deal with the complex nature of sedentary behaviours and improve our understanding. In terms of dealing with the interdependence of sedentary behaviours and the interrelationships between sedentary behaviours, physical activity, and sleep, the GRANADA consensus decision tree has recently been developed by a team of experts [59]. The decision tree includes novel analytical approaches and aims to assist researchers' decision-making. One of these analytical approaches is compositional data analysis. Compositional data analysis considers the distribution of time throughout the day as a single mathematical object that can be used in the statistical model and has been advocated [35] because it is congruent with reality and provides a solid mathematical formalism with a long history [60]. Integrating sedentary behaviours into multiple behaviour *Healthy lifestyle profiles as an integrated approach also looks promising* [61]. *In terms of epidemiological modelling to understand the determinants of sedentary behaviours adopting probabilistic modelling techniques such as Bayesian Networks might be very informative especially if this is coupled with simulation studies investigating different scenarios of possible societal changes and their effect on sedentary behaviours. This is a combined approach that is being used in obesity research* [54, 55, 62].

26.2.4 Solutionist Approach, Realist Perspective, and Natural Experiments

Given the complexity of factors influencing sedentary behaviours, there are almost infinite combinations of factors that we could try to address in intervention and experimental studies. Following the usual medical research route of proof of concept trial followed by feasibility, efficacy trials, and then multi-centre trials, it would take a very long time and a lot of resources to locate in this very vast parameter space of possible intervention, which one is optimal or even identify those that work for sedentary behaviours. Adopting a solutionist approach might be better suited to this type of complex problem [63]. Enabling local actors to define localized and tailored solutions in very specific contexts (work, education, transport) and for different population and life stages might allow us to sample this large parameter space more efficiently and get to a feasible solution quicker. Next, applying a realist perspective might be superior to more traditional perspectives when dealing with complex behaviours such as sedentary behaviours. The realist approach is a theory-driven approach that moves away from generalizable claims and universal regularities towards exploratory questions about how behaviours are shaped by particular contexts and about which mechanisms are triggered when contexts are conducive [64]. A realist thinker uses retroductive reasoning (i.e., going back from, below, or behind observed patterns to discover what produces them) to unearth the causal mechanisms underlying a specific phenomenon, or in the case of sedentary behaviours, a specific behaviour. Both processes could be complemented with careful analyses of societal changes and natural experiments, which might be facilitated by advances in big data and the Internet of Things discussed below. This, however, requires to let go in part from the positivist ontology that epidemiology is founded upon.

26.2.5 Measuring the Context of Sedentary Behaviours

Good measurement methods for sedentary behaviours and their determinants are key for sedentary behaviours research and tackling the heterogeneity of sedentary behaviours. In the next phase of research we might have to reconsider how we measure sedentary behaviours [65]. One of the important shifts is to change the emphasis from measuring accurately sedentary time to measuring accurately other dimensions such as context and type of sedentary behaviours. Measures of total sedentary behaviours may be important to identify high-risk groups and discover associations with health; however, information about context and type of sedentary behaviours seems more important now as it may reveal which contexts and types of sedentary behaviours should be targeted in future interventions.

Several innovations in objective and sensor-based measurements but also in self-reported tools are driving this shift. For a basic description of sedentary behaviour measurement, see Chap. 3 of this book.

Self-report tools such as questionnaires are flexible tools to explore context and type of sedentary behaviours. Recently, multiple tools have been developed to measure specifically sedentary time in different contexts and different types of sedentary behaviour [66]. Generally, those questionnaires ask about the time spent sedentary for different activities such as watching TV or context such at home or at work. Total sedentary time is then assessed by summing the answers, but in addition, valuable information about context and type is captured.

Some contexts of sedentary behaviours are similar for most age groups (e.g., reading and TV-viewing), but there are also important age-specific contexts, e.g., school-context for adolescents, work-context for adults, and sitting while caring (grandchildren) for older adults. Up to recently, no age-specific questionnaires were available measuring potential variables associated with all relevant contexts of sedentary behaviours. In order to fill this gap, Busschaert et al. developed three age-specific questionnaires to assess context-specific sedentary behaviours and its potential associated variables: one for adolescents, one for adults, and one for older adults [67]. The reliability and validity of the ActivPal™ were tested in the three age groups. The questionnaire was self-administered in adolescents and adults, while older adults were interviewed.

The questionnaires showed acceptable test-retest reliability and criterion validity against the ActivPal™. Sitting during TV viewing and computer use were the contexts with the highest reliability among all age groups. This may not be surprising as these activities are common in daily life, are structured, and are rarely interrupted for long times. The overall validity and results among older adults were better than adolescents and adults. Participants over-reported total sedentary time (except for weekend days in older adults) compared to the activPAL™, for weekday, weekend day, and average day, respectively, by +57%, +46, +53% in adolescents; +40%, +19%, +33% in adults; +10%, −6%, +4% in older adults.

The over-reporting can be attributed to the inclusion of multiple contexts of sedentary behaviours and to the fact that different sedentary behaviours often occur simultaneously (e.g., media multitasking like being on Facebook while watching TV). The questionnaires attempted to avoid double-reporting by using several reminders regarding this issue. However, they may not have completely prevented it. The fact that less over-reporting was detected in older adults can be explained by the fact that in this age group, interviews were used and the fact that media multitasking may be less prevalent in older adults. The newly developed age-specific questionnaires may enhance the knowledge of context-specific sedentary behaviours and its potential correlates. However, the over-reporting needs to be taken into account for adolescents and adults when considering total sedentary time. An online tool may be an option to avoid over-reporting by summing all relevant domains/contexts of sedentary behaviours and a system of notifications on the screen when participants report unrealistic levels of total sedentary behaviours, or truncating self-reported total sedentary time so that it does not exceed the total waking time based on the average sleeping time.

While context-specific self-reports of sedentary behaviours clearly have their merit, nowadays advances in measurement technology provide significantly enhanced scientific devices, helping to deal with the methodological limitation of measurement error related to the use of self-reports. There are currently three major avenues for measuring context and type of sedentary behaviours using objective methods; lifelogging, detection of specific sedentary behaviours from movement sensors, and location sensors.

Wearable time-lapse camera technology enables to record pictures of a person's surroundings at high frequency. This is known as lifelogging and emerged from sousveillance, i.e., recording by individuals of their surrounding using wearable cameras, and mobile computing research [68]. Sensecam (developed by Microsoft) was one of the first devices to be used to record context of sedentary behaviours [9, 69]. This technology is very powerful but presents some challenges. First, it is computationally very demanding. Storing and analysing the thousands of pictures taken daily is time-consuming and difficult to automate [70]. Currently, there are no convincing algorithms to extract and classify sedentary behaviours from lifelogs, and most of the analyses have to be done by hand. Second, the technology presents some ethical issues [71] that make it difficult to fund studies, despite the fact that users report that they find the technology not necessarily intrusive [72].

Movement sensors such as accelerometers and inclinometers are now routinely used to detect and measure sedentary behaviours [5]. One avenue to obtain contextual information is to use advanced signal processing techniques to detect more specific sedentary behaviours [73]. Early laboratory and controlled studies were very promising, but the technology does not transfer easily to free-living conditions due to the complexity and variability of activities in free-living [73].

Loveday et al. [74] recently did a systematic review to identify and critique technology to assess the location of physical activity and sedentary behaviours. The location in which sedentary behaviours take place can provide valuable behavioural information. The prevalence and correlates of the behaviour may depend on the context/location. Sedentary behaviours are likely, though not exclusively, to occur indoors at the home, at work or school, or in leisure pursuits. The ability to assess where behaviours occur in an indoor environment may be particularly elucidating for sedentary behaviours. With the ability to assess where sedentary behaviours occur at work (e.g., in a meeting room or at a desk) and at home (e.g., sofa, desk, or dining table), behavioural researchers would possess a more comprehensive profile of the context in which sedentary behaviours occur, which could further illuminate the most common modes of sedentary behaviours [74].

Objective monitoring could provide a robust means to measure the location of sedentary behaviours. Based on their review Loveday et al. described three technologies: global positioning systems (GPS), real-time locating systems (RTLS), and wearable cameras.

Global positioning systems (GPS) are the most widely used location technology in the published research. However, these methods are only able to differentiate indoor from outdoor and do not provide room- or subroom-level location (except for single-story buildings with a wooden roof or high-story buildings with large windows).

Real-time locating systems (RTLS), however, are able to assess the location of people or assets within an indoor environment. Loveday et al. pointed out that, for example, if researchers are undertaking a standing desk intervention to reduce sitting time, participants are currently often asked to self-report how much time they spend at their desk. The amount of time the participants spend at their desk may impact any possible reduction in sitting time due to the standing desk. With RTLS, researchers would be able to objectively determine the amount of time their participants were at their standing desk and thus determine the success, or otherwise, of the intervention with greater certainty. Or, RTLS could be used to assess whether individual residents are more sedentary alone in their bedrooms or when mixing with other residents in communal areas. Depending on the findings, some residents may then be best suited to an individual intervention focusing on bedroom-based sedentary behaviours while other residents may be more suited to a group intervention focusing on communal area sedentary behaviours [74].

The systematic review also identified several other location monitoring technologies, such as Radio-Frequency Identification (RFID) and Integrated Circuit tags that are less "ready to use" than the three main technologies discussed above. While these technologies, particularly RFID, may have a substantial research base behind them, there appears to be no "off the shelf" complete system, which is readily purchasable for location tracking. According to Loveday et al., future research should, therefore, investigate the feasibility of incorporating these technologies, with particular reference to the wearability of the devices, the integration of data streams, and the generation of meaningful behavioural outcomes.

In addition to objective monitoring, context, and type of sedentary behaviours can also be investigated using ecological momentary assessment (EMA) [75, 76]. EMA is a research method in which real-time data are frequently collected in many contexts and real-world settings. EMA has recently emerged as a promising alternative to acquire context-specific sedentary behaviour data. In EMA studies, users are repeatedly prompted to report on their behaviours, cognitions, affect, and context at fixed or random times per day (i.e., time-based EMA) or in those situations where a specific event (such as prolonged sedentary behaviour) occurs (i.e., event-based EMA) [77]. In the latter case, accelerometer data are mostly used to trigger the EMA questionnaire. Next to acquiring context-specific information, EMA also enables capturing information on the dynamic determinants of sedentary behaviours. EMA data might be useful to inform just-in-time adaptive interventions (JITAIs) [75, 76] (see 18.1.3).

26.2.6 Taxonomy of Sedentary Behaviours

If we want to tackle the complexity and heterogeneity of sedentary behaviours and understand context, we need to have a robust set of definitions and classification system that is shared by all disciplines involved in sedentary behaviours research. Considering the variety of ways we are and will be measuring context and type of sedentary behaviours, it is very important that we invest in developing data standards and behaviour classifications that are universal to facilitate data aggregation, harmonization, and comparison. This is why Chastin et al. developed a taxonomy of sedentary behaviours from a multidisciplinary consensus perspective [78]. This taxonomy enables to code any instance of sedentary behaviours and define in a universal way its contextual information. The taxonomy of sedentary behaviours is outlined in Chap. 3 of this book.

26.3 Future Opportunities

26.3.1 Life Course Approach

The life-course perspective takes into account the importance of time and timing to study the causal link between exposure and health outcomes to understand changes in behaviour through individuals' life-course and population trends [79, 80]. The importance of time in the study of sedentary behaviours is explained by the fact that consequences of exposure to sedentary behaviours [81–83] and their determinants [18, 44, 45, 84] change with age and that societal and technological transformations are altering sedentary behaviours over time [22, 46]. Understanding the dynamics of sedentary behaviours through time is crucial to

- Elucidate the effect of long-term exposure to excessive sitting;
- Identify determinants, their interactions, and how these changes through the life-course;
- Understand how biological, social, environmental, and societal processes integrate to drive individuals to become more or less sedentary;
- Identify critical periods of the life course and societal changes that increase time spent sedentary;
- Monitor population secular trends.

Currently, there is a real dearth of evidence about the life-course epidemiology of sedentary behaviours. The majority of our evidence stems from cross-sectional studies.

Life-course epidemiology relies heavily on good, large-scale scale and, in particular, longitudinal data at all stages of life. Progress will come from cross-referencing results or combined analyses of cohort studies in different countries or settings. Advances will, therefore, strongly depend on the availability of such information. From 2013 to 2016, the European Joint Programme Initiative Action DEDIPAC was tasked to develop an inventory of European datasets that could be analysed with a life-course approach [57]. The aim was to use the diversity in Europe as a laboratory to advance our understanding of determinants of key lifestyles including sedentary behaviours. DEDIPAC identified 129 datasets across Europe emerging from European-funded projects and analysed their potential for secondary data analysis. A number of challenges emerged and are briefly summarized here.

First, sedentary behaviours are relatively new concepts so very few cohort studies or repeated cross-sectional surveys have actually included it in their assessment. In those surveys that have included assessment of sedentary behaviours, indicators used are usually relatively crude (e.g., sitting time without indication of setting or day of the week, such as in the European-wide Eurobarometer survey). In the United States, surveys like National Health and Nutrition Examination Survey (NHANES) have included assessment of sedentary behaviours quite early on and have used objective measures such as accelerometry, but not longitudinally. The U.K. is very rich in cohort studies, but information on sedentary behaviours is only available in very recent waves, and historical data are lacking [85, 86].

A second challenge is access to the data. Less than 50% of the datasets identified by DEDIPAC were in the public domain. While open science is growing, early cohort studies were largely developed using restricted data sharing and access rules. This is understandable considering the investment, time, resources, and efforts required to design, undertake, and maintain cohort studies. Finally, when data are available, the lack of standardization of methods for the assessment of sedentary behaviours, their determinants, and health outcomes present another considerable challenge for data pooling and harmonization.

Overall, there is a real dearth of data on sedentary behaviours, especially from the perspective of the life-course, and there is a real need to improve standardization in data collection and facilitate data access and data sharing supported by robust data model and taxonomy [78]. One option to address this gap and track the long-term effect of the changing nature of sedentary behaviours on the youngest generations would be to develop new cohort studies with a long-time frame, covering various countries or regions and sampling younger as well as older subjects, using up-to-date methodology to assess the variety of sedentary behaviours of interest. Such projects are challenging given not only the current economic climate and ensuing funding restrictions, but also because of growing fear amongst the public about data privacy. Recent attempts to start new cohort studies that took place in the U.K. and U.S.A. were discontinued because of low recruitment rate [87]. Therefore, new avenues would need to be explored for gathering the needed data in the life-course epidemiology of sedentary behaviours. For a life-course perspective of the association between sedentary behaviour and cardiovascular disease, see Chap. 8 of this book. Chapter 2 provides a life-course perspective of the association between sedentary behaviour and psychosocial health.

26.3.2 Big Data and Internet of Things in Relation to Sedentary Behaviours

To respond to the challenges in harmonizing existing data and developing new cohort studies as highlighted above, it seems of interest to look into the potential of "Big data" and the "Internet of Things" (IoT).

"Big Data" has been defined as "large volumes of high velocity, complex, and variable data that require advanced techniques and technologies to enable the capture, storage, distribution, management and analysis of the information" [88]. The healthcare sector historically has generated large amounts of data, driven by record keeping, compliance and regulatory requirements, and patient care that we could tap into.

In addition, a key contemporary trend emerging in Big Data science is the so-called "quantified self". Quantified self refers to individuals engaging in self-tracking of any kind of biological, physical, behavioural, or environmental information [89].

Nowadays, self-quantifying is no longer limited to early adopters, geeks, fitness freaks, or patients suffering serious health problems. Self-tracking devices have shrunk in size, become cheaper, more easily connected with other mobile technologies and the internet (the so-called Internet of Things). As populations age and health-care costs increase, there is likely to be an even greater emphasis on self-sensing and people taking a more active role, sometimes called "Health 2.0". In other words, self-tracking is becoming mainstream (driven by the private sector) and institutionalizing of self-sensing is on its way. It could become an important part of e-health including new avenues for prevention and care of non-communicable diseases.

The increased use of self-sensing and the associated capacity to generate data on individuals' continuous movements and behaviours have increased the potential to go beyond the more traditional health-care data and to collect Big Data related to sedentary behaviours.

Furthermore, Big Data may raise opportunities to perform natural experiments on a big scale and to develop the so-called "living labs". A natural experiment usually takes the form of an observational study in which the researcher cannot control or withhold the allocation of an intervention to particular areas or communities, but where natural or predetermined variation in allocation occurs. This applies to area-based interventions in which changes in health are not the intended outcome but rather constitute "spill-over" effects [90–92]. Natural experiments can be a pragmatic, cost-effective research design if data are already available for analysis in national data sources. They can provide an opportunity to answer research questions that it may not be possible to address in any other way (particularly given the ethical and practical constraints of "randomization"). They may identify effective interventions and provide a useful tool for policy evaluation. The increasing collection and availability of data in cities have the potential to turn urban areas into large-scale experimental test beds for data-driven innovation. Limitations of the natural experiment approach were highlighted in reviews about methods and the utility it may have [93]. Recommendations for future research were proposed, including improved study designs (beyond the pre-post type of studies), careful selection of comparison groups, and control for confounding by matching on key demographic and socio-economic factors, as well as treatment of drop-outs and missing data. Beyond recognized limitations and difficulties in implementation, follow-up, and analyses, because they are aligning with realities of public health practice on the ground, and given their population reach, natural experiments remain attractive and hold promise for informing policy decisions [92]. Currently, 340 European cities are part of the "European network of Living labs" through four key elements: co-creation of new services by users and procedures, exploration of emerging usages, behaviours, and market opportunities; experimentation with implementing live scenarios with a community of lead users and evaluation of concepts, products, and services (http://openlivinglabs.eu/). One of the Living labs is the Food & Health Living Lab, which comprises seven fundamental pillars including nutrition, food, physiotherapy, psychology, genetics, physical activity, and clinical analysis. It seems worth exploring how sedentary behaviours research can learn from these Living Labs and how these kinds of initiatives can be used outside the private sector.

The term "Internet of Things" was originally used in the context of supply chain management. However, in the past decade, the definition has been more inclusive, covering a wide range of applications like healthcare, utilities, transport, etc. [94]. Although the definition of "Things" has changed as technology evolved, the main goal of making a computer sense information without the aid of human intervention remains the same. Fuelled by the prevalence of devices enabled by open wireless technology such as Bluetooth, Wi-Fi, and telephonic data services, IoT has gained popularity. In 2011, the number of interconnected devices on the planet overtook the actual number of people and currently there are 50 billion interconnected devices, and it is expected to reach 100 billion devices by 2030 [95]. Also, in the scope of behaviour change and health promotion, and therefore of interest to the field of sedentary behaviours research, the IoT may hold promise, especially since it offers a two-way communication system as body-worn sensors and devices used by the individual could be used to implement Just-In-Time Adaptive interventions (JITAIs) [96]. JITAIs are interventions in which the provision of support (e.g., the type and intensity) is adapted over time, taking into account an individual's changing needs and contextual state. Ideally, JITAIs deliver support at the moment that the person needs it most and is most likely to be receptive. Despite its enormous potential, research into the development, evaluation, and implementation of JITAIs focusing on the reduction of sedentary behaviours in still in its infancy.

While Big Data, living labs and the Internet of Things may hold promise to yield insights for research on sedentary behaviours, some limitations/pitfalls must be acknowledged:

– Currently, the trend to make Big Data go mainstream is mainly driven by the private sector. Critical thinking and the involvement of researchers, also those who do not typically work with Big Data will be important to its effective use as a tool for public health research and for both personal and public health benefit. Big Data collection is not hypothesis driven. Currently, Big Data on sedentary behaviours appear limited. But even if they emerge, we need to carefully think about how we will use them to generate useful insights. Big Data may become overwhelming not only because of their volume but also because of the diversity of data types and the speed at which they must be managed. Big Data are so large and complex that they are difficult (or impossible) to manage with traditional software and hardware; nor can they be easily managed with traditional or common data management tools and methods. Furthermore, the models of continuous data and modern computation contain too many variables and complex relationships for most people to understand.
– There is a need for novel, easy-to-understand visualization and interpretation tools that can be widely accessed on different platforms and which can be

designed for different applications, and for strong underpinning behaviour taxonomies and classification [78].

– Another classic Big Data science problem is extracting signals from noise. Ultimately, 99% of the data may be useless and would need to be discarded.
– Big Data may hold potential to advance health risk "profiling" and enable more cost-effective ways to tailor health services. But as Khoury and Ioannidis put it, the promise of Big Data also brings the risk of "Big Error" [97].
– The problem is how to do research on Big Data produced by the broad population. How can we motivate tracking companies to give access to raw data feeds? These companies are consumer-oriented, and the incentives for them seem non-existing or limited. One major challenge for Big Data and the living lab concept is to protect individual privacy. User concerns about surveillance, privacy, and data security will have to be taken into account. The research community, healthcare IT experts, the commercial tracking companies, and the individual self-trackers will have to collaborate to make broad population data available to academic researchers, and the privacy impasse will have to be resolved.

To conclude, technology may allow us to solve some problems in highly original ways and create new incentives to promote healthy behaviours and reduce sedentary time. However, many pitfalls are still in place, and it is yet to prove that we can overcome the many difficulties, like complexity and privacy issues.

Furthermore, Morozov argues in his work "The Folly of Technological Solutionism" [98] that the temptation of the digital age is to fix everything—from crime to corruption to pollution to obesity—by digitally quantifying, tracking, or gamifying behaviour. But when we change the motivations for our moral, ethical, and civic behaviour, we may also change the very nature of that behaviour. Technology, Morozov proposes, can be a force for improvement—but only if we keep solutionism in check and learn to appreciate the imperfections of liberal democracy. To conclude, the promise of Big Data exists, but it should not overshadow the use of smaller scale (e.g., survey, qualitative interview) data and experimental studies. Research funding is finite, and popular trends could unduly influence the allocation of resources to studies proposing to use Big Data.

26.4 Conclusion

In the next phase of research on sedentary behaviours, changes in insights and moving towards finding solutions *are unlikely to come from a single perspective but more likely from a combination of approaches and increased multidisciplinary working. It might be necessary to let go of some ontologies, ways of working and methods that served us right in the past but might not be adapted to the new challenges we face and impede progress. Recognizing and engaging with the complexity of sedentary behaviours is likely to be key in the future. This requires* *that we invest in developing robust and transdisciplinary models and framework for classification, measurement, and analysis. Combining life-course with system-based approaches, in a solutionist or realist mind-set while making the most of the opportunity given by new advance in technologies (*e.g.*, Big Data) appears as the most exciting and promising avenue to be able to address the challenge of the health burden of an increasingly sedentary lifestyle.*

References

1. Dietz WH. The role of lifestyle in health: the epidemiology and consequences of inactivity. Proc Nutr Soc. 1996;55:829–40.
2. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population-health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38:105.
3. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior: determinants and interventions. Am J Prev Med. 2011;41:189–96.
4. Sallis JF, Owen N, Fisher E. Ecological models of health behavior. In: Health behavior: Theory, research, and practice. San Francisco: Jossey-Bass/Wiley; 2015. p. 5.
5. Chastin S, Granat MH. Methods for objective measure, quantification and analysis of sedentary behaviour and inactivity. Gait Posture. 2010;31:82–6.
6. Sedentary Behaviour Research Network. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". Ment Health Phys Act. 2013;6:55–6.
7. Stamatakis E, Coombs N, Jago R, Gama A, Mourão I, Nogueira H, Rosado V, Padez C. Type-specific screen time associations with cardiovascular risk markers in children. Am J Prev Med. 2013;44:481–8.
8. Stamatakis E, Davis M, Stathi A, Hamer M. Associations between multiple indicators of objectively-measured and self-reported sedentary behaviour and cardiometabolic risk in older adults. Prev Med. 2012;54:82–7.
9. Leask CF, Harvey JA, Skelton DA, Chastin SF. Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). Eur Rev Aging Phys Act. 2015;12:1–8.
10. Kesse-Guyot E, Charreire H, Andreeva VA, Touvier M, Hercberg S, Galan P, Oppert J-M. Cross-sectional and longitudinal associations of different sedentary behaviors with cognitive performance in older adults. PLoS One. 2012;7(10):e47831.
11. Cardon GM, De Clercq DL, De Bourdeaudhuij IM. Back education efficacy in elementary schoolchildren: a 1-year follow-up study. Spine. 2002;27:299–305.
12. Hinckson E, Salmon J, Benden M, Clemes SA, Sudholz B, Barber SE, Aminian S, Ridgers ND. Standing classrooms: research and lessons learned from around the world. Sports Med. 2016;46:977–87.
13. Liao Y, Liao J, Durand CP, Dunton GF. Which type of sedentary behaviour intervention is more effective at reducing body mass index in children? A meta-analytic review. Obes Rev. 2014;15: 159–68.
14. Biddle SJ, O'Connell S, Braithwaite RE. Sedentary behaviour interventions in young people: a meta-analysis. Br J Sports Med. 2011;45:937–42.
15. Gardner B, Smith L, Lorencatto F, Hamer M, Biddle SJ. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. Health Psychol Rev. 2016;10:89–112.
16. Chastin SF, Fitzpatrick N, Andrews M, DiCroce N. Determinants of sedentary behavior, motivation, barriers and strategies to reduce sitting time in older women: a qualitative investigation. Int J Environ Res Public Health. 2014;11:773–91.

17. Greenwood-Hickman MA, Renz A, Rosenberg DE. Motivators and barriers to reducing sedentary behavior among overweight and obese older adults. The Gerontologist. 2016;56:660–8.
18. Stierlin AS, De Lepeleere S, Cardon G, Dargent-Molina P, Hoffmann B, Murphy MH, Kennedy A, O'donoghue G, Chastin SF, De Craemer M. A systematic review of determinants of sedentary behaviour in youth: a DEDIPAC-study. Int J Behav Nutr Phys Act. 2015;12:1–19.
19. Leatherdale ST, Wong SL. Modifiable characteristics associated with sedentary behaviours among youth. Int J Pediatr Obes. 2008;3:93–101.
20. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. JAMA. 2003;289: 1785–91.
21. Bucksch J, Sigmundova D, Hamrik Z, Troped PJ, Melkevik O, Ahluwalia N, Borraccino A, Tynjälä J, Kalman M, Inchley J. International trends in adolescent screen-time behaviors from 2002 to 2010. J Adolesc Health. 2016;58:417–25.
22. Matrix S. The Netflix effect: teens, binge watching, and on-demand digital media trends. Jeunesse: young people, texts, cultures. 2014;6:119–38.
23. Brasel SA, Gips J. Media multitasking behavior: concurrent television and computer usage. Cyberpsychol Behav Soc Netw. 2011;14:527–34.
24. Christensen CG, Bickham D, Ross CS, Rich M. Multitasking with television among adolescents. J Broadcast Electron Media. 2015;59:130–48.
25. Choudrie J, Grey S, Tsitsianis N. Evaluating the digital divide: the silver Surfer's perspective. Electron Gov Int J. 2010;7(2):148–67.
26. Stephens SK, Winkler EA, Trost SG, Dunstan DW, Eakin EG, Chastin SF, Healy GN. Intervening to reduce workplace sitting time: how and when do changes to sitting time occur? Br J Sports Med. 2014;48:1037–42.
27. Dowd KP, Harrington DM, Bourke AK, Nelson J, Donnelly AE. The measurement of sedentary patterns and behaviors using the activPAL™ professional physical activity monitor. Physiol Meas. 2012;33:1887.
28. Goldberger AL, Amaral LA, Hausdorff JM, Ivanov PC, Peng C-K, Stanley HE. Fractal dynamics in physiology: alterations with disease and aging. Proc Natl Acad Sci. 2002;99: 2466–72.
29. Vázquez A, Oliveira JG, Dezsö Z, Goh K-I, Kondor I, Barabási A-L. Modeling bursts and heavy tails in human dynamics. Phys Rev E. 2006;73:036127.
30. Nicolai S, Benzinger P, Skelton DA, Aminian K, Becker C, Lindemann U. Day-to-day variability of physical activity of older adults living in the community. J Aging Phys Act. 2010;18(1):75–86.
31. Chastin SF, Winkler EA, Eakin EG, Gardiner PA, Dunstan DW, Owen N, Healy GN. Sensitivity to change of objectively-derived measures of sedentary behavior. Meas Phys Educ Exerc Sci. 2015;19:138–47.
32. Chastin SF, Egerton T, Leask C, Stamatakis E. Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. Obesity. 2015;23:1800–10.
33. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ, Owen N. Breaks in sedentary time: beneficial associations with metabolic risk. Diabetes Care. 2008;31:661–6.
34. Pedišić Ž. Measurement issues and poor adjustments for physical activity and sleep undermine sedentary behaviour research—the focus should shift to the balance between sleep, sedentary behaviour, standing and activity. Kinesiology. 2014;46:135–46.
35. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. PLoS One. 2015;10:e0139984.
36. Chaput J-P, Carson V, Gray CE, Tremblay MS. Importance of all movement behaviors in a 24 hour period for overall health. Int J Environ Res Public Health. 2014;11:12575–81.
37. Charreire H, Casey R, Salze P, Kesse-Guyot E, Simon C, Chaix B, Banos A, Badariotti D, Touvier M, Weber C. Leisure-time physical activity and sedentary behavior clusters and their associations with overweight in middle-aged French adults. Int J Obes. 2010;34:1293–301.

38. Buman MP, Winkler EA, Kurka JM, Hekler EB, Baldwin CM, Owen N, Ainsworth BE, Healy GN, Gardiner PA. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. Am J Epidemiol. 2014;179:323–34.
39. Pearson N, Biddle SJ. Sedentary behavior and dietary intake in children, adolescents, and adults: a systematic review. Am J Prev Med. 2011;41:178–88.
40. Santaliestra-Pasías A, Mouratidou T, Huybrechts I, Beghin L, Cuenca-García M, Castillo M, Galfo M, Hallstrom L, Kafatos A, Manios Y. Increased sedentary behaviour is associated with unhealthy dietary patterns in European adolescents participating in the HELENA study. Eur J Clin Nutr. 2014;68:300–8.
41. Gubbels JS, van Assema P, Kremers SP. Physical activity, sedentary behavior, and dietary patterns among children. Curr Nutr Rep. 2013;2:105–12.
42. Lipsky LM, Iannotti RJ. Associations of television viewing with eating behaviors in the 2009 health behaviour in school-aged children study. Arch Pediatr Adolesc Med. 2012;166:465–72.
43. Charreire H, Kesse-Guyot E, Bertrais S, Simon C, Chaix B, Weber C, Touvier M, Galan P, Hercberg S, Oppert J-M. Associations between dietary patterns, physical activity (leisure-time and occupational) and television viewing in middle-aged French adults. Br J Nutr. 2011;105: 902–10.
44. Chastin SF, Buck C, Freiberger E, Murphy M, Brug J, Cardon G, O'Donoghue G, Pigeot I, Oppert J-M. Systematic literature review of determinants of sedentary behaviour in older adults: a DEDIPAC study. Int J Behav Nutr Phys Act. 2015;12:1–12.
45. O'donoghue G, Perchoux C, Mensah K, Lakerveld J, Van Der Ploeg H, Bernaards C, Chastin SF, Simon C, O'gorman D, Nazare J-A. A systematic review of correlates of sedentary behaviour in adults aged 18–65 years: a socio-ecological approach. BMC Public Health. 2016;16:1–25.
46. Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. Obes Rev. 2012;13:659–80.
47. Milton K, Gale J, Stamatakis E, Bauman A. Trends in prolonged sitting time among European adults: 27 country analysis. Prev Med. 2015;77:11–6.
48. Loyen A, van der Ploeg HP, Bauman A, Brug J, Lakerveld J. European sitting championship: prevalence and correlates of self-reported sitting time in the 28 European Union member states. PLoS One. 2016;11:e0149320.
49. Glass TA, Goodman SN, Hernán MA, Samet JM. Causal inference in public health. Annu Rev Public Health. 2013;34:61.
50. Susser M. Does risk factor epidemiology put epidemiology at risk? Peering into the future. J Epidemiol Community Health. 1998;52:608–11.
51. Co-operation OE. Development: applications of complexity science for public policy. Paris: OECD; 2008.
52. Homer JB, Hirsch GB. System dynamics modeling for public health: background and opportunities. Am J Public Health. 2006;96:452–8.
53. Leischow SJ, Milstein B. Systems thinking and modeling for public health practice. Am Public Health Assoc. 2006;96:403–5.
54. Luke DA, Stamatakis KA. Systems science methods in public health: dynamics, networks, and agents. Annu Rev Public Health. 2012;33:357.
55. Butland B, Jebb S, Kopelman P, McPherson K, Thomas S, Mardell J, Parry V. Foresight. Tackling obesities: future choices. Project report. *Foresight Tackling obesities: future choices Project report* 2007.
56. Richard L, Gauvin L, Raine K. Ecological models revisited: their uses and evolution in health promotion over two decades. Annu Rev Public Health. 2011;32:307–26.
57. Lakerveld J, van der Ploeg HP, Kroeze W, Ahrens W, Allais O, Andersen LF, Cardon G, Capranica L, Chastin S, Donnelly A. Towards the integration and development of a cross-European research network and infrastructure: the DEterminants of DIet and physical ACtivity (DEDIPAC) knowledge hub. Int J Behav Nutr Phys Act. 2014;11:1–10.

58. Chastin SF, De Craemer M, Lien N, Bernaards C, Buck C, Oppert J-M, Nazare J-A, Lakerveld J, O'Donoghue G, Holdsworth M. The SOS-framework (Systems of Sedentary behaviours): an international transdisciplinary consensus framework for the study of determinants, research priorities and policy on sedentary behaviour across the life course: a DEDIPAC-study. Int J Behav Nutr Phys Act. 2016;13:1–13.
59. Migueles JH, Aadland E, Andersen LB, Brønd JC, Chastin SF, Hansen BH, Konstabel K, Kvalheim OM, McGregor DE, Rowlands AV. GRANADA consensus on analytical approaches to assess associations with accelerometer-determined physical behaviours (physical activity, sedentary behaviour and sleep) in epidemiological studies. Br J Sports Med. 2022;56:376–84.
60. Aitchison J. The statistical analysis of compositional data. J R Stat Soc: Series B (Methodological). 1982;44:139–60.
61. Ding D, Do A, Schmidt H-M, Bauman AE. A widening gap? Changes in multiple lifestyle risk behaviours by socioeconomic status in New South Wales, Australia, 2002–2012. PLoS One. 2015;10:e0135338.
62. Harding NJ. *Application of Bayesian networks to problems within obesity epidemiology*. The University of Manchester (United Kingdom); 2011.
63. Finegood DT, Merth TD, Rutter H. Implications of the foresight obesity system map for solutions to childhood obesity. Obesity. 2010;18:S13.
64. Jagosh J. Realist synthesis for public health: building an ontologically deep understanding of how programs work, for whom, and in which contexts. Annu Rev Public Health. 2019;40:361–72.
65. Owen N, Bauman A, Brown W. Too much sitting: a novel and important predictor of chronic disease risk? Br J Sports Med. 2009;43:81–3.
66. Mensah K, Maire A, Oppert J-M, Dugas J, Charreire H, Weber C, Simon C, Nazare J-A. Assessment of sedentary behaviors and transport-related activities by questionnaire: a validation study. BMC Public Health. 2016;16:1–9.
67. Busschaert C, De Bourdeaudhuij I, Van Holle V, Chastin SF, Cardon G, De Cocker K. Reliability and validity of three questionnaires measuring context-specific sedentary behaviour and associated correlates in adolescents, adults and older adults. Int J Behav Nutr Phys Act. 2015;12:1–13.
68. Mann S, Nolan J, Wellman B. Sousveillance: inventing and using wearable computing devices for data collection in surveillance environments. Surveill Soc. 2003;1:331–55.
69. Kerr J, Marshall SJ, Godbole S, Chen J, Legge A, Doherty AR, Kelly P, Oliver M, Badland HM, Foster C. Using the SenseCam to improve classifications of sedentary behavior in free-living settings. Am J Prev Med. 2013;44:290–6.
70. Doherty AR, Smeaton AF. Automatically segmenting lifelog data into events. In: 2008 Ninth international workshop on image analysis for multimedia interactive services. New York: IEEE; 2008. p. 20–3.
71. Kelly P, Marshall SJ, Badland H, Kerr J, Oliver M, Doherty AR, Foster C. An ethical framework for automated, wearable cameras in health behavior research. Am J Prev Med. 2013;44:314–9.
72. Harvey J, Chastin S, Skelton D. The art and science of defining the context of sedentary behaviour by older adults, using interview, activity monitoring and body worn cameras. Clin Rehabil. 2015;29:314.
73. Mannini A, Intille SS, Rosenberger M, Sabatini AM, Haskell W. Activity recognition using a single accelerometer placed at the wrist or ankle. Med Sci Sports Exerc. 2013;45:2193.
74. Loveday A, Sherar LB, Sanders JP, Sanderson PW, Esliger DW. Technologies that assess the location of physical activity and sedentary behavior: a systematic review. J Med Internet Res. 2015;17:e4761.
75. Maher JP, Rebar AL, Dunton GF. Ecological momentary assessment is a feasible and valid methodological tool to measure older adults' physical activity and sedentary behavior. Front Psychol. 2018;9:1485.

76. Degroote L, DeSmet A, De Bourdeaudhuij I, Van Dyck D, Crombez G. Content validity and methodological considerations in ecological momentary assessment studies on physical activity and sedentary behaviour: a systematic review. Int J Behav Nutr Phys Act. 2020;17:1–13.
77. Giurgiu M, Niermann C, Ebner-Priemer U, Kanning M. Accuracy of sedentary behavior–triggered ecological momentary assessment for collecting contextual information: development and feasibility study. JMIR Mhealth Uhealth. 2020;8:e17852.
78. Chastin SFM, Schwarz U, Skelton DA. Development of a consensus taxonomy of sedentary behaviors (SIT): report of Delphi round 1. PLoS One. 2013;8:e82313.
79. Ben-Shlomo Y, Kuh D. A life course approach to chronic disease epidemiology: conceptual models, empirical challenges and interdisciplinary perspectives, vol. 31. Oxford: Oxford University Press; 2002. p. 285–93.
80. Kuh D, Ben-Shlomo Y, Lynch J, Hallqvist J, Power C. Life course epidemiology. J Epidemiol Community Health. 2003;57:778.
81. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent health outcomes in adults: a systematic review of longitudinal studies, 1996–2011. Am J Prev Med. 2011;41:207–15.
82. Rezende LFM, Rey-López JP, Matsudo VKR, Luiz OC. Sedentary behavior and health outcomes among older adults: a systematic review. BMC Public Health. 2014;14:1–9.
83. Tremblay MS, LeBlanc AG, Kho ME, Saunders TJ, Larouche R, Colley RC, Goldfield G, Gorber SC. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Act. 2011;8:1–22.
84. Brug J, Chinapaw M. Determinants of engaging in sedentary behavior across the lifespan; lessons learned from two systematic reviews conducted within DEDIPAC. Int J Behav Nutr Phys Act. 2015;12:1–4.
85. Council MR. Maximising the value of UK population cohorts. 2014.
86. Celis-Morales CA, Lyall DM, Petermann F, Anderson J, Ward J, Iliodromiti S, Mackay DF, Welsh P, Bailey ME, Pell J. Do physical activity, commuting mode, cardiorespiratory fitness and sedentary behaviours modify the genetic predisposition to higher BMI? Findings from a UK biobank study. Int J Obes. 2019;43:1526–38.
87. Pearson H. Massive UK baby study cancelled. Nature. 2015;526:620–1.
88. Gandomi A, Haider M. Beyond the hype: big data concepts, methods, and analytics. Int J Inf Manag. 2015;35:137–44.
89. Swan M. Emerging patient-driven health care models: an examination of health social networks, consumer personalized medicine and quantified self-tracking. Int J Environ Res Public Health. 2009;6:492–525.
90. Petticrew M, Cummins S, Ferrell C, Findlay A, Higgins C, Hoy C, Kearns A, Sparks L. Natural experiments: an underused tool for public health? Public Health. 2005;119:751–7.
91. Craig P, Katikireddi SV, Leyland A, Popham F. Natural experiments: an overview of methods, approaches, and contributions to public health intervention research. Annu Rev Public Health. 2017;38:39.
92. Ogilvie D, Adams J, Bauman A, Gregg EW, Panter J, Siegel KR, Wareham NJ, White M. Using natural experimental studies to guide public health action: turning the evidence-based medicine paradigm on its head. J Epidemiol Community Health. 2020;74:203–8.
93. Crane M, Bohn-Goldbaum E, Grunseit A, Bauman A. Using natural experiments to improve public health evidence: a review of context and utility for obesity prevention. Health Res Policy Syst. 2020;18:1–13.
94. Sundmaeker H, Guillemin P, Friess P, Woelfflé S. Vision and challenges for realising the internet of things. Cluster of European research projects on the internet of things. European Commision. 2010;3:34–6.
95. Bhattacharya S, Pandey M. Internet of things for green technology. In: *Green engineering and technology*. Boca Raton: CRC Press; 2021. p. 243–58.

96. Nahum-Shani I, Smith SN, Spring BJ, Collins LM, Witkiewitz K, Tewari A, Murphy SA. Just-in-time adaptive interventions (JITAIs) in mobile health: key components and design principles for ongoing health behavior support. Ann Behav Med. 2018;52:446–62.
97. Khoury MJ, Ioannidis JP. Big data meets public health. Science. 2014;346:1054–5.
98. Morozov E. To save everything, click here: the folly of technological solutionism. J Inf Policy. 2014;4:173–5.

Chapter 27
From a Public to a Global and Planetary Health Perspective on Sedentary Behaviour Epidemiology

Carmen Jochem and Michael F. Leitzmann

Abstract Against the background of global environmental change including climate change and urbanization, this chapter considers sedentary behaviour epidemiology from a public health, global health, and planetary health perspective. It describes the importance of global guidelines for sedentary behaviour, highlighting the global action plan on physical activity from the World Health Organization and discussing sedentary behaviour epidemiology in the context of the risk transition occurring in many low- and middle-income countries. It also provides an overview of the economics of sedentary behaviour. Furthermore, it highlights the role of sedentary behaviour in the COVID-19 pandemic as a global health challenge. Finally, it views sedentary behaviour from a holistic, planetary health perspective and portrays a vision of the potentially critical role sedentary behaviour plays for planetary health.

Key Points

- Whereas sedentary behaviour is recognized as a public and global health concern, a planetary health perspective on sedentary behaviour is not yet established.
- The COVID-19 pandemic—as a global health topic—has shown that health behaviours such as sedentary behaviour and physical (in)activity interact with pandemic-related public health measures.
- Global environmental change, including climate change and urbanization, are interlinked with sedentary behaviour epidemiology, and sedentary behaviour has to be considered within these complex contexts.

(continued)

C. Jochem (✉) · M. F. Leitzmann
Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany
e-mail: carmen.jochem@ukr.de; michael.leitzmann@ukr.de

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_27

- A planetary health perspective on sedentary behaviour adopts a holistic perspective on sedentary behaviour and health for well-being societies in the context of ecological limits.

27.1 Introduction

Although the prevalence of sedentary behaviour differs between countries and populations, sedentary behaviour is a health behaviour of global relevance. Yet most studies on sedentary behaviour originate from high-income countries. Many low- and middle-income countries are currently experiencing a risk transition characterized by increasing urbanization, sedentary jobs, and sedentary modes of transportation. In addition, the economics of sedentary behaviour (i.e., the economic burden of sedentary behaviour and the costs of interventions that reduce sedentary behaviour) are of great interest for public and global health. Furthermore, the COVID-19 pandemic—as an important global health topic—has shown that health behaviours such as sedentary behaviour or physical activity interact with pandemic-related public health measures. Existing global health challenges such as COVID-19 and climate change highlight the crucial role of environmental determinants of health that need to be considered from a planetary health perspective.

27.2 From a Public to a Global (Public) Health Perspective on Sedentary Behaviour

In most high-income countries, sedentary behaviour is recognized as a public health concern, with both high prevalence of sedentary behaviour and existing recommendations to reduce sedentary behaviour (see Recommendations in Sect. 1.3). However, few studies have investigated sedentary behaviour in low- and middle-income countries in terms of prevalence, determinants, health impacts, and other factors. This section briefly explains sedentary behaviour epidemiology from a risk transition perspective and the corresponding role sedentary behaviour plays for low- and middle-income countries. In addition, a health economic perspective on sedentary behaviour is shown. Further, the role of COVID-19 as a global health challenge for sedentary behaviour will be described. Finally, the existence of global guidelines on sedentary behaviour provides the basis for tackling sedentary behaviour at the global level.

27.2.1 Sedentary Behaviour Epidemiology and the Risk Transition

In 2019, the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2019 assessed the magnitude of risk factor exposure, relative risk, and attributable burden of disease of 87 risk factors in 204 countries and territories between 1990 and 2019 [1]. Among the five leading risks with respect to the global burden of disease across all ages are metabolic risks, including high systolic blood pressure, high fasting plasma glucose, and high body mass index. as well as behavioural risks, including smoking and low birthweight. Compared to 1990, the burden of disease attributable to these risk factors has increased. In contrast, the attributable burden of disease due to environmental and occupational risks, such as unsafe water and unsafe sanitation decreased over time. In 2019, low levels of physical activity as a behavioural risk factor ranked 18th in attributable disability-adjusted life years (DALYs) [1]. However, sedentary behaviour was not included in the assessment of the GBD Study, likely because sedentary behaviour is a relatively new research area, the assessment of which is still insufficient at the global level and for comparisons across decades.

Even though sedentary behaviour plays a smaller role than other behavioural risk factors, such as smoking or alcohol consumption (see Box 27.1 for a comparison between sitting and smoking), sedentary behaviour should not be underestimated as a risk factor for human health at the global scale. As shown in Chap. 2, sedentary behaviour is highly prevalent among Western societies, where many people live in urban areas in an environment characterized by passive transportation, sedentary jobs, and media and communication technologies that encourage a sedentary lifestyle. Similarly, economic and societal transitions in low- and middle-income countries come along with increased urbanization and more sedentary jobs and societies [2]. Therefore, sedentary behaviour must be considered within the general risk transition (i.e., the shift in risk factors for health) from “traditional” to “modern” risks. However, different social and cultural perceptions of sedentary behaviour between countries need to be considered. For example, work-related sedentary behaviour or transportation-related sedentary behaviour during commuting (by car) may be associated with the social perception of a higher socioeconomic status.

As reported by Dempsey et al. (2020), there is inequality regarding the evidence on sedentary behaviour between high-income countries and low- and middle-income countries [2]. Future research should provide high-quality data from a broad range of populations in low- and middle-income countries. Specifically, the role of the broader determinants of sedentary behaviour needs to be investigated across a wider range of countries. Furthermore, a global perspective that incorporates sedentary behaviour issues (including global surveillance data) from both high and low- and middle-income countries is crucial.

Box 27.1 Is Sitting the New Smoking?
In recent years, media coverage often used headlines such as "Sitting is the new smoking" with regard to the high prevalence of sedentary behaviour and the health risks associated with high levels of sedentary behaviour. In order to assess the (in)comparability between sitting and smoking, Vallance et al. (2019) evaluated the evidence on sitting, smoking, and health [3]. This box briefly highlights the main findings regarding the question "Is Sitting the New Smoking?".

Sitting could be considered the new smoking because. . .

- Both sedentary behaviour and smoking are modifiable risk factors with adverse effects on human health.
- Both sedentary behaviour and smoking are risk factors that are highly prevalent in many societies and populations.
- Both sedentary behaviour and smoking are risk factors that are avoidable through prevention measures.

But: sitting is <u>not</u> the new smoking because. . .

- The health risks related to smoking are considerably higher than the health risks related to sedentary behaviour.
- No single disease is attributable to such a large amount of sedentary behaviour as lung cancer is attributable to smoking.
- Small bouts of sitting (e.g., resting on a bench or sitting during eating) are not associated with adverse effects on human health, whereas there is no safe lower dose of tobacco consumption because the combustion of tobacco or tobacco smoke always contains toxic substances.
- Sedentary behaviour does not harm the health of other people, whereas second-hand smoke has adverse effects on the health of other people.
- Sedentary behaviour is a habit, but it does not seem to be an addictive behaviour, whereas smoking leads to nicotine dependence.
- The economic burden associated with sedentary behaviour appears to be smaller than the economic burden related to smoking.

Smoking was described as one of the greatest global public health disasters of the twentieth century, and it remains among the risk factors that contribute to the largest burden of disease worldwide [1, 4]. Whereas smoking leads to an absolute risk difference of more than 2000 excess deaths from any cause per 100,000 persons per year among the heaviest smokers compared with never smokers, higher compared to lower levels of sitting lead to 190 excess deaths per 100,000 persons per year [3]. Furthermore, the relative risks of death associated with smoking show that "any level of smoking increases risk of dying from any cause by approximately 180% versus a 25% risk increase for sitting" [3]. Regarding the population-attributable fraction of sitting-related

(continued)

Box 27.1 (continued)
all-cause mortality, sitting is responsible for approximately 3.8% of all-cause mortality [5]. Smoking, however, is responsible for 21% of deaths among men and 17% of deaths among women [6]. Based on these and other data, Vallance et al. (2019) conclude that "equating sitting with smoking is unwarranted, misleading for the public, and may serve to distort and trivialize the ongoing and serious risks of smoking" [3]. Thus, the correct answer to the question of whether sitting is the new smoking should definitely be: "no".

27.2.2 A Health Economic Perspective on Sedentary Behaviour

For decision-makers and policymakers that act in the field of public and global (public) health, a health economic perspective may add crucial information. On the one hand, the direct and indirect costs that are attributable to sedentary behaviour may be of interest to policymakers and decision-makers. On the other hand, the costs associated with interventions to reduce sedentary behaviour should be taken into account to draw informed decisions for public health.

The Economic Burden of Sedentary Behaviour

Whereas the economic impact of physical inactivity is relatively well studied [7], little research exists on the economic burden of sedentary behaviour. Existing research is restricted to health economic perspectives of individual countries. For example, Heron and colleagues assessed the direct health care costs of prolonged sedentary behaviour (≥6 hours/day) for the National Health Service (NHS) in the UK [8]. Over a one-year period (in 2016–2017), a total of £0.8 billion were attributable to prolonged sedentary behaviour, and that estimate included expenditures on cardiovascular disease (£424 million), type 2 diabetes (£281 million), colon cancer (£30 million), lung cancer (£19 million), and endometrial cancer (£seven million). In addition to cost savings, the elimination of prolonged sedentary behaviour might have avoided 69,276 UK deaths in 2016 [8].

For future research, national and international studies are needed that investigate both direct and indirect costs of sedentary behaviour based on the current evidence regarding health outcomes associated with sedentary behaviour. In addition to direct costs, indirect costs that include productivity losses and the associated financial burden on society can be considerable. Also, additional highly prevalent diseases, including cancers such as breast cancer, and other conditions such as musculoskeletal and mental diseases, as well as further health outcomes with moderate-to-high evidence regarding the association between sedentary behaviour and health outcome, such as ovarian cancer, should be taken into consideration.

Costs of Interventions that Reduce Sedentary Behaviour

From a global public health perspective, costs attributable to sedentary behaviour per se and costs associated with interventions that aim to reduce sedentary behaviour are of relevance. However, few studies have investigated the health economic aspects of sedentary behaviour.

An umbrella review and meta-analysis by Lam and colleagues investigated the effectiveness and costs of interventions to reduce sedentary behaviour across all age groups and populations in different settings [9]. The health economic considerations of that umbrella review included a total of 22 studies, most of which were conducted on office workers ($n = 7$), school children ($n = 6$), and older adults ($n = 3$). Ten studies included multicomponent interventions, seven studies investigated physical environment interventions such as sit–stand workstations or treadmill desks, four studies examined personal behaviour interventions such as booklets and manuals, and one study analyzed social environment interventions. The intervention costs per study participant ranged from € 0 to € 3587 due to very heterogeneous types of interventions. Physical environment interventions were classified as the most effective intervention category for reductions in sedentary behaviour, with intervention costs ranging from € 334 to € 3587 per participant. Those costs depended on the particular desk used, i.e., a treadmill desk produced greater costs than a sit–stand workstation. The costs of personal behaviour interventions (the second most effective intervention category) were between € 5 and € 57 per participant [9]. However, those costs refer to acquisition costs only. The authors of the umbrella review reference two studies with separate health economic evaluations that reported details on costs incurred and a cost-benefit or cost-effectiveness analysis [10, 11]. Munir and colleagues assessed the increase in productivity (in monetary units) and reported net cost savings of £1770 after the subtraction of intervention costs and costs for lost work time due to the implementation of the intervention [10]. The incremental cost-effectiveness ratio (ICER) was between £8 and £17 per minute per workday [10]. Sevick and colleagues performed a cost-effectiveness analysis and reported costs of $9 and $36 for intervention groups 1 and 2, respectively, at six months of follow-up in terms of cost per month per hour of reduced sedentary behaviour per week [11]. At 24 months of follow-up, costs were $15 and $7, respectively.

Another systematic review that investigated the economics of sedentary behaviour included three studies that assessed the healthcare costs associated with high amounts of sedentary behaviour, and six studies reported economic evaluations of interventions targeting sedentary behaviour [12]. In terms of the costs of illness, healthcare costs associated with high amounts of sedentary behaviour were substantial. However, none of the studies investigated non-health sector costs. Studies ($n = 5$) that investigated the economics of interventions targeting sedentary behaviour of adults in office workplaces were cost-effective. The key costs were caused by sit-stand desks, active workstations, and other physical environment changes [12]. One intervention performed in children was cost-saving, and the authors concluded that sedentary behaviour may lead to increased healthcare costs. In addition, and in line with the findings by Lam et al., interventions targeting sedentary behaviour in workplaces seem to be cost-effective.

For future health economic research, intervention studies should provide all relevant costs (including implementation and evaluation costs) to enable the calculation of total intervention costs.

27.2.3 COVID-19: A Global Health Challenge for Sedentary Behaviour

From a global health perspective, it is of interest to consider the association between the COVID-19-pandemic and sedentary behaviour epidemiology. As a reaction to the spread of COVID-19 in early 2020, many countries imposed homestay public health strategies (such as lockdowns) in order to decrease contacts among individuals for communicable disease control. Research shows that COVID-19-related lockdowns had an influence on sedentary behaviour, with increasing levels of sedentary behaviour across all age groups [13–15].

Runacres and colleagues performed a systematic review and meta-analysis that investigated the influence of COVID-19-related lockdowns on sedentary behaviour and physical, mental, and social health outcomes [14]. The authors included a total of 64 studies (encompassing 282,202 participants) in the qualitative review, of which 45 studies were conducted in adults (two of those in older adults) and 19 in children and adolescents. The vast majority of studies had an observational or cross-sectional design (95.2%), were based on online questionnaires (93.8%), and recruited from the general population (89%). Most studies were from Europe ($n = 25$), followed by studies from Asia ($n = 18$), North America ($n = 12$), South America ($n = 8$), and Africa ($n = 1$). Overall, time spent in sedentary behaviour increased by 135.0 (± 46.0) minutes per day following COVID-19-related lockdowns. There was a statistically significant difference between children and adults, with higher increases in sedentary behaviour in children (+159.5 ± 142.6 minutes per day) than adults (+126.9 ± 42.4 minutes per day). In older adults, there was a non-significant increase in sedentary behaviour (+46.9 ± 22.0 minutes per day). For all age groups, increases in sedentary behaviour were apparent, regardless of COVID-19-related restrictions implemented at the time of data collection. In total, children spent 383.9 (± 138.2) minutes per day in sedentary behaviours. Adults and older adults spent 510.5 (± 167.9) and 586.3 (± 25.2) minutes per day in sedentary behaviours, respectively. There were no statistically significant differences by sex in children or adults. However, in adults, time spent in sedentary behaviours varied by geographic region, with adults residing in Asian countries spending less time in sedentary behaviours (350.7 ± 184.2 minutes per day) than adults in European countries (512.2 ± 225.3 minutes per day), North America (515.0 ± 146.0 minutes per day), and South America (530.0 ± 20.0 minutes per day). Regarding specific sedentary behaviours, screen time accounted for 57.2% of the total daily time spent in sedentary behaviour in adults. In children, screen time accounted for 46.8% of the total daily time spent sedentary.

According to the systematic review by Runacres and colleagues, several studies investigated the associations between changes in sedentary behaviour and health outcomes, with quality of life as the most commonly measured health outcome, followed by anxiety and depression, and global mental health. The authors found weak but statistically significant negative correlations between COVID-19-related increases in sedentary behaviour and poorer quality of life ($r^2 = -0.05$; $p > 0.05$) and global mental health ($r^2 = -0.10$; $p > 0.05$). Higher compared to lower amounts of sedentary behaviour were more likely to track with depression and anxiety (odds ratio (OR) = 1.35–1.57).

Another systematic review conducted by Rivera and colleagues investigated COVID-19-related changes in sedentary behaviour, specifically in undergraduate and graduate students during lockdowns [15]. The authors included a total of six studies in their systematic review (all of them were also included in the systematic review by Runacres et al.). Four studies reported results for undergraduate students, and two studies separately analyzed data for undergraduate and graduate students. Whereas time spent in sedentary behaviour increased in undergraduate students, graduate students did not show statistically significant changes in sedentary time during COVID-19-related lockdowns. Furthermore, the authors summarized the findings from studies on changes in physical activity in relation to pre-lockdown sedentary behaviour and showed that students who were more sedentary prior to the lockdown increased or did not change their levels of moderate-to-vigorous physical activity. However, students with lower levels of pre-lockdown sedentary behaviour decreased their levels of moderate-to-vigorous physical activity during COVID-19-related lockdowns. For more information regarding sedentary behaviour during the COVID-19 pandemic, see Sect. 23.1.5.

In sum, the COVID-19 pandemic affected the lives of many people—not only in terms of direct effects due to infection with COVID-19, but also in terms of changes in daily life. Altered patterns of sedentary behaviour are only one example. Due to COVID-19-related lockdowns, sedentary behaviour increased in many population groups. Although the COVID-19 pandemic is a global health challenge, it offers the opportunity to reconsider current patterns of sedentary behaviour and physical activity for the future (see Sect. 27.3) and to be prepared for future outbreaks of infectious diseases and other global changes that may affect human behaviour.

27.2.4 Global Environmental Change and Sedentary Behaviour

The COVID-19 pandemic is only one global health challenge that influences human behaviours, including sedentary behaviour. Another, and maybe "the biggest global health threat of the twenty-first century", is climate change [16]. Climate change impacts human health both directly and indirectly [17]. Heat stress, for example, leads to direct effects on human health such as heat-related illness—especially in vulnerable and disadvantaged population groups. Whereas there is increasing evidence that extreme temperatures, air pollution, and natural disasters have negative effects on levels of physical activity [18], the association between climate change and sedentary behaviour is less investigated. A mini umbrella review that investigated the interrelations of climate change, 24-hour movement behaviours, and health showed that there was no published systematic review that focused on the associations between climate change and sedentary behaviour [19]. However, a few studies investigated the association between certain aspects of climate change and sedentary behaviour. A cohort study that included 9000 students from Beijing, China, showed that an increase in air pollution was associated with an increase in the total number of weekly hours spent sedentary [20]. Another study revealed high levels of sedentary behaviour among children with post-traumatic stress as a result of having experienced the hurricane Ike [21]. Furthermore, natural environmental factors such as season of the year, precipitation levels, and photoperiod are related to sedentary behaviour and can promote or discourage sedentariness, although the strength of the evidence is not yet clear [22]. Thus, the direct and indirect effects of climate change on sedentary behaviour and its determinants need to be investigated in more detail.

In addition to climate change, global environmental change encompasses further aspects related to sedentary behaviour, such as urbanization. There is a strong interrelationship between urbanization, global environmental change, and urban health. Currently, more than 55% of the world's population lives in urban areas, and it is expected that by 2050 more than two-thirds of the world's population will be living in cities, whereby most urban growth will take place in developing countries [23]. Therefore, it is crucial to consider factors related to the built environment, such as urbanization level and availability of recreational facilities [24]. An increase in population density is associated with reduced levels of sedentary behaviour [25]. Furthermore, factors such as neighbourhood walkability, public transportation infrastructure, street connectivity, walking and cycling facilities, and access to services influence sedentary behaviour [26]. For further information regarding the neighbourhood environment and sedentary behaviour, see Sect. 23.2.6.

27.2.5 From National to Global Recommendations on Sedentary Behaviour

As part of public health measures, many countries have published recommendations to reduce sedentary behaviour. For the first time, the World Health Organization (WHO) in 2020 incorporated recommendations on sedentary behaviour for all age groups and subpopulations in their Guidelines on Physical Activity and Sedentary Behaviour (see Sect. 1.3) [27]. Those recommendations are of global health relevance because they are applicable to population groups worldwide, irrespective of country or region. They incorporate the most recent overall evidence regarding the adverse effects of prolonged sedentary behaviour and the importance of reducing such behaviour for human health. However, in order to achieve behavioural change and to improve public and global health, there is a strong need to move from recommendations and knowledge to action and to effectively implement guidelines in everyday practices. The WHO Global Action Plan on Physical Activity 2018–2030 provides the basis for global policy action to reduce sedentary behaviour [28].

Figure 27.1 shows a simplified representation of a public, global, and planetary health perspective on sedentary behaviour and sedentary behaviour epidemiology and existing guidelines.

27.3 A Planetary Health Perspective on Sedentary Behaviour

Planetary health is defined as “the achievement of the highest attainable standard of health, well-being, and equity worldwide through judicious attention to the human systems—political, economic, and social—that shape the future of humanity and the Earth’s natural systems that define the safe environmental limits within which humanity can flourish” [29]. In other words, “planetary health is the health of human civilisation and the state of the natural systems on which it depends” [29]. In line with the concept of planetary health, the Geneva Charter for Well-being states “the urgency of creating sustainable well-being societies, committed to achieving equitable health now and for future generations without breaching ecological limits” [30].

Whereas well-being societies are strongly interlinked with planetary health, the connection between planetary health, well-being societies, and sedentary behaviour may not be obvious at first glance. However, looking at lifestyle choices and human behaviour in general shows that “our lifestyle is making us ill and is destroying the planet” [31]. Specifically, the current scientific report of the Intergovernmental Panel on Climate Change (IPCC) shows that human lifestyles such as meat consumption, air conditioning, flying, and driving cars are among high carbon lifestyle choices on the rise [32]. Of course, it is not only driving cars but the transportation sector in general, and private motorized transportation in particular, that largely contribute to global greenhouse-gas emissions, energy consumption, and air pollution. Thus, driving a car constitutes a lose-lose option in terms of planetary health: it has negative effects on both the natural environment and human health. The adverse effects on human health, in turn, are based on local pollutant emissions and sedentary behaviour—risk factors that contribute to the development of various chronic diseases. Furthermore, the transportation sector substantially contributes to climate change that, in turn, affects human health.

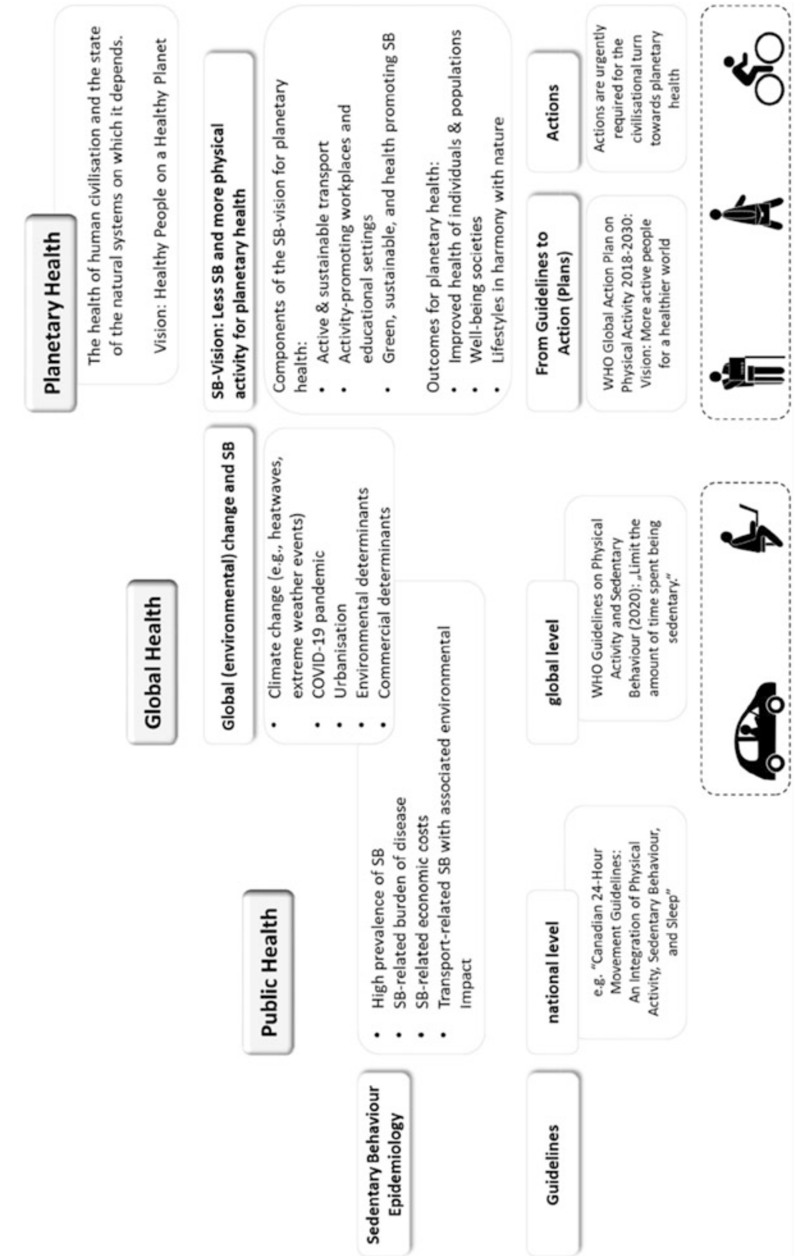

Fig. 27.1 A simplified representation of a public, global, and planetary health perspective on sedentary behaviour and sedentary behaviour epidemiology and existing guidelines. Abbreviation: *SB* sedentary behaviour

Although the bidirectional relationship between planetary health and sedentary behaviour is barely investigated, it is crucial for future research and policy actions to better understand sedentary behaviour from a planetary health perspective.

27.3.1 Sedentary Behaviour and the Global Action Plan for a Healthier World

The "Global action plan on physical activity 2018–2030: more active people for a healthier world" published by the WHO in 2018 sets out strategic objectives and policy actions to reduce levels of both physical inactivity and sedentary behaviour under consideration of the Sustainable Development Goals (SDGs) [28]. This global action plan applies to all countries worldwide, irrespective of their starting points regarding levels of physical activity and sedentary behaviour. The four objectives of the action plan are (1) Create active societies; (2) Create active environments; (3) Create active people; and (4) Create active systems. To achieve these four overarching objectives, the Global Action Plan recommends 20 evidence-based and multidimensional policy actions that can be implemented by all member states. Figure 27.2 shows the four objectives and 20 policy actions. Acknowledging that there is no single solution that fits different countries and contexts, the action plan offers a "system-based approach, universally applicable to all countries" [28]. The long-term goal for each country should be to achieve full implementation at a national scale. Figure 27.2 shows the existing challenges regarding sedentary behaviour and the four objectives and 20 policy actions proposed by the Global Action Plan on Physical Activity 2018–2030 for "more active [and less sedentary] people for a healthier world" [28].

27.3.2 Sedentary Behaviour and the Sustainable Development Goals (SDGs)

There are multiple direct and indirect pathways by which policies to reduce sedentary behaviour, especially through active transportation, contribute to the achievement of several SDGs. Table 27.1 provides an overview of selected SDGs with their corresponding targets and the pathways that may link sedentary behaviour with specific targets. Reducing sedentary behaviour will directly contribute to SDG3 (good health and well-being). Replacing sedentary behaviour (at least partly) with physical activity at school, at work, or during transportation are further ways towards achieving several SDGs. However, reducing transportation-related sedentary behaviour may have the strongest beneficial possibilities as a win–win strategy to minimize sedentary behaviour as a risk factor for human health and to enable active mobility for sustainability and planetary health. Furthermore, as people spend large

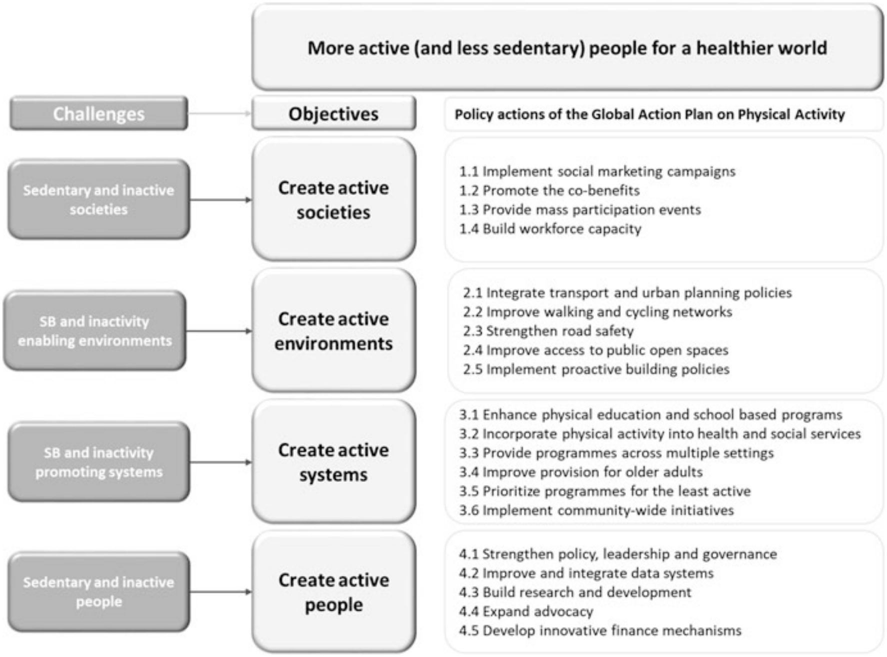

Fig. 27.2 The current challenges with regard to sedentary behaviour and the four objectives and 20 policy actions of the Global Action Plan on Physical Activity 2018–2030 (adapted from [insert Ref]). Abbreviation: *SB* sedentary behaviour

amounts of their time at work, the workplace is a further domain that may be promising with respect to win–win strategies for public and planetary health and well-being societies.

27.3.3 Vision: Health-Promoting Workplaces, Active Transportation, and Green and Health-Promoting Sedentary Behaviour as Win-Win-Strategies for Planetary Health and Well-being Societies

The two most promising domains that may lead to win-win situations for reductions in sedentary behaviour and improvements in planetary health are workplaces (including education) and transportation. However, sedentary behaviour per se should not be regarded as completely incompatible with planetary health. Recreational sedentary behaviour is necessary for the recovery of body and mind (as a response to sufficient physical activity). Another win-win strategy should therefore focus on the optimal dose and frequency of green, sustainable, and health-promoting sedentary behaviour.

Table 27.1 Selected examples of sustainable development goals (SDGs) and corresponding targets and the pathways that may link sedentary behaviour with these targets (adapted from [28)])

SDG	Target	Pathway
3 GOOD HEALTH AND WELL-BEING	3.4 reduce one-third of premature mortality from NCDs through prevention and treatment to promote mental health and Well-being	As a risk factor for the development of several NCDs, reducing levels of SB contribute to the prevention and treatment of NCDs. Reducing SB further will reduce overall mortality and promote mental health
	3.6 halve the number of global deaths and injuries from road traffic accidents	Reducing private motorized transportation and improving infrastructure that enables equitable access to safe walking, cycling, and use of public transportation contributes to a reduction in road traffic accidents while promoting increased physical activity participation and reducing transportation-related sedentary behaviour
	3.9 substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination	Replacing private motorized transportation (especially car use) by active mobility (e.g., walking and cycling) and public transportation decreases air pollution, thereby reducing the number of deaths and illnesses from air pollution
4 QUALITY EDUCATION	4.A build and upgrade education facilities that are child, disability, and sex sensitive and provide safe, nonviolent, inclusive, and effective learning environments for all	Better and effective learning environments should allow children to be active instead of sedentary (in safe, inclusive, and accessible places)
8 DECENT WORK AND ECONOMIC GROWTH	8.3 promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity, and innovation, and encourage the formalization and growth of micro-, small-, and medium-sized enterprises, including through access to financial services	Reducing work-related sedentary behaviour (both at the workplace and during commuting from and to work) can contribute to development-oriented policies for productive activities
	8.5 achieve full and productive employment and decent work for all women and men, including for young people and persons with	Reducing sedentary behaviour at workplaces can contribute to increased productivity as well as reduced absenteeism

(continued)

Table 27.1 (continued)

SDG	Target	Pathway
	disabilities, and equal pay for work of equal value	
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	9.1 develop quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure to support economic development and human Well-being with a focus on affordable and equitable access for all	Sustainable infrastructure to support Well-being should include walking and cycling networks. Replacing car use by walking and cycling can contribute to reduced levels of sedentary behaviour and increased levels of physical activity, thereby contributing to sustainable transportation and human Well-being
11 SUSTAINABLE CITIES AND COMMUNITIES	11.2 provide access to safe, affordable, accessible, and sustainable transportation systems for all, improving road safety, notably by expanding public transportation with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities, and older persons	Safe, affordable, accessible, and sustainable transportation systems for all should foster active transportation, including cycling and walking, and improve public transportation (also in terms of enabling activity instead of sedentary behaviour)
	11.3 enhance inclusive and sustainable urbanization and capacity for participatory, integrated, and sustainable human settlement planning and management in all countries	Sustainable town planning policies tend to support physical activity, as people are more physically active and less sedentary in dense, inter-connected urban areas
	11.6 reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	Improved transportation infrastructure contributes to increased walking, cycling and use of public transportation and decreased sedentary behaviour and automobile use, which in turn leads to fewer emissions and thereby reduces the adverse per capita environmental impact of cities
	11.7 provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons, and persons with disabilities	Universal and safe access to open green and public spaces facilitates the use of these spaces for physical activity, green exercise, and (green) sedentary behaviour
	11.A support economic, social, and environmental links between urban, peri-urban, and rural areas by strengthening national and regional developmental planning	Spatial and developmental planning needs to enable participation in physical activity and reduce sedentary behaviour, e.g., through compact local neighbourhood design that increases walking and cycling

(continued)

Table 27.1 (continued)

SDG	Target	Pathway
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	12.8 ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	Education for planetary health is necessary to access and understand the relevant information (within the complex information landscape) and to make informed decisions for health, sustainable development, and lifestyles in harmony with nature
13 CLIMATE ACTION	13.2 integrate climate change measures into national policies, strategies, and planning	Policies, strategies, and planning that include both climate change measures and measures targeting physical activity and sedentary behaviour (e.g., reduced sedentary behaviour and automobile use and increased physical activity by walking and cycling) helps mitigate climate change and has co-benefits for human health

Note: The use of the SDG icons in this table is with permission from the United Nations. The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or member states. For further information on the United Nations SDGs, see https://www.un.org/sustainabledevelopment/

Thus, the vision of less sedentary behaviour for planetary health includes the following components (see Fig. 27.1):

1. **Active transportation.**

Active transportation offers a great opportunity to fight both climate change and sedentary behaviour. Cycling, walking, or other modes of active transportation instead of sitting and driving a car leads to reduced emissions (see Table 27.1) and thereby helps mitigate climate change. Furthermore, active modes of transportation replace sedentary behaviour and reduce health risks associated with sedentary behaviour. Therefore, a sustainable urban and rural infrastructure in line with the SDGs is necessary.

2. **Activity-promoting workplaces and educational settings.**

Workplaces and educational settings that enable health-promoting activity patterns instead of sedentary behaviour may increase the positive effects of physical activity and decrease the adverse effects of sedentary behaviour on human health. Furthermore, knowledge regarding the co-benefits of physical activity for human and planetary health can be provided and acquired across all levels of education. Together with activity-promoting educational settings and workplaces, this knowledge may lead to a planetary health literate well-being of society.

3. **Green, sustainable, and health-promoting sedentary behaviour.**

There is little research on the beneficial effects of limited amounts of sedentary behaviour for the recovery of the body and mind. In addition, sedentary behaviour is often accompanied by social interaction (e.g., during meals) that may positively influence human health. Thus, the vision of less sedentary behaviour for planetary health encompasses the "right" amount of sedentary behaviour that is beneficial for human health and relates to settings and contexts where sedentary behaviour may be in line with planetary health. For example, sitting on a bench in a green urban space or on a tree trunk in the forest can be considered green and sustainable sedentary behaviour (compared to sitting while driving a car). However, the health effects of such green and sustainable sedentary behaviour are not yet investigated and could be addressed in the context of the emerging research area around green exercise [33].

This vision and its main components bear great potential for several outcomes. Less sedentary behaviour and increased physical activity leads to improved health of individuals and populations, thus improving public and global health. They enable lifestyles in harmony with nature, thus improving planetary health. Furthermore, they positively contribute to well-being societies.

27.3.4 Challenges for Reducing Sedentary Behaviour for Planetary Health

It has to be acknowledged that the above-mentioned vision needs to be investigated in more detail. The scientific evidence base that already exists for the adverse health effects of excessive sedentary behaviour and the negative environmental impact of car use is often restricted to its corresponding research sector (i.e., sedentary behaviour research or transportation research). This separation of research areas is reflected by separately acting policy sectors. As suggested by the WHO Global Action Plan for Physical Activity, there is a need for a whole-of-government approach that uses cross-sectoral synergies.

Furthermore, there is a need to move from knowledge to action because large-scale political and societal actions are urgently required for the civilizational turn towards planetary health. The broader planetary health challenges, i.e., knowledge, imagination, and implementation challenges [29], also apply to sedentary behaviour in the context of planetary health.

Addressing these challenges will make it necessary to address commercial determinants that influence sedentary behaviour. Specifically, the role of the automobile industry in policy decisions should be investigated in more detail. Furthermore, the sociocultural and socioeconomic determinants of sedentary behaviour need to be addressed in order to achieve a planetary health vision of sedentary behaviour. Here, the role of habits may be crucial, and the potential of educational systems that promote physical activity instead of sedentary behaviour should be considered.

Taken together, broadening the current sedentary behaviour research perspective from public and global health to a holistic planetary health approach will create several new research questions regarding sedentary behaviour.

27.4 Summary

Facing the high prevalence of sedentary behaviour in the context of global environmental change, this chapter considers sedentary behaviour epidemiology from a public, global, and planetary health perspective. The chapter provides a global (public) health perspective on sedentary behaviour, with a focus on the economics of sedentary behaviour and on COVID-19 as a global health challenge and its relation to sedentary behaviour. Furthermore, sedentary behaviour is considered from a holistic, planetary health perspective. This chapter presents a vision of the potential role of sedentary behaviour for planetary health and well-being societies. Future research on the complex interrelatedness between sedentary behaviour and planetary health is necessary.

References

1. G. B. D. Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990-2019: a systematic analysis for the global burden of disease study 2019. Lancet. 2020;396(10258):1223–49.
2. Dempsey PC, Biddle SJH, Buman MP, Chastin S, Ekelund U, Friedenreich CM, et al. New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. Int J Behav Nutr Phys Act. 2020;17(1):151.
3. Vallance JK, Gardiner PA, Lynch BM, D'Silva A, Boyle T, Taylor LM, et al. Evaluating the evidence on sitting, smoking, and health: is sitting really the new smoking? Am J Public Health. 2018;108(11):1478–82.
4. US Department of Health and Human Services. The health consequences of smoking - 50 years of progress: a report of the surgeon general. Atlanta, GA: Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2014.
5. Rezende LFM, Sa TH, Mielke GI, Viscondi JYK, Rey-Lopez JP, Garcia LMT. All-cause mortality attributable to sitting time: analysis of 54 countries worldwide. Am J Prev Med. 2016;51(2):253–63.
6. Fenelon A, Preston SH. Estimating smoking-attributable mortality in the United States. Demography. 2012;49(3):797–818.
7. Ding D, Lawson KD, Kolbe-Alexander TL, Finkelstein EA, Katzmarzyk PT, van Mechelen W, et al. The economic burden of physical inactivity: a global analysis of major non-communicable diseases. Lancet. 2016;388(10051):1311–24.
8. Heron L, O'Neill C, McAneney H, Kee F, Tully MA. Direct healthcare costs of sedentary behaviour in the UK. J Epidemiol Community Health. 2019;73(7):625–9.
9. Lam K, Baurecht H, Pahmeier K, Niemann A, Romberg C, Biermann-Stallwitz J, et al. How effective and how expensive are interventions to reduce sedentary behavior? An umbrella review and meta-analysis. Obes Rev. 2022;23(5):e13422.

10. Munir F, Miller P, Biddle SJH, Davies MJ, Dunstan DW, Esliger DW, et al. A cost and cost-benefit analysis of the stand more AT work (SMArT work) Intervention. Int J Environ Res Public Health. 2020;17(4):1214.
11. Sevick MA, Dunn AL, Morrow MS, Marcus BH, Chen GJ, Blair SN. Cost-effectiveness of lifestyle and structured exercise interventions in sedentary adults: results of project ACTIVE. Am J Prev Med. 2000;19(1):1–8.
12. Nguyen P, Le LK, Ananthapavan J, Gao L, Dunstan DW, Moodie M. Economics of sedentary behaviour: a systematic review of cost of illness, cost-effectiveness, and return on investment studies. Prev Med. 2022;156:106964.
13. Stockwell S, Trott M, Tully M, Shin J, Barnett Y, Butler L, et al. Changes in physical activity and sedentary behaviours from before to during the COVID-19 pandemic lockdown: a systematic review. BMJ Open Sport Exerc Med. 2021;7(1):e000960.
14. Runacres A, Mackintosh KA, Knight RL, Sheeran L, Thatcher R, Shelley J, et al. Impact of the COVID-19 pandemic on sedentary time and behaviour in children and adults: a systematic review and meta-analysis. Int J Environ Res Public Health. 2021;18(21):11286.
15. Rivera PA, Nys BL, Fiestas F. Impact of COVID-19 induced lockdown on physical activity and sedentary behavior among university students: a systematic review. Medwave. 2021;21(8):e8456.
16. Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, et al. Managing the health effects of climate change: lancet and University College London Institute for Global Health Commission. Lancet. 2009;373(9676):1693–733.
17. Rocque RJ, Beaudoin C, Ndjaboue R, Cameron L, Poirier-Bergeron L, Poulin-Rheault RA, et al. Health effects of climate change: an overview of systematic reviews. BMJ Open. 2021;11(6):e046333.
18. Bernard P, Chevance G, Kingsbury C, Baillot A, Romain AJ, Molinier V, et al. Climate change, physical activity and sport: a systematic review. Sports Med. 2021;51(5):1041–59.
19. Zisis E, Hakimi S, Lee EY. Climate change, 24-hour movement behaviors, and health: a mini umbrella review. Glob Health Res Policy. 2021;6(1):15.
20. Yu H, Cheng J, Gordon SP, An R, Yu M, Chen X, et al. Impact of air pollution on sedentary behavior: a cohort study of Freshmen at a University in Beijing, China. Int J Environ Res Public Health. 2018;15(12):2811.
21. Lai B, La Greca A, Llabre M. Children's sedentary activity after hurricane exposure. Psychol Trauma Theory Res Pract Policy. 2014;6(3):280–9.
22. Turrisi TB, Bittel KM, West AB, Hojjatinia S, Hojjatinia S, Mama SK, et al. Seasons, weather, and device-measured movement behaviors: a scoping review from 2006 to 2020. Int J Behav Nutr Phys Act. 2021;18(1):24.
23. World Health Organization. Urban Health: WHO; 2022. Available from: https://www.who.int/health-topics/urban-health#tab=tab_1.
24. Buck C, Loyen A, Foraita R, Van Cauwenberg J, De Craemer M, Mac Donncha C, et al. Factors influencing sedentary behaviour: a system based analysis using Bayesian networks within DEDIPAC. PLoS One. 2019;14(1):e0211546.
25. Van Cauwenberg J, Loyen A, Lakerveld J, Cardon G, De Craemer M, Gheysen F, et al. Differential influences of population densification and economic growth on Europeans' physical activity and sitting time. Cities. 2018;82:141–9.
26. O'Donoghue G, Perchoux C, Mensah K, Lakerveld J, van der Ploeg H, Bernaards C, et al. A systematic review of correlates of sedentary behaviour in adults aged 18-65 years: a socio-ecological approach. BMC Public Health. 2016;16:163.
27. World Health Organization. WHO guidelines on physical activity and sedentary behaviour. Geneva: WHO; 2020.
28. World Health Organization. Global action plan on physical activity 2018–2030: more active people for a healthier world. Geneva: WHO; 2018.

29. Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, de Souza Dias BF, et al. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation-lancet commission on planetary health. Lancet. 2015;386(10007):1973–2028.
30. World Health Organization. The Geneva Charter for Well-being. Geneva: WHO; 2021.
31. German Advisory Council on Global Change (WBGU). Planetary health: what we need to talk about. Berlin: WBGU; 2021.
32. IPCC. Climate Change 2022: Impacts, adaptation, and vulnerability. contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change. In: Pörtner H-O, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A, Rama B, editors. IPCC. Cambridge: Cambridge University Press; 2022.
33. Loureiro A, Veloso S. Green exercise, health and Well-being. In: Fleury-Bahi G, Pol E, Navarro O, editors. Handbook of environmental psychology and quality of life research, international handbooks of quality-of-life. Champaign, Illinois, USA: Springer International Publishing Switzerland; 2017. p. 149–69.

Chapter 28
Ergonomic Support for Physiologically Correct Sitting

Joachim Grifka

Abstract The need to work from home due to the COVID-19 pandemic led to numerous musculoskeletal conditions, especially those of the spine. Whereas institutions typically provide employees with specially equipped computer workstations, working from home potentially lacks adequate ergonomic support for physiologically correct sitting. Studies revealed excessive strain to the spine resulting from incorrect sitting. In order to address this issue, we recommend improvements to office equipment, particularly to the backrest of the chair. Whereas the usual contour of a conventional backrest induces lumbar hyperlordosis leading to unhealthy anatomical stress, we recommend the introduction of thoracic support with specially positioned pads.

Key Points

- The COVID-19 pandemic led to significant changes with enforced working from home, adding to already existing health problems resulting from excessive sedentary behaviour, especially spinal diseases.
- Guidelines for setting up computer workstations in institutions must be applied to working from home circumstances.
- Recommendations for bodily movement and improving home office equipment are made.
- Results of our research suggest that chairs with a thoracic pad provide improved support, thereby avoiding lumbar hyperlordosis.
- An ergonomic solution is provided for a complete home office station, which ensures physiologically correct chair and desk positioning, namely with a standing desk, adequate lighting, and safety measures.

J. Grifka (✉)
Department of Orthopaedics, University of Regensburg, Regensburg, Germany

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_28

28.1 Orthopaedic Problems Due to Unhealthy Workplaces

Early studies revealed that poor ergonomics in the workplace, including working from home, may adversely affect musculoskeletal health [1], but even large reviews fail to provide biomechanical considerations or practical advice for physiologically correct sitting [2]. Some reports acknowledge a deterioration of ergonomic conditions but do not provide potential solutions [3] or describe the unfavourable ergonomic status quo and propose more appropriate desks and chairs but do not follow agreed-upon prerequisites [4]. Individual studies report that creating ergonomic working conditions reduces muscle tenseness [5, 6] and that improvements in chair design tend to decrease musculoskeletal symptoms [7]. However, a Cochrane review of 15 RCTs and 2165 workers showed inconsistent, low, or very low evidence that an arm support, a computer mouse, or taking breaks resulted in reduced musculoskeletal disorders of the neck, right shoulder, upper arm, right forearm, wrist, or hand. Further, the use of sit-to-stand desks showed no positive effect on upper limb pain and discomfort [8]. These findings highlight the need to more closely examine the biomechanical load and non-physiological positioning of the body during sitting.

In the past, epicondylitis presented as a disease typically arising from excessive use of a typewriter. With computer use, that condition has completely disappeared. Also, one no longer finds tendinitis or other forms of inflammation as a result of strenuous finger movement against the resistance of typewriter keys. Instead, one now frequently encounters the so-called repetitive strain injury, which is the result of continuous enforced tension of the extensor muscles due to constant overload when holding the forearms in a horizontal position. Tenseness can reach up to the neck and head.

As early as 2007, a survey of 1000 employees doing computer work showed that 54% of respondents experienced neck pain within 12 months of having commenced work [9]. As people have progressively been turning to home offices in recent years, the number of outpatients with neck complaints in our clinic increased by about 40%. Complaints typically include head and neck pain, problems of the cervical spine, including disc protrusions and extrusions, increased severe muscle tension, and nerve disorders of the arm. This is not surprising given the circumstances under which working on a computer often takes place at home. Frequently, there is no proper place to work: the laptop is often simply placed on the lap or on a coffee table, an appropriate office chair is lacking, and there is no space to place documents like when working at a desk.

In line with the increasing number of patients complaining about neck pain due to computer work, we observed an increased number of patients with lower back pain. Similarly, a cross-sectional study of 528 office workers found that 55% of respondents complained about lower back pain, with females suffering more than males [10]. Figures nearly doubled during the first year of the COVID-19 pandemic. A cross-sectional survey of 4112 people working from home during COVID-19 suggested that disproportionate office equipment was related to musculoskeletal problems, independent of age [11]. Thus, there is a need to more closely examine non-physiological sitting equipment, including modern desk chairs.

28.2 Orthopaedic Reflections

From an orthopaedic point of view, people should aim to achieve a healthy sitting position, keep the muscles active, counteract fatigue, and prevent pain and discomfort. It is generally accepted that children should not sit in the same bodily position for too long. However, they are taught to sit quietly at nursery school. When travelling in vehicles, they sit in child car seats for safety reasons. At school, they need to sit for hours and, moreover, most of them spend several hours on their computers or mobile devices, again in a seated position. Finally, upon completing their education, many people start working in an office, once more being forced to sit most of the time. This puts the body under excessive stress. Ideally, people should move around and not sit constantly, alternating regularly between sitting and moving or standing, and when sitting, this should take place in a physiologically correct posture.

In general, one can distinguish between two unfavourable ergonomic scenarios: inappropriate office equipment and appropriate office equipment used incorrectly. Using a conventional office chair to sit at a desk leads to slumping of the upper body. The shoulders are bent forward, and the thoracic spine is curved to a kyphosis (exaggerated forward rounding), hampering the expansion of the thorax and lungs. The back muscles are overstretched, whereas the chest muscles are shortened or even contracted. If such sitting is combined with working on a monitor, the head is raised to look at the screen. This gives rise to hyperlordosis (exaggerated inward curve) of the cervical spine, which can cause increased muscle tension in the neck and shoulders. Over time, hyperlordosis of the cervical spine can result in spinal lesions, with disc protrusions and extrusions and even nerve compression. In addition, traditional lumbar pads induce forward tilting of the pelvis, producing hyperlordosis of the lumbar spine. Thus, from an orthopaedic perspective, using inappropriate office equipment or using appropriate office equipment incorrectly causes two adverse postural conditions adversely affecting the spine, namely, enforced lordosis of the cervical spine and enforced lordosis of the lumbar spine.

Figure 28.1 illustrates the consequences of lordosis in the cervical and lumbar spine. When the spine is straight, the dorsal bony structures (facet joints) are not in contact with one another, and the opening through which the nerve root leaves the spinal canal (foramen intervertebrale) is wide. The opposite occurs when the spine is lordotic: the facet joints are pressed together, and the foramen is narrow. This may lead to pain in the area where the facets are compressed and to referred pain along the course of the nerve to the arm or leg. In lumbar spinal stenosis, a narrowing of the spinal canal common among people over aged 50 years, lordotic bending leads to

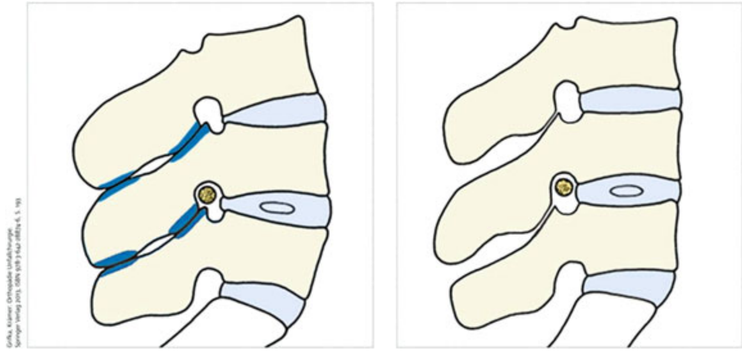

Fig. 28.1 Comparison between lordosis (left) and straight spine (right). Left: Compression of facet joints and spinal processus with a narrowing of the intervertebral foramen and enforced load on the dorsal disc. Right: Relief of the facet joints and spinal processus with enlargement of the intervertebral foramen and relief of the dorsal disc

Fig. 28.2 Typical side view of enforced lumbar lordosis leading to unfavourable static load

spinal cord or nerve compression, causing numbness and dysaesthesia of the limbs. On the other hand, straightening the spine and avoiding lordosis provides space for the spinal cord and nerve roots. This explains the need to avoid lumbar pads and slumping of the thoracic spine leading to cervical hyperlordosis (Fig. 28.2).

28.3 Requirements for Seats

In general, one can distinguish between seats in a vehicle, seats for relaxing at home, and seats for working at a desk. A seat in a vehicle needs to accommodate bodily reactions due to speed and changes in direction while driving. Whereas the seats of train drivers or pilots normally do not need to be adapted to quick changes of direction, drivers' seats in cars, trucks, etc., need to match lateral forces. For high-speed vehicles, driver stability is paramount, the extreme case being racing cars. They are built to accelerate quickly, with strong lateral forces coming into play when negotiating bends. In such situations, the body needs to be restrained to resist the different forces using a customized seat shell that exactly matches the body size. The torso of the driver needs to be kept in a fixed position so that they can react with free momentum. Specifically, the torso is tilted slightly backwards, the knees are slightly bent, and no movement of the pelvis or trunk takes place (Fig. 28.3).

Seats in ordinary cars used for daily travel permit more freedom of movement than racing car seats, but in principle, the seat follows the same principle of keeping the body stable while the driver can respond to the effects of the speed and movement of the vehicle. Ordinary cars typically lack individual seat shells, but

Fig. 28.3 Formula 1 seat, which represented merely a shell and belonged to world champion Michael Schumacher

Fig. 28.4 **a + b** Development of car seats: Goggomobil with basic seats

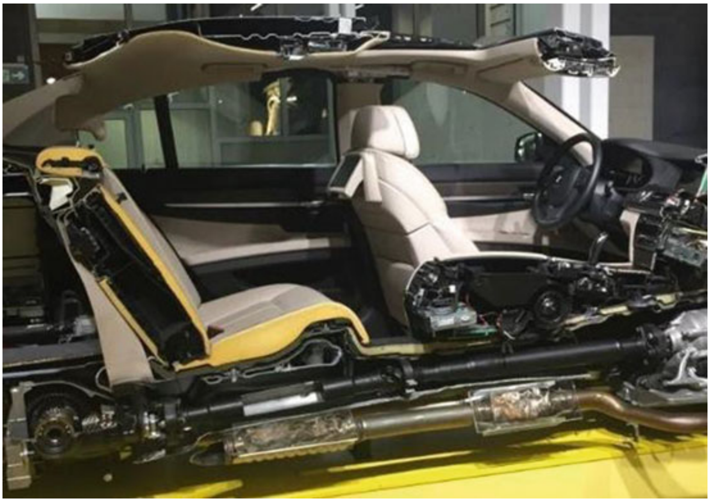

Fig. 28.5 Upper class luxury seats

they do include various elements of lateral support for the torso and support for the thighs, which are normally adjustable to individual preference, with up to 14 small devices mounted for such adjustments, adding additional weight to the vehicle (Figs. 28.4, 28.5 and 28.6).

In electric vehicles, the weight of the seat needs to be substantially reduced. Therefore, the seat is much thinner, and it needs to be adjustable using fewer mechanisms to reduce weight and extend the vehicle's range (Fig. 28.7).

In the 1970s, RECARO developed a seat with lumbar support, enforcing lordosis of the lumbar spine. The seat was similar to that of racing cars and was subsequently introduced to passenger vehicles. Ever since, passenger car seats include pads down low on the backrest that tilt the pelvis forward and produce enforced lordosis. In contrast to the original, rather bulky RECARO seat, subsequent research led to the development of an ultra-light seat that meets the physiological demands of correct

Fig. 28.6 Thin seat shells for an e-car

positioning of the spine and avoids anterior pelvis tilt and lumbar lordosis. Moreover, it provides additional useful features, making it an excellent seat for extended use by professional drivers. For use in delivery trucks for short distances, the seat is fixed in a rotational frame (Fig. 28.8).

28.4 Conditions for an Office Chair

Office chairs vary widely. Most can rotate between the leg frame and the seat plate. The lower part of the chair can consist of a four-legged stand or an underframe of five castors. The chair itself can exhibit more or less elaborate seat plates and backrests. These can be basic, or they can follow the body contour, with a rounding on the front edge of the seat and curvatures on the backrest. They typically include a lumbar pad, which increases anterior pelvic tilt and lumbar lordosis. Armrests are helpful to maintain a stable arm position, for example, when typing, because they help minimize continuous muscular action required to hold the forearms in a horizontal position. Headrests are not normally used when working at a desk and therefore represent a more symbolic addition to an office chair.

Fig. 28.7 The first vehicle seat with lordotic support: Recaro Orthopäd

In an increasing number of chair models, the coupling between the leg frame and the seat plate has both the ability to rotate and to be flexible for sideward inclination. This tilts the seat plate sideways when the seated person shifts their weight to one side. Such sideward tilting is minimal but induces the muscular activity of the body core, such that static sitting is transformed into dynamic sitting. Dynamic sitting is an effective method to counteract muscle fatigue, and it helps train muscles to keep the torso upright. In a systematic study amongst 74 office workers, we showed that a slightly flexible buttock plate reduced impairments due to back pain, as evidenced by an approximately 50% improvement in the Oswestry Disability Index [12], a tool for assessing functional status in patients with low back pain. Dynamic sitting is distinct from other approaches that fail to address important ergonomic and orthopaedic requirements for healthy sitting, such as stationary bicycles integrated in desk workspaces.

28.5 Thoracic Support for Correct Vertebral Positioning

The problem of lordosis of the lumbar and cervical spine, induced by a lumbar pad and due to slumping of the body, can be solved by introducing thoracic support. This allows for a straight lumbar spine with adequate space for the nerve roots in the spinal canal and nerves passing through the foramina. Moreover, it provides support

Fig. 28.8 Ultra-light vehicle seat with integrated thoracic support

for the back and prevents the body from slumping, the latter of which leads to cervical lordosis.

For a vehicle seat, we integrated thoracic support using a V-shaped pad that can take the load while ensuring a comfortable sitting position and allowing the driver to lean back, thereby remaining in continuous contact with the backrest. The V-shape ensures that the pad has an appropriate size for persons of different body lengths.

Whereas a fixed position is required for thoracic support in a car seat, flexible support is needed when it comes to office chairs. To enable the body to move freely, the thoracic pads need to give way when bending to the side or slightly turning the body. This is achieved by the thoracic pads either being anchored at one or two points to allow flexibility of the pads or by separate pads being arranged for the right and left body halves. The pads need to be height-adjustable to provide support to the lower thoracic area according to body length (Figs. 28.9, 28.10 and 28.11).

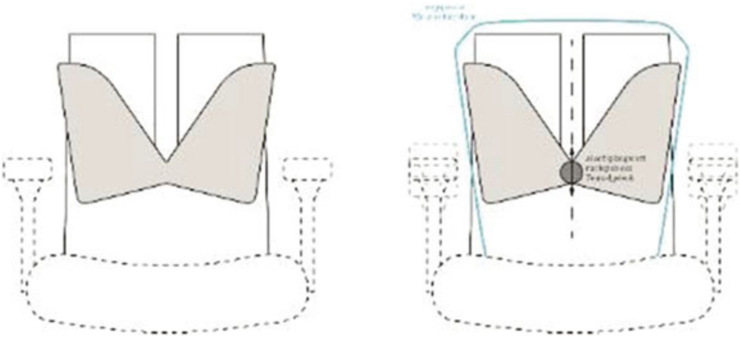

Fig. 28.9 Arrangement of thoracic pads with individual adjustments in height and width

28.6 Specific Requirements and Solutions for a Home Office Unit

The COVID-19 pandemic fundamentally changed the way people conduct office work and attend meetings. The need to keep a safe distance and avoid personal contact led to an abrupt need for more home office space. Following the widespread introduction of home office circumstances, the work sphere entered employees' personal living space. Because housing tends to be expensive in urban areas, most people lacked access to a dedicated home office and needed to make due with the limited space they had. Many people were unable to install a home office desk and position a monitor in an appropriate way and thus were faced with the so-called "kitchen meetings", placing their laptops on the kitchen table, on the sofa, or simply on their laps. Workplace regulations existing in some countries could not be followed in home office settings, even though institutions remained accountable for providing their employees with appropriate work environments and were mandated to compensate for absenteeism resulting from work-related illnesses or disorders.

In major cities, the so-called "third places" were introduced (first place: home environment; second place: work environment). Whereas originally, a third place represented a neighborhood space for people to gather, talk, and interact [3], today's third place refers to a specifically arranged work environment that avoids the challenges of working from home. For example, WeWork is a privately held company that rents communal or co-working office space for short-term use. Similarly, hotels facing financial losses as a result of COVID-related travel restrictions began offering rooms for use as quiet, individual work spaces, although those spaces merely consisted of a small desk in a room originally designed for spending the night.

A study published by the University of Darmstadt reported that 7% of employees in Germany were open to considering alternative workspaces to the traditional office and the home office [4]. In addition, co-working space tends to spawn positive

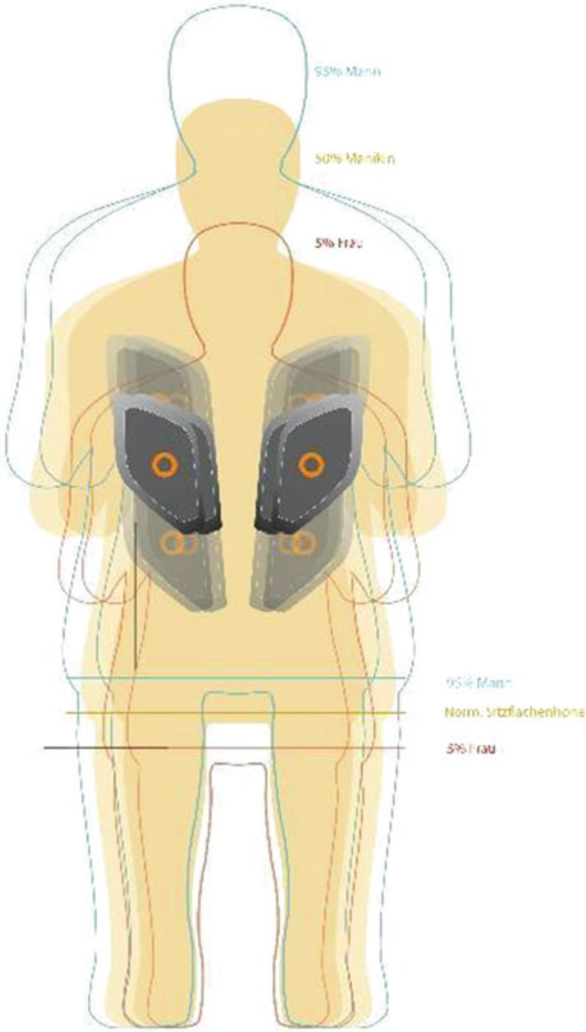

Fig. 28.10 Ergonomic study of a multifunctional seat with adjustable thoracic pads providing thoracic support

effects on traditional working environments such that today, corporations provide superior working environments for office employees. Appropriate working conditions are also highly relevant to the home office. Moreover, people currently tend to have longer working lives, and elderly office workers need ergonomically adequate home office environments to avoid the risk of developing degenerative musculoskeletal conditions.

Fig. 28.11 Office chair with thoracic pads that can be adjusted to individual needs

28.7 Ergonomic Parameters for Computer Work Space

Over the past hundred years, there have been significant changes in office furniture design. Not all those modifications are beneficial to musculoskeletal health. For example, schools used to feature desks with slanted tabletops, whereas nowadays schools use flat tabletops. Today, we recognize that a flat tabletop makes the body bend forward and curves the spine, whereas a slight tabletop slope of about 15 degrees ensures a more physiologic positioning of the spine and proper desk posture. Thus, in some ways, school furniture used to have superior design compared to today (Figs. 28.12 and 28.13).

Certain fundamental parameters for correct ergonomic chair, desk, and monitor arrangement must be fulfilled in our daily routine to meet human physiological needs and protect our health. Among these is the so-called three-level placement, where the feet, thighs, and forearms should all be oriented in a horizontal plane. The seat has the right height when the feet are placed flat on the ground with the thighs in a horizontal position. The desk should be positioned slightly lower than the forearms so that they need not be elevated when the fingers are placed on the keyboard, but rather, can remain in a resting position without muscle activation. This avoids repetitive strain injury of the extensor muscles of the lower arm. The front edge of

Fig. 28.12 School desk more than 100 years old, fulfilling ergonomic requirements

Fig. 28.13 Left panel: tilted desktop for upright sitting. Right panel: positioning of the screen to keep the head slightly flexed

the seat should leave about a hand's width space to the hollow of the knees. The top of the monitor should be positioned a little lower than the eyes so that the head is slightly flexed. This avoids having to look up and provoking increased lordosis of the cervical spine. The distance between the eyes and the screen should be about 50 cm, depending on screen size. To perform paperwork, the tabletop should be tilted about 10 to 15 degrees [13]. The lighting of the table area should be at least 500 lux [14].

In addition, it is advisable to use a standing desk to allow changes in body position throughout the work day. This can be organized by elevating the regular desk or, better still, using a dedicated standing desk for all office activities that can be done standing. When standing, it is important to refrain from simply placing both feet flat on the ground, because such a body position enforces lumbar lordosis. Rather, the standing desk should include a footrest allowing one foot to be positioned slightly higher than the other, which avoids exaggerated inward curving of the lumbar spine. Using a footrest in this manner, people can learn to become aware of what a normally aligned lower back feels like [13].

According to a US study, the cost–benefit ratio for ergonomic improvements ranges between US$ 2.3 and US$ 5.9 for each dollar spent [15]. On average, productivity improves by 25%, and loss of productivity decreases by 75% [16].

28.8 Specific Requirements and Solutions for a Home Office Unit

Home office work not only requires IT support but must also follow specific ergonomic considerations. We developed a home office unit with the aim of creating an arrangement that fulfils ergonomic requirements by not only individually focusing on a chair or desk but providing a comprehensive environment for an individual working pod or co-working space. Three models were developed to serve individual needs. The first model is a basic version that can be used as a mobile office terminal (Fig. 28.14).

The second model is a unit integrated into a closet, whereas the third model additionally contains all items necessary for a healthy work space that can be completely closed and locked to guarantee data protection (Fig. 28.15).

The complete unit consists of a portable closet with a height-adjustable desk with optional slope. A shelf helps store items as large as folders. It has space for a computer with a monitor, and it supplies optimal lighting. The doors can be opened 180 degrees, and they contain further elements for ergonomic working, including a foldable, stable standing desk with a footrest (Fig. 28.16).

The chair plays an important role in this office unit. In model 3, a chair with all the necessary features needed for healthy sitting is integrated into the unit. The chair is attached to the frame of the mobile closet. It can be pulled out from the stowed position. The backrest has a frame that can be lowered such that it can be positioned

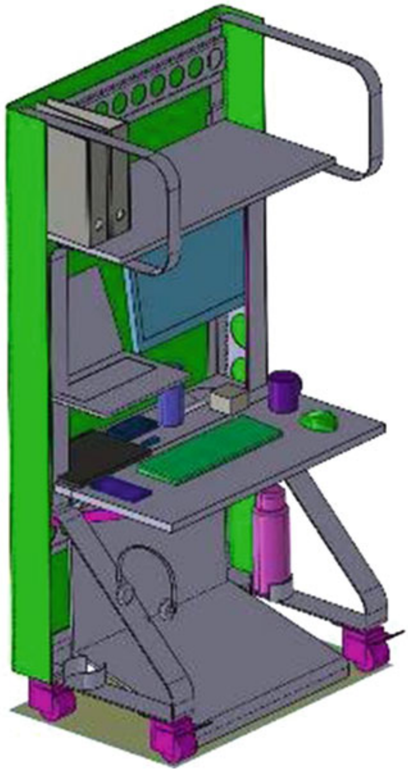

Fig. 28.14 Basic mobile office terminal

under the desk. The heights and widths of the thoracic pads attached to the Y-shaped back frame are individually adjustable. The unit enables long periods of focused computer work under ideal ergonomic conditions, and it fulfills all safety requirements, including data protection. Lack of a suitable work environment has been shown to represent one of the top adverse health stressors [17], highlighting the importance of reducing occupational stress in the home office setting.

28.9 Advantages of Desk Sharing, Mobile Working, and Working from Home

The COVID-19 pandemic has changed peoples' attitudes towards new types of desk work. Digitalization affects our daily routine in many ways. Employees, especially young and middle-aged desk workers, are accustomed to digital communication and work. The traditional mindset of attempting to get everyone physically "on board" in the office setting is outdated. Indeed, studies have shown the benefits of working from home. Positive effects include, for example, that family life is better supported when one partner has more time for children, the partner, or a family member in need

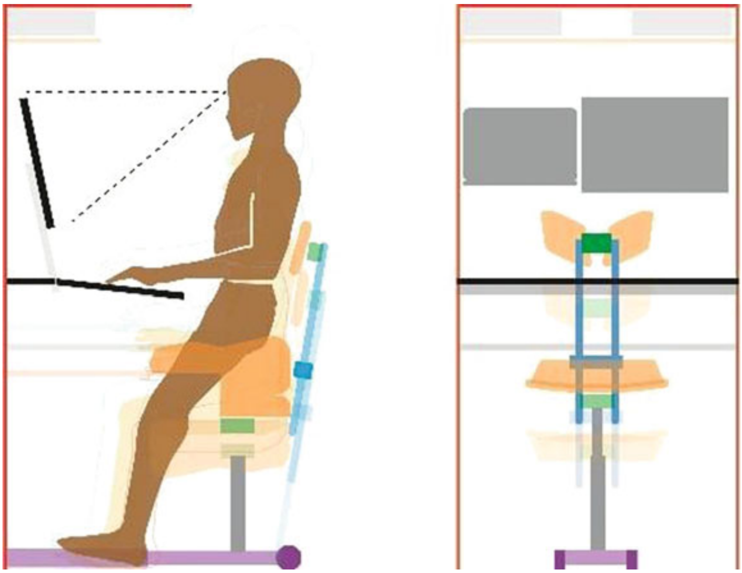

Fig. 28.15 Schematic diagram of models 2 and 3 with back friendly, adjustable seat and movable thoracic pads

Fig. 28.16 Hybrid office terminal (model 3), which features a height adjustable and tiltable desktop, a foldable desk serving as a large working area with additional space, a footrest, and an integrated seat

of care. Such flexibility allows for an improved work-life balance [18]. According to an estimate from Germany, 80% of time saved by not having to commute on a daily basis is spent as additional time with family [19].

Working from home also generates numerous advantages for businesses. Companies save on rental space and fixed costs, including office furniture, housekeeping, sanitary expenses, electricity, heating, and wear and tear. In addition, working from home opens the labor market to employees who prefer more freedom in determining the times they work [19]. However, home office also bears the risk of working overtime if it is not accompanied by self-responsible time management. In the future, we expect office work to continue to be newly defined.

In the 1990s, the concept of New Ways of Working was introduced for digitalization, offering flexible work time and local independence [20]. Traditional office-based work will continue to shift to desk sharing, mobile working, and mostly working from home. Before the COVID-19 pandemic in 2018 and 2019, only 8.6% of office employees in Germany worked from home [21], and only 26% of companies conceived offering staff the option to work from home [22]. The pandemic subsequently led to a rapid transformation from office-based work to working from home. For example, a survey conducted in Germany during the pandemic in March 2020 showed that office work was reduced to a core team physically present at the office, with 43% of 1595 employees working at least partly from home [23]. During the lockdown in Germany, 10,5 million employees reportedly worked exclusively from home, and 8,3 million employees worked partially from home [24]. One study showed that office workers claimed spending 54–57% of their time working from home, corresponding to two to three days per week [4]. According to a survey, 68% of all interviewed employees were positive that they could fulfill their tasks at home [23]. Working from home on a regular basis also represents a step towards reducing greenhouse gas emissions. A systematic review reported that time flexibility and reduction of carbon emissions and air pollution correspond to about 30% of overall perceived advantages of teleworking [25]. Mark Zuckerberg predicts that in 10 years' time, half of Facebook's employees will be working from home and that, in general, 20% of all employees will constantly be working from home. Others predict that in the future, institutions will offer a larger number of employees the possibility of working from home [26].

References

1. Mann S, Holdsworth L. The psychological impact of teleworking: stress, emotions and health. N Technol Work Employ. 2003;18:196–211.
2. Grifka J, Tingart M, Hofbauer R, Peters T. Der Bürobildschirmarbeitsplatz aus orthopädisch-arbeitsmedizinischer Sicht. Orthopade. 2002;31:1015–22.
3. Oldenburg R, Brissett D. The third place. Qual Sociol. 1982;5:265–84.
4. Pfnür A, Gauger F, Bachtal Y, Wagner B. Homeoffice im Interessenkonflikt: Ergebnisbericht einer empirischen Studie. Technische Universität Darmstadt, Forschungscenter Betriebliche Immobilienwirtschaft; 2021. Available from: http://hdl.handle.net/10419/250143.
5. Hassaïne M, Hamaoui A, Zanone P-G. Effect of table top slope and height on body posture and muscular activity pattern. Ann Phys Rehabil Med. 2015;58:86–91.
6. Dowler E, Kappes B, Fenaughty A, Pemberton G. Effects of neutral posture on muscle tension during computer use. Int J Occup Saf Ergon. 2001;7(1):61–78.
7. van Niekerk SM, Louw QA, Hillier S. The effectiveness of a chair intervention in the workplace to reduce musculoskeletal symptoms. A systematic review. BMC Musculoskelet Disord. 2012;13:145.

8. Hoe VC, Urquhart DM, Kelsall HL, Zamri EN, Sim MR. Ergonomic interventions for preventing work-related musculoskeletal disorders of the upper limb and neck among office workers. Cochrane Database Syst Rev. 2018;10(10):CD008570.
9. Feldmann J. Beschwerden und Erkrankungen der oberen Extremitäten an Bildschirmarbeitsplätzen. Methodenentwicklung zur Risikoabschätzung sicher ist sicher. 2007;58:328–9.
10. Celik S, Celik K, Dirimese E, Tasdemir N, Arik T, Buyukkara I. Determination of pain in musculoskeletal system reported by office workers and the pain risk factors. Int J Occup Med Environ Health. 2018;31(1):91–111.
11. Du T, Iwakiri K, Sotoyama M, Tokizawa K. Computer and furniture affecting musculoskeletal problems and work performance in work from home during COVID-19 pandemic. J Occup Environ Med. 2022;64(11):964–9.
12. Dingeldey E, Dullien S, Grifka J. Wirksamkeit und Sitzdynamik des Dondola - Bürostuhls mit beweglicher Sitzfläche bei chronischen Rückenschmerzen. [Dissertation]: Universität Regensburg; 2006.
13. Grifka J. Rücken: Beschwerden wirksam begegnen: Ursachen, Therapie, Training. 2nd ed. München: Zuckerschwerdt; 2020.
14. DGUV. Arbeiten im Homeoffice – nicht nur in der Zeit der SARS-CoV-2-Epidemie. Deutsche Gesetzliche Unfallversicherung, Fachbereich Verwaltung; 2022. Available from: https://publikationen.dguv.de/regelwerk/publikationen-nach-fachbereich/verwaltung/buero/3925/fbvw-402-arbeiten-im-homeoffice-nicht-nur-in-der-zeit-der-sars-cov-2-epidemie.
15. Kramer I, Bödeker W. Return on Investment im Kontext der betrieblichen Gesundheitsförderung und Prävention - die Berechnung des prospektiven Return on Investment: eine Analyse von ökonomischen Modellen - IGA-Report 16. BKK: Initiative Gesundheit & Arbeit; 2008. Available from: https://www.iga-info.de/fileadmin/redakteur/Veroeffentlichungen/iga_Reporte/Dokumente/iga-Report_16_Analyse_ROI-Kalkulatoren.pdf.
16. Bodanowitz J. DAK-Gesundheitsreport 2018. DAK-Gesundheit; 2018. Available from: https://www.dak.de/dak/bundesthemen/gesundheitsreport-2018-2108874.html#/.
17. Eschenwecker L. As-is and subjective evaluation of potential stressors in home-based telework by employees. Masterarbeit: Ostbayerische Technische Hochschule, Amberg-Weiden; 2020.
18. Backhaus N, Tisch A, Kagerl C, Pohlan L. Arbeit von zuhause in der Corona-Krise: Wie geht es weiter? Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA); 2020. Available from: https://doi.org/10.21934/BAUA:BERICHTKOMPAKT20201123.
19. BMfSFJ. Digitale Vereinbarkeit: Home-Office und mobiles Arbeiten – eine Toolbox für Unternehmen und Beschäftigte mit Familienaufgaben. Bundesministerium für Familie, Senioren, Frauen und Jugend; 2017. Available from: https://www.bmfsfj.de/bmfsfj/service/publikationen/digitale-vereinbarkeit-home-office-und-mobiles-arbeiten-118754.
20. Fincke I, Harth V, Mache S. Arbeitsbedingungen in innovativen Bürokonzepten unter gesundheitsrelevanten und arbeitswissenschaftlichen Aspekten. Zentralblatt für Arbeitsmedizin, Arbeitsschutz und Ergonomie. 2018;68:168–76.
21. Statistisches Bundesamt. Qualität der Arbeit - Erwerbstätige, die von zu Hause aus arbeiten. Arbeit 2021. Available from: https://www.destatis.de/DE/Themen/Arbeit/Arbeitsmarkt/Qualitaet-Arbeit/Dimension-3/home-office.html.
22. Grunau P, Ruf K, Steffens S, Wolter S. Homeoffice bietet Vorteile, hat aber auch Tücken - IAB-Kurzbericht. Institut für Arbeitsmarkt- und Berufsforschung der Bundesagentur für Arbeit; 2019. Available from: https://doku.iab.de/kurzber/2019/kb1119.pdf.
23. Stürz R, Stumpf C, Mendel U, Harhoff D. Digitalisierung durch Corona? Verbreitung und Akzeptanz von Homeoffice in Deutschland: Ergebnisse zweier bidt-Kurzbefragungen. Bayerisches Forschungsinstitut für Digitale Transformation; 2020. Available from: https://doi.org/10.35067/XYPQ-KN62.
24. Holdampf-Wendel A, Paulsen N. Homeoffice in Zeiten der Corona-Pandemie. 2023. Available from: https://www.bitkom.org/Themen/Corona/Homeoffice-in-Zeiten-der-Corona-Pandemie.

25. de Macedo TAM, Cabral E, Silva Castro WR, de Souza Junior CC, da Costa Junior JF, Pedrosa FM, et al. Ergonomics and telework: a systematic review. Work. 2020;66(4):777–88.
26. Franz F. Home office could be here to stay in Germany – if the internet in rural areas holds up. Heinrich Böll Stiftung European Union; 2020. Available from: https://eu.boell.org/en/2020/06/02/home-office-could-be-here-stay-germany-if-internet-rural-areas-holds

Chapter 29
Limitations in Sedentary Behaviour Research and Future Research Needs

Daniela Schmid, Carmen Jochem, and Michael F. Leitzmann

Abstract This chapter discusses limitations and uncertainties in sedentary behaviour research and briefly presents future research needs in the field. These include but are not limited to better understanding the association between sedentary behaviour and health, increasing the validity and reliability of measuring sedentary behaviour, more clearly identifying the determinants and correlates of sedentary behaviour, devising appropriate interventions to reduce sedentary behaviour, and effectively translating research findings aimed at decreasing extended periods of sitting into practice. Specifically, there is a need for prospective studies using objective measures of sedentary behaviour and sophisticated statistical methods to determine how long people should maximally sit per day and how often they should interrupt their daily sitting to prevent the harmful effects of prolonged sitting. The combined use of self-report and accelerometer-derived measures is needed to enhance the validity and comprehensiveness of existing sedentary behaviour assessments. Future studies should also expand their exposure assessments to include sedentary behaviours in the transportation and household domains. To formulate personalized disease prevention strategies, enhanced research efforts are needed for certain population subgroups, such as persons with chronic diseases or disabilities, overweight/obese individuals, children and youth, the elderly, socially disadvantaged individuals, and ethnic minorities. In addition, additional mechanistic and experimental work is required to identify the etiologic pathways through which sedentary behaviour impacts upon the etiology of chronic diseases.

D. Schmid (✉)
Department of Public Health, Health Services Research and Health Technology Assessment, UMIT – University for Health Sciences, Medical Informatics and Technology, Hall in Tirol, Austria
e-mail: daniela.schmid@umit-tirol.at

C. Jochem · M. F. Leitzmann
Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany
e-mail: carmen.jochem@ukr.de; michael.leitzmann@ukr.de

M. F. Leitzmann et al. (eds.), *Sedentary Behaviour Epidemiology*, Springer Series on Epidemiology and Public Health, https://doi.org/10.1007/978-3-031-41881-5_29

What Is New?

- Although considerable progress has been made in sedentary behaviour research over the past decade, a number of uncertainties and limitations remain that are related to methodology, scientific evidence for an association with health-related outcomes, influential factors, effective interventions, and their successful transition to practise.
- Applying more advanced analytical methods such as target trial emulation might be a useful approach to causal inference from observational data.
- While previous research has focused on the general population, development and evaluation of effective sedentary behaviour interventions among population subgroups and in different settings, such as the workplace or school, is a research priority.
- Further study addressing cultural and social factors within and between countries is desired to investigate variation by culture, social disadvantage, and inequality.

Mounting epidemiologic evidence suggests that sitting for long periods of time poses risk for developing chronic diseases and pre-term death [1]. Although considerable progress has been made in sedentary behaviour research over the past years, numerous uncertainties and limitations remain that require further attention. Evidence linking sedentary behaviour to health-related outcomes largely bears on observational studies, which do not allow interpretation of causal relationships. Applying more advanced analytical methods such as target trial emulation might be a useful approach to causal inference from observational data. Confirmatory evidence from intervention and experimental studies is sparse. Understanding the underlying biologic mechanisms and identifying factors that influence sedentary behaviour is crucial to further our knowledge about the role of sedentary behaviour in disease prevention and to devise appropriate public health guidelines. Additionally, investigation of other potential influencing or mediating factors such as eating behaviour, sleep, or smoking is essential to infer independent associations. Further under-researched areas include different settings, social determinants, and inequality in relation to sedentary behaviours, and research on how effective intervention programmes can be introduced to different populations.

Research in the field of sedentary behaviour epidemiology describes a dynamic process continuously creating new knowledge about the influence of sedentary behaviour on health. Although we believe that the available scientific evidence base is sufficient to explain a pivotal role of prolonged sedentary time for the development of chronic diseases, knowledge in this relatively new research discipline needs to further grow to facilitate effective public health interventions. A number of public health organisations expanded their physical activity guidelines to recommend avoiding sedentary behaviour, which is an important step in thwarting the rapid increase in a sedentary lifestyle (see Sect. 1.3). However, the available scientific evidence base does not allow specific recommendations beyond broad formulations to "reduce sedentary time" or to "break up prolonged sitting time frequently".

Briefly worded, there is a line of inquiry that needs to be resolved before we can take the next step in informing effective disease prevention strategies. In the following section, we will discuss limitations and uncertainties in sedentary research, followed by a presentation of future research needs in this field. We will use the *behavioural epidemiology framework* proposed by Sallis et al. [2], which specifies a sequence of five research phases regarding health-related behaviours. These five phases are i) establishing relationships between the behaviour and health outcomes; ii) developing behaviour measures; iii) identifying influences on the behaviour; iv) evaluating interventions to impact the behaviour; and v) translating findings into practice [2]. This framework was recently adapted to sedentary behaviour epidemiology [3]. For further detail on the behavioural epidemiology framework, please refer to Chap. 15.

29.1 What Do We Know About the Relationship Between Sedentary Behaviour and Health-Related Outcomes?

A large proportion of studies reporting on harmful associations of prolonged time spent sedentary with disease outcomes and mortality argue that sedentary behaviour independently affects health [4]. That conclusion is primarily based on studies that showed consistent findings from models that were adjusted for physical activity and those that were not adjusted for physical activity. The method of comparing adjusted and unadjusted effect estimates, however, represents a rather crude approach to exploring independent effects. Numerous prospective studies investigating the joint effects of sedentary behaviour and moderate-to-vigorous physical activity (MVPA) on mortality risk [5–11] presented inconsistent findings. A previous harmonised meta-analysis [12] of self-reported data investigating joint associations between sedentary behaviour and physical activity revealed that one hour of moderate physical activity spread over the day was sufficient to oppose the adverse effect of sitting for more than eight hours. In contrast, the detrimental association of sitting with mortality persisted for television (TV) viewing, regardless of physical activity level [12]. Combining accelerometer-based sedentary behaviour data with physical activity data revealed that high amounts of sedentary time (>10.7 hours per day) were associated with a higher risk of mortality, particularly among those with low or very low levels of MVPA. Among active individuals accumulating 30–40 minutes of MVPA per day, the association of high sedentary time with mortality risk was not significantly different from those with low amounts of sedentary time [13].

Recent evidence summarized by an international group of public health scientists and practitioners to guide the new World Health Organization (WHO) guidelines on physical activity and sedentary behaviour indicates that sedentary behaviour increases the risk for all-cause, cardiovascular disease (CVD) and cancer mortality, as well as the incidence of CVD, cancer, and type 2 diabetes at moderate certainty evidence [1]. The associations remained after adjustment for potential confounding variables and may vary by level of MVPA. Further, modest evidence was considered for non-linear dose-response relations of sedentary behaviour with all-cause, CVD, and cancer mortality, with specific thresholds for the sedentary time being likely to vary across health outcomes, by levels of MVPA, and among population subgroups. Insufficient or low-certainty systematic review evidence has been concluded on the type or domain of sedentary behaviour, or the frequency and duration of bouts or breaks in sedentary behaviour [1].

Previous studies employed isotemporal substitution models to explore the effect of substituting time spent in one activity behaviour for the same amount of time spent in another activity behaviour [14]. That approach may help guide people in optimising their daily activity behaviour aimed at replacing sedentary time with ambulatory movement [14]. For example, using accelerometer data from the National Health and Nutrition Examination Survey (NHANES) 2003–3006, Schmid et al. found that replacing 30 minutes per day of objectively measured sedentary time with an equal amount of light activity or MVPA was associated with 14% and 50% reduced risks of all-cause mortality, respectively [15]. Recent substitution analyses of the NHANES 2003–2006 [16] and Whitehall II epidemiological cohorts [17] further indicated that re-allocations of sedentary time to MVPA were associated with improved circulating levels of triglycerides [16, 17], high-density lipoprotein (HDL)-cholesterol [16, 17], insulin [16], homeostasis model assessment of insulin sensitivity [16], and adiposity [17]. A novel statistical avenue in sedentary behaviour research includes compositional data analysis, which enables comprehensive investigation of the proportional distributions of daily time spent in sedentary behaviour and other activities in relation to health outcomes [18]. Future studies are needed to resolve whether and to what extent physical activity can alleviate the deleterious health consequences associated with prolonged sitting time. Clearly, sedentary behaviour and physical activity describe distinct behaviours, yet both represent co-dependent elements of daily energy expenditure during a finite number of waking hours, that is, spending time in one activity behaviour ultimately replaces time spent in another activity behaviour.

It is worth noting that previous studies largely relied on self-reported measures of sedentary behaviour, which are prone to measurement error resulting from recall and reporting biases and thus, likely under- or overestimated the true effect of sedentary behaviour on health-related outcomes. As such, future studies using objective measures of sedentary time are desirable to confirm findings from previous reports.

Few observational studies used pooled analyses or harmonised meta-analyses to address questions related to sedentary behaviours and health-related outcomes. Meta-analyses using harmonised data or pooled analyses may be more economical and may provide a more sophisticated approach to answering research questions more precisely with greater internal and external validity than that of an individual study.

Likewise, the identification of causal links in observational data remains unresolved. To address this limitation, more sophisticated analytic methods are now available. For example, as randomised controlled trials that may answer causal questions are often not feasible, ethical, or timely, target trial emulation can be regarded as an attempt at establishing causal inference from observational studies [19]. Further methods include g formula methods and marginal structural models that can be used to quantify time-varying exposures in the presence of time-varying confounding factors [20, 21]. The Mendelian randomization method enables the estimation of causal associations in observational studies using genetic variants [22].

While the vast majority of sedentary behaviour research has focused on the general population, little is known about whether sedentary behaviour differently impacts upon health among population subgroups. Persons with chronic diseases or disabilities, overweight/obese individuals, the elderly, socially disadvantaged individuals, and ethnic minorities are at increased risk of exposure to high volumes of sedentary behaviour and may face several barriers to overcome physical inactivity. Thus, enhanced research in population subgroups represents an important step forward in devising personalised disease prevention interventions.

Another avenue in sedentary behaviour research is a deeper study of domain-specific sedentary behaviours, such as the investigation of passive (e.g., TV viewing) versus mentally active (e.g., reading, workplace) sedentary behaviour in relation to mental health outcomes. For example, individuals with a higher socio-economic status may spend more time sitting at the workplace, whereas those with a lower socio-economic status usually spend more time watching TV [23] while being exposed to more physically demanding occupations. In this context, further study of cultural and social factors within and between countries is crucial to investigate variation by culture, social disadvantage, and inequality.

Another question that remains insufficiently answered concerns the physiologic mechanisms linking sedentary behaviour to health-related outcomes. Although experimental studies on sedentary behaviour in humans are accumulating, such as investigations of the metabolic consequences of interruptions to prolonged sitting (see Chap. 5), little is known about the precise etiologic pathways through which sedentary behaviour affects health-related outcomes. Important insights into the biologic consequences of sedentary behaviour have been obtained from animal experiments conducted by Hamilton and colleagues [24, 25], who found that reduced contractile activity localised at the two hindlimbs of mice led to a suppression of skeletal muscle lipoprotein lipase (LPL) activity, which is crucial for triglyceride uptake and production of HDL-cholesterol. We do not know whether similar physiologic consequences of sedentary behaviour on LPL activity occur in humans. Previous studies of interruptions of sitting time on blood lipids in healthy adults revealed inconsistent findings [26, 27]. Discrepancies between study results may have arisen from variations in study populations, sample sizes, study duration, initial metabolic state, and type of intervention. Yet, experimental studies on interrupted sitting regimens may deliver important information about how long individuals should maximally sit per day and how often extended periods of sitting time should be interrupted to improve metabolic function and other health-related conditions. For example, a recent study found that breaks in sitting resulted in improvements in postprandial glucose and insulin responsiveness, and the beneficial effect was greater in individuals who frequently interrupted prolonged sitting by short activity bouts than in those who interspersed a single bout of continuous physical activity between a long period of sitting [28].

While most experimental studies in humans examined the effect of extended sitting time and interruptions of sitting time on glucose and lipid metabolism, there is a paucity of data on other biomarkers that may be operative in the development of chronic diseases, such as adipokines (e.g., leptin, adiponectin), pro-inflammatory cytokines (e.g., interleukin (IL)-6, tumour necrosis factor (TNF)-α), and insulin-like growth factor (IGF) and insulin-like growth factor binding protein (IGFBP) (e.g., IGF-I, IGFBP-III). Moreover, sitting interruption studies in high-risk populations such as overweight or obese individuals with type 2 diabetes mellitus or pregnant women with gestational diabetes mellitus may provide more effective personalised intervention opportunities. While experimental studies have mostly identified acute effects of experimentally controlled behavioural changes, studies on long-term effects in free-living environments are lacking.

Thus, to infer successful public health initiatives, combing epidemiologic observational data with evidence from controlled experimental studies and intervention studies in free-living settings on the biological effects of changing sedentary behaviour is imperative.

29.2 How Can We Validly and Reliably Measure Sedentary Behaviour?

Existing data on sedentary behaviour are limited by the heterogeneity of methods used to assess sedentary behaviour and the poor to modest validity of self-reported sedentary behaviour measures (see Chap. 3). Inconsistencies in study findings may stem from misconception and misclassification of the term "sedentary behaviour" in individual studies. In our understanding, sedentary behaviour is defined as "any waking behaviour characterised by an energy expenditure ≤1.5 metabolic equivalents of task (METs) while in a sitting or reclining posture" [29]. A plethora of epidemiologic studies used mixed categories of sedentary behaviour and physical activity in the sedentary behaviour context, and thus, may have introduced some degree of misclassification error [30]. High levels of sedentary time may coincide with high levels of physical activity [30]. For example, office workers spending hours sedentary at their desks may accumulate an appreciable amount of moderate-to-vigorous exercise in the gym after work. Comparing a high sedentary behaviour level with the "most physically active" category as the reference category would neglect the co-existence of high amounts of both sedentary behaviour and physical activity [30]. In addition, inferring occupational sitting from job titles represents a potential source of exposure misclassification [30]. To obtain comparable and valid results, future studies of sedentary behaviour should be consistent in their terminology and measurement structure.

Rapid advances have been made in the use of device-based measures in epidemiologic studies over the past years, yet most studies to date evaluated sitting time based on self-report measurements. Self-reported methods are feasible in large population studies, and they capture important information about the type of sedentary behaviour (e.g., TV watching) occurring in a specific domain (e.g., recreation, household, occupation, transport). However, they are prone to measurement error, resulting in potential distortion of the true relationship [31–33]. A new avenue for self-report measures is the use of 24-h recalls, which provide contextual information (e.g., the time spent on certain behaviours) and have shown moderate validity as compared with device-based measures [23].

Advances in measurement technology now deliver affordable objective methods such as accelerometers and inclinometers that help overcome the limitations of self-report assessments [31]. Device-based measurements have been demonstrated to more accurately assess total sedentary behaviour than self-report measurements [31–33]. Self-reported measures may underestimate the true time spent sedentary relative to sedentary time assessed using objective monitoring devices [27]. For example, for population-level sedentary behaviour, a median of 5.5 h per day from self-report measures compared to a median of 8.2 h per day from device-based measures was reported in the review by Bauman et al. (Chap. 2).

While TV time has reasonable recall properties, it cannot be extrapolated to represent overall sitting time. Objective monitoring devices enable assessment of total sedentary time across the day, and they provide important information about patterns of sedentary behaviour accumulation, e.g., durations of sedentary bouts and interruptions in sedentary time [33]. Advanced activity monitoring using the activPAL allows different postures such as sitting/lying and standing to be distinguished [34]. However, device-based measurement does not discriminate between different types and domains of sedentary behaviour. In addition, there are several methodologic issues with regard to accelerometer measurements (e.g., definitions of epoch length, wear time, non-wear time, cut-points for sedentary behaviour, number of valid wear days) that have not yet been resolved and require further study.

Combining self-reported measures with objectively derived data has been recommended to improve the comprehensiveness and accuracy of sedentary behaviour measurements [31, 33]. A previous study utilizing data from around 10,000 adults aged ≥20 years from the NHANES 2003–2006 provides an example of how a more comprehensive measure of sedentary behaviour can be achieved from the combinatorial use of self-reported and objective instruments [33]. The descriptive epidemiology of sedentary time determined by self-reported measures and accelerometer-derived measures was compared [33]. The main results indicated that both self-reported measures and accelerometer-derived measures identified women to spend more time in sedentary pursuits than men, and the self-reported measures were able to uncover the prevalence of TV viewing, computer use, and screen time to be lower in women than men. Moreover, domain-specific variation in sedentary time across different ethnicity groups could be identified by self-reported measures. For example, non-Hispanic whites and non-Hispanic blacks were more likely to be sedentary than Mexican Americans according to all sedentary behaviour measures, with the exception of TV viewing time [33]. Stratifying sedentary behaviour by both ethnicity and life span, self-reported measures detected significant differences in women, while important differences in men were noted using accelerometer-based measures [33]. Future measurements should extend beyond self-reported measures of sedentary behaviour to allow for a more valid objective measurement of sedentary behaviour accumulated throughout the day. For more precisely identifying accumulation patterns, more sophisticated analytical techniques such as multivariate pattern analysis [35], machine learning techniques [36], accelerometer time-series raw data [37], and sequence maps and clusters [38] have entered sedentary behaviour research over recent years.

The vast majority of sedentary behaviour studies are limited in that they evaluated sedentary time at a single point in time, typically the time at study entry. Repeated measurements allow the extraction of information about diverse patterns and changes of sedentary behaviour over time and identification of specific time periods in life that are sensitive to prolonged sedentary time. For example, a recent study utilizing data from the National Institutes of Health (NIH)-AARP Diet and Health Study evaluated change in TV viewing time between 1994–1996 and 2004–2006 in relation to death occurring until 2011 [39]. High versus low amounts of TV viewing at both time points were related to a statistically significant increased risk of mortality, but the hazardous relation tended to be most marked at the second time point [39]. Moreover, the above-mentioned study [39] was able to discover important findings related to changes in TV viewing and mortality risk. Specifically, an increase in TV viewing between the two measurement points was related to an increased risk of mortality, and a decline in TV viewing was associated with a reduction in mortality risk [39]. Another study found that hourly increments of change in TV viewing over a five-year period were associated with increases in biological markers (body mass index, waist circumference, fasting insulin, and insulin resistance) of postmenopausal breast cancer risk [40]. The sedentary lifestyle of an individual does not remain constant over the lifetime but rather, it alters during the life course, with the elderly usually spending more time in sedentary activities than young or middle-aged adults [33]. Likewise, hormonal and metabolic changes occur over the life span [41, 42], leading to potential different biologic responses to sedentary behaviour among various age groups. Thus, the exploration of sedentary behaviour at different life stages may provide important insights into time-sensitive effects of sedentary behaviour on disease outcomes and etiology.

29.3 What Are the Determinants and Correlates of Sedentary Behaviour?

Sedentary behaviour scientists have been extensively engaged in research on the effect of sedentary behaviour on various health-related outcomes. In future research, more emphasis should be placed on the study of factors that drive sedentary behaviour. There are numerous potential factors that may influence sedentary behaviour, including demographic, psychological, social, economical, and environmental factors. Identifying correlates and determinants of sedentary behaviour at a multi-level represents an important step in designing appropriate intervention programmes aimed at reducing sedentary behaviour. Ecologic approaches in correlates research may help navigate the numerous possible influences of sedentary behaviour and identify important interactions across levels relevant for being targeted in sedentary behaviour interventions (see Chap. 15). To understand why persons are inactive and others are not, research into correlates should expand beyond the study of individual factors to identify the potential of changes in contextual and environmental factors for preventing non-communicable diseases. In this regard, understanding environmental correlates of transportation and recreational activity in low-income and middle-income countries has been formulated as a research priority to support the development of contextually tailored interventions aiming to reduce the rapid proliferation of inactivity brought about by increased urbanisation, passive entertainment, and motorised commuting [43].

29.4 What Are Feasible Interventions to Reduce Sedentary Behaviour?

To determine which specific public health initiatives to pursue, results from intervention programmes aiming to change sedentary behaviour are essential. In particular, evaluating the effectiveness of large-scale and national physical activity promotion programmes at the population level is very demanding, and thus, limited evidence on such initiatives is available. Intervention studies designed to reduce sedentary behaviour have proliferated during recent years, and while some intervention programmes are aimed at changing an individual's behaviour, others have directed their attention towards environmental factors. Several intervention studies have focused on alterations in the work environment and have introduced sit-to-stand desks to combat the dangers of numerous hours sitting in the office [44]. Findings of numerous studies showing prolonged sedentary behaviour to harmfully affect health-related outcomes have led public health scientists to the logical conclusion that replacing hours being seated by standing would be a feasible alternative to produce a healthy working environment. The creation of "movement-friendly" places for working include computer-based prompts and personal motion assessment devices, placement of toilets and kitchens on different floors, promotion of stair use, and standing meetings [44]. There is a need for future prospective studies and randomised controlled trials to evaluate standing and light activity interventions in real office environments [44], taking into account the feasibility, acceptability, sustainability, and safety of the interventions. Moreover, exploration of the long-term effects of such interventions on health-related outcomes requires further research attention. In particular, intervention studies that can be easily integrated into daily routines are needed.

Another key setting for health promotion and early disease prevention includes the school environment, which represents a place where children and youth spend large amounts of time, and where behavioural education can be easily incorporated into the curriculum and school environment. For example, active lessons (e.g., integrating activity for a learning outcome) and active breaks (e.g., interrupting a class lesson for a sitting break) have been shown to effectively reduce and break up children's sedentary time in the classroom. Watson et al. [45] summarised 26 studies on active breaks and 13 studies on physically active lessons and concluded overall increases in children's physical activity, improvements in classroom behaviour outcomes, and better academic achievements.

The efficacy of interventions for reducing time spent sitting in the household and transportation domains is largely unexplored. There is likely to be value in future intervention studies aiming to reduce sitting during transportation. Self-reported data from the US, Australia, and Belgium [46] revealed that adults spent on average 326.7 to 478.6 minutes per week in motorised transportation. People would meet the physical activity recommendations of 150 minutes per week of moderate-intensity activity [47] if they replaced half of the time spent in a car or bus for commuting with moderate-intensity pursuits of walking or bicycling.

The majority of intervention studies published to date involved only healthy individuals, and thus, analyses of understudied population groups such as individuals with chronic disease or disabilities, ethnic minorities, the elderly, or overweight/obese individuals are a research priority. Such groups are at an increased risk for high levels of sedentary time and subsequent adverse health consequences and may particularly benefit from effective intervention programmes aiming to reduce sedentary behaviour. The development of intervention programmes with particular attention paid to these subgroups is suggested to inform personalised disease prevention strategies. Conducting mixed-methods studies to examine the social, physical, and attitudinal barriers and facilitators to physical activity of these individuals may help develop effective personalised physical activity programmes.

29.5 How Can Research Findings Be Effectively Translated into Practice?

Complementing evidence on epidemiology, measurement, mechanisms, and interventions is needed to inform appropriate public health guidelines and policy. In a final step, public health initiatives need to be informed by evidence from the preceding phases. The design of an intervention programme that has proven efficacy in the study scenario may be unwise if it cannot be effectively applied to a real-life setting. The last phase deals with questions about how we can properly disseminate, implement, and maintain effective interventions and public health initiatives. This important area of future research will require mobilising transdisciplinary collaboration.

Implementation issues are complex, and they have a host of barriers in that multiple aspects need to be taken into account, including feasibility, acceptability, cost-effectiveness; and other environmental, organisational, and political factors. Moreover, it typically takes several years to translate research into public health practice and policy. Clearly, more research is needed to ensure the successful translation of evidence-based intervention programmes into real-life settings. Because this field has now become a funding priority over the past years, research opportunities will continue to grow, ultimately leading to advances in research-to-public health practice translation for successful interventions.

29.6 Summary

Although a considerable amount of knowledge has been accomplished in the field of sedentary behaviour epidemiology over the past decades, further progress in sedentary behaviour research is needed to inform effective intervention programmes aimed at reducing long periods of sitting. Future prospective studies using objective measures (e.g., accelerometers) are needed to confirm findings from self-report studies on the relationships between sedentary behaviour and a variety of health-related outcomes. The combined use of self-report measures and accelerometer-derived measures may represent a valuable future approach to enhance the comprehensiveness and validity of sedentary behaviour measurements. Likwise, applying more sophisticated analytical methods to draw more robust evidence from available sedentary behaviour data is needed. While previous studies have predominantly focused on TV viewing or total sitting time, future studies should place more emphasis on other domains such as transportation and the household to expand the potential for interventions. Moroever, research in more specific domains such as passive and mentally active sedentary behaviours might provide new insights into the relations of sedentary behaviour with health outcomes.

Enhanced research efforts are suggested for different settings such as the workplace or schools as well as different population subgroups to allow for personalised disease prevention strategies. Moreover, future mechanistic and experimental studies are needed to identify the biological pathways through which sedentary behaviour affects the aetiology of various disease outcomes. Equally important are studies that explore how long people should maximally sit and how often they should interrupt their sitting to prevent the harmful effects of prolonged sitting on health. Such data are needed to build a stronger basis for sedentary behaviour recommendations. Moreover, research into correlates should expand beyond factors at the individual level to identify different social and environmental contexts that can be targeted in future intervention programmes. Finally, efforts to implement and disseminate intervention programmes need to be evaluated to ensure the successful implementation of evidence-based research findings in real-life settings.

References

1. Dempsey PC, Biddle SJH, Buman MP, Chastin S, Ekelund U, Friedenreich CM, et al. New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. Int J Behav Nutr Phys Act. 2020;17(1):151.
2. Sallis JF, Owen N. Physical activity and behavioral medicine. Thousand Oaks, CA: Sage; 1999.
3. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010;38(3):105–13.
4. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32.
5. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009;41(5):998–1005.
6. Patel AV, Bernstein L, Deka A, Feigelson HS, Campbell PT, Gapstur SM, et al. Leisure time spent sitting in relation to total mortality in a prospective cohort of US adults. Am J Epidemiol. 2010;172(4):419–29.
7. Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. Am J Clin Nutr. 2012;95(2): 437–45.
8. Kim Y, Wilkens LR, Park SY, Goodman MT, Monroe KR, Kolonel LN. Association between various sedentary behaviours and all-cause, cardiovascular disease and cancer mortality: the multiethnic cohort study. Int J Epidemiol. 2013;42(4):1040–56.
9. Pavey TG, Peeters GG, Brown WJ. Sitting-time and 9-year all-cause mortality in older women. Br J Sports Med. 2015;49(2):95–9.
10. Van der Ploeg HP, Chey T, Korda RJ, Banks E, Bauman A. Sitting time and all-cause mortality risk in 222 497 Australian adults. Arch Intern Med. 2012;172(6):494–500.
11. Schmid D, Ricci C, Leitzmann MF. Associations of objectively assessed physical activity and sedentary time with all-cause mortality in US adults: the NHANES study. PLoS One. 2015;10 (3):e0119591.
12. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet. 2016;388(10051):1302–10.
13. Ekelund U, Tarp J, Fagerland MW, Johannessen JS, Hansen BH, Jefferis BJ, et al. Joint associations of accelero-meter measured physical activity and sedentary time with all-cause mortality: a harmonised meta-analysis in more than 44 000 middle-aged and older individuals. Br J Sports Med. 2020;54(24):1499–506.
14. Mekary RA, Willett WC, Hu FB, Ding EL. Isotemporal substitution paradigm for physical activity epidemiology and weight change. Am J Epidemiol. 2009;170(4):519–27.
15. Schmid D, Ricci C, Baumeister SE, Leitzmann MF. Replacing sedentary time with physical activity in relation to mortality. Med Sci Sports Exerc. 2016;48(7):1312–9.
16. Buman MP, Winkler EA, Kurka JM, Hekler EB, Baldwin CM, Owen N, et al. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005-2006. Am J Epidemiol. 2014;179(3):323–34.
17. Hamer M, Stamatakis E, Steptoe A. Effects of substituting sedentary time with physical activity on metabolic risk. Med Sci Sports Exerc. 2014;46(10):1946–50.
18. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. PLoS One. 2015;10(10):e0139984.
19. Hernan MA, Robins JM. Using big data to emulate a target trial when a randomized trial is not available. Am J Epidemiol. 2016;183(8):758–64.
20. Naimi AI, Cole SR, Kennedy EH. An introduction to g methods. Int J Epidemiol. 2017;46(2): 756–62.

21. Robins JM, Hernan MA, Brumback B. Marginal structural models and causal inference in epidemiology. Epidemiology. 2000;11(5):550–60.
22. Verduijn M, Siegerink B, Jager KJ, Zoccali C, Dekker FW. Mendelian randomization: use of genetics to enable causal inference in observational studies. Nephrol Dial Transplant. 2010;25 (5):1394–8.
23. Owen N, Healy GN, Dempsey PC, Salmon J, Timperio A, Clark BK, et al. Sedentary behavior and public health: integrating the evidence and identifying potential solutions. Annu Rev Public Health. 2020;41:265–87.
24. Zderic TW, Hamilton MT. Physical inactivity amplifies the sensitivity of skeletal muscle to the lipid-induced downregulation of lipoprotein lipase activity. J Appl Physiol (1985). 2006;100(1): 249–57.
25. Bey L, Hamilton MT. Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. J Physiol. 2003;551(Pt 2): 673–82.
26. Cooper AR, Sebire S, Montgomery AA, Peters TJ, Sharp DJ, Jackson N, et al. Sedentary time, breaks in sedentary time and metabolic variables in people with newly diagnosed type 2 diabetes. Diabetologia. 2012;55(3):589–99.
27. Bailey DP, Locke CD. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. J Sci Med Sport. 2015;18 (3):294–8.
28. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. Am J Clin Nutr. 2013;98(2):358–66.
29. Barnes J, Behrens TK, Benden ME, Biddle S, Bond D, Brassard P, et al. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". Appl Physiol Nutr Metabol. 2012;37(3):540–2.
30. Lynch BM, Boyle T. Distinguishing sedentary from inactive: implications for meta-analyses. Br J Cancer. 2014;111(11):2202–3.
31. Matthews CE, Moore SC, George SM, Sampson J, Bowles HR. Improving self-reports of active and sedentary behaviors in large epidemiologic studies. Exerc Sport Sci Rev. 2012;40(3): 118–26.
32. Celis-Morales CA, Perez-Bravo F, Ibanez L, Salas C, Bailey ME, Gill JM. Objective vs. self-reported physical activity and sedentary time: effects of measurement method on relationships with risk biomarkers. PLoS One. 2012;7(5):e36345.
33. Healy GN, Clark BK, Winkler EA, Gardiner PA, Brown WJ, Matthews CE. Measurement of adults' sedentary time in population-based studies. Am J Prev Med. 2011;41(2):216–27.
34. Lyden K, Kozey Keadle SL, Staudenmayer JW, Freedson PS. Validity of two wearable monitors to estimate breaks from sedentary time. Med Sci Sports Exerc. 2012;44(11):2243–52.
35. Aadland E, Holmoy OK, Nilsen AKO. The multivariate physical activity signature associated with body mass index in young children. Prev Med. 2021;145:106437.
36. Kerr J, Carlson J, Godbole S, Cadmus-Bertram L, Bellettiere J, Hartman S. Improving hip-worn accelerometer estimates of sitting using machine learning methods. Med Sci Sports Exerc. 2018;50(7):1518–24.
37. Backes A, Gupta T, Schmitz S, Fagherazzi G, van Hees V, Malisoux L. Advanced analytical methods to assess physical activity behavior using accelerometer time series: a scoping review. Scand J Med Sci Sports. 2022;32(1):18–44.
38. Chinapaw MJ, Wang X, Andersen LB, Altenburg TM. From Total volume to sequence maps: sophisticated accelerometer data analysis. Med Sci Sports Exerc. 2019;51(4):814–20.
39. Keadle SK, Arem H, Moore SC, Sampson JN, Matthews CE. Impact of changes in television viewing time and physical activity on longevity: a prospective cohort study. Int J Behav Nutr Phys Act. 2015;12(1):156.

40. Wiseman AJ, Lynch BM, Cameron AJ, Dunstan DW. Associations of change in television viewing time with biomarkers of postmenopausal breast cancer risk: the Australian diabetes, obesity and lifestyle study. Cancer Causes Control. 2014;25(10):1309–19.
41. Roberts SB, Rosenberg I. Nutrition and aging: changes in the regulation of energy metabolism with aging. Physiol Rev. 2006;86(2):651–67.
42. Roth GS. Hormone action during aging: alterations and mechanisms. Mech Ageing Dev. 1979;9(5–6):497–514.
43. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW, et al. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012;380(9838):258–71.
44. Buckley JP, Hedge A, Yates T, Copeland RJ, Loosemore M, Hamer M, et al. The sedentary office: an expert statement on the growing case for change towards better health and productivity. Br J Sports Med. 2015;49(21):1357–62.
45. Watson A, Timperio A, Brown H, Best K, Hesketh KD. Effect of classroom-based physical activity interventions on academic and physical activity outcomes: a systematic review and meta-analysis. Int J Behav Nutr Phys Act. 2017;14(1):114.
46. Van Dyck D, Cerin E, Conway TL, De Bourdeaudhuij I, Owen N, Kerr J, et al. Associations between perceived neighborhood environmental attributes and adults' sedentary behavior: findings from the U.S.A., Australia and Belgium. Soc Sci Med. 2012;74(9):1375–84.
47. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc. 2011;43(7):1334–59.