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Sedentary Behaviour Epidemiology

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Michael F. Leitzmann • Carmen Jochem •
Daniela Schmid
Editors

Sedentary Behaviour Epidemiology

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

Carmen Jochem
Epidemiology and Preventive Medicine
Universität Regensburg
Regensburg, Germany

Daniela Schmid
Epidemiology and Preventive Medicine
Universität Regensburg
Regensburg, Germany

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Preface

In contemporary society, increasing time spent in television viewing and using the computer coupled with less physically demanding occupations have given rise to prolonged sedentary behaviour. Research 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 recognizes sedentariness as a significant medical and public health problem in all its facets and evaluates the potential of decreasing the time spent sedentary to avert chronic disease and enhance quality of life.

Sedentary Behaviour Epidemiology is organized into three major parts that build on one another to expand the readers' comprehension of this multifaceted problem. 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 for 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 organized
Sedentary Behaviour Epidemiology is organized into three parts and 28 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, this chapter offers an overview of recommendations on sedentary behaviour developed by different countries and organizations, highlighting potential limitations of current guidelines.

In Chap. 2, 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 3 focuses on the comprehensive sedentary behaviour data that have become available by the 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.

In Chap. 4, the descriptive epidemiology of sedentary behaviour is presented. There is also a discussion of correlates of sedentary behaviour, including socio-demographic 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.

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 for 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, including effects of sedentary behaviour on metabolism, cardiovascular function, immunologic and inflammatory factors, and the musculoskeletal system. The influence of sedentary behaviour on the hormonal regulation of appetite, dietary intake, and energy balance is discussed.

In Chap. 6, the evidence on prolonged time spent sedentary in relation to 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 randomized controlled trials. The possibility of a bidirectional association between sedentary behaviour and adiposity in adults is alluded to.

Chapter 7 focuses on the association between non-exercise activity thermogenesis (NEAT) and adiposity, highlighting differences in weight gain between individuals with low and high NEAT in response to overfeeding. A potential biologic mechanism regulating NEAT is presented. In addition, a method to quantify NEAT is provided, and an example of a programme to reduce sedentary behaviours in schools and workplaces is given.

In Chap. 8, 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.

Chapter 9 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.

In Chap. 10, the evidence on sedentary behaviour in relation to overall and site-specific cancer incidence and mortality is summarized. Potential biological mechanisms are discussed, while it is recognized that the cellular processes linking sedentary behaviour to carcinogenesis are incompletely understood. These include endogenous sex hormones, metabolic hormones, inflammatory adipokines, and immune function.

Chapter 11 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.

In Chap. 12, the understudied area of sedentary behaviour in relation to psychosocial health is reviewed, with particular attention being paid to bullying/victimization, 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.

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.

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

Part III uses theories and models of sedentary behaviour as a framework to develop 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 utilized 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.

In Chap. 16, individual level approaches to reduce sedentary behaviour are reviewed. The chapter opens with a discussion of correlates of 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.

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.

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.

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.

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 summarizes 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.

In Chap. 22, the focus is on interventions targeting sedentary behaviour among racial/ethnic minority groups. Information on the prevalence and correlates 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 elaborates on the correlates of sedentary behaviour, discusses factors that impact upon sedentary behaviour, summarizes intervention studies that target sedentary behaviour, and provides recommendations for future steps.

In Chap. 24, social and physical environmental correlates of 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.

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 summarized. An example of a successful policy initiative influencing sedentary behaviour reduction is provided.

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.

Chapter 27 reviews the genetics of sedentary behaviour. 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.

Chapter 28 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 characterizing correlates and determinants of sedentary behaviour, refining interventions of sedentary behaviour, and translating results into practice.

Regensburg, Germany

Michael F. Leitzmann
Carmen Jochem
Daniela Schmid

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Michael F. Leitzmann
Carmen Jochem
Daniela Schmid

Contents

Part I
Fundamentals of Sedentary Behaviour Epidemiology

Chapter 1
Introduction to Sedentary Behaviour Epidemiology

Carmen Jochem, Daniela Schmid, 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 characterized by an energy expenditure $\leq$1.5 metabolic equivalents (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. However, existing recommendations target mostly children and young people and do not provide specific information for adults and the elderly. Strengthening the evidence base regarding the relation between sedentary behaviour and health is critical for successfully developing and implementing comprehensive sedentary behaviour recommendations that include provisions for specific population subgroups, such as persons with pre-existing diseases or the elderly.

1.1 Definition of Sedentary Behaviour

1.1.1 Introduction

Sedentary behaviour (Latin: *sedere*: "to sit") comprises sitting during leisure time, commuting, and in the workplace and household. Examples of sedentary behaviours are television (TV) viewing, video game playing, computer use, reading,

C. Jochem • D. Schmid • M.F. Leitzmann (✉)
Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany
e-mail: carmen.jochem@ukr.de; daniela.schmid@ukr.de; michael.leitzmann@ukr.de

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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) [1]. Hence, sedentary behaviours comprise those that involve sitting and a low amount of energy expenditure. 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 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).

1.1.2 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 [2]. In addition, it has been recognized that the correlation between sedentary behaviour and moderate-to-vigorous physical activity is low [3] and that an individual can accumulate substantial amounts of both sedentary behaviour and moderate-to-vigorous physical activity in the course of a day [4]. 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 [5]. Thus, too much sitting and too little physical activity represent fundamentally distinct concepts.

However, there have been inconsistencies in the literature regarding the definition of the term sedentary. In the sedentary behaviour literature, the term sedentary typically describes “any waking behaviour characterized by an energy expenditure $\leq$1.5 metabolic equivalents (METs) while in a sitting or reclining posture” [6]. 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 characterize the lack of some threshold of moderate-to-vigorous physical activity [7]. 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 [8]. 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 [9]. 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. 15.2.

1.1.3 Summary

The current section provides a conceptual definition of sedentary behaviour, emphasizing 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 [10]. In comparison with that early ancestor, the evolution of *Homo erectus* was characterized by a large increase in brain size, changes in anatomy which favoured hunting and long-distance running, and the ability to make tools [10]. 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 stabilization and enabled bipedalism [11]. 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 characterized by changes in social and cultural behaviour and improved locomotion. Thus, the life of our early ancestors during the Palaeolithic Era was characterized by a highly physically active lifestyle based on gathering and hunting, the use of tools, and a predominantly mobile lifestyle. However, with begin 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 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).

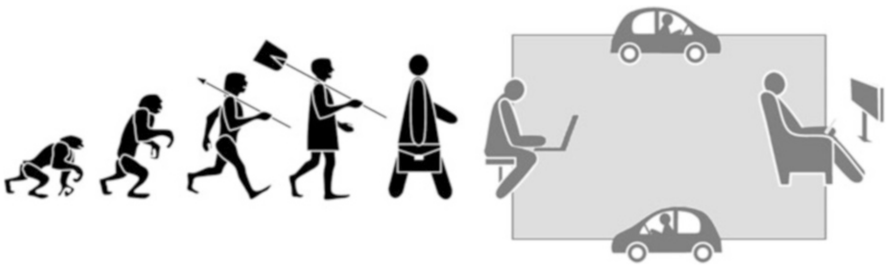

Fig. 1.1 The evolution of *Homo sedens*. *Homo erectus* replaced the quatripedal posture with an upright and bipedal locomotion. Modern *Homo sapiens* spends a large amount of his waking time in sedentary behaviours and increasingly becomes a *Homo sedens*. Figure from Simone Thiemer

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 4 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 television 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 [12]. 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 [13]. 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 secularized 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, conference rooms, class rooms, 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 [13]. 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 characterized by urbanization, 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). 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. 4.

Data from the cross-sectional Eurobarometer surveys that were collected in 28 European Union member states in 2013 show the prevalence of sitting time of 26,617 Europeans aged 18 years and older [14]. A total of 15.4% reported sitting 3.5–4.5 h per day and 18.5% reported sitting 7.5 h or more per day (including time spent sitting at a desk, visiting friends, studying, or watching television). However, the distribution of reported daily sitting time of more than 7.5 h varied widely across countries, with 8.9% in Spain to 32.1% in the Netherlands. Even after adjustment for socio-demographic variables, a north-south gradient was observed across Europe, with citizens of southern European countries reporting less sitting, while northern Europeans reported sitting more. The median reported sitting time per day was 300 min (interquartile range: 180–420), ranging from a median of 180 min in Portugal to 360 min in Denmark and the Netherlands.

These findings fit with the results of an international study that compared the prevalence of sitting time in 20 countries across the world [15]. In total, 49,493 adults aged 18–65 years reported on how much time they usually spend sitting on a weekday. In the overall sample, a median sitting time of 300 min per day

Fig. 1.2 Different domains of sedentary behaviour

(interquartile range: 180–480) was reported. However, median sitting time varied widely across countries. Adults in Portugal, Brazil and Columbia reported the lowest sitting times (median $\leq$ 180 min/day), whereas countries reporting the highest daily sitting times included the Czech Republic, Hong Kong, Lithuania, Norway, Taiwan, Japan, and Saudi Arabia.

Data from the National Health and Nutrition Examination Survey (NHANES) 2009/2010 provides information about self-reported sitting time among 5911 US adults aged $\geq$20 years [16]. Participants reported how much time they usually spend sitting on a typical day. Mean reported sitting time was 285 min/day (95% confidence interval (CI): 278–292) for men and 281 min/day (95% CI: 272–289) for women. Mexican-Americans reported significantly less sitting than non-Hispanic Whites and Blacks. However, findings need to be interpreted with caution because sitting time was based on self-reports, which are prone to measurement error.

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.

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 socio-cultural influences such as institutional sitting in schools. 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. Existing sedentary behaviour recommendations mainly target children and young people. Table 1.1 provides an overview of existing recommendations on sedentary behaviour for health. This section aims at summarizing those recommendations, discussing their shortcomings and emphasizing the need for additional national and international 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. 4) and its public health significance requires a population-based approach to decrease levels of sedentary behaviour. The development, dissemination, and implementation of national and

Table 1.1 Existing recommendations on sedentary behaviour for health

Country/Region	Age group	Recommendation	Institution and type of document	References	Comments
Australia	0–5	Infants, toddlers, and preschoolers should not be sedentary, restrained, or kept inactive *for more than 1 h at a time*, with the exception of sleeping. Screen time: Children younger than 2 years of age *should not spend any time* watching television or using other electronic media (DVDs, computer, and other electronic games). For children 2–5 years of age, sitting and watching television and the use of other electronic media (DVDs, computer, and other electronic games) should be limited to *less than 1 h/day*.	Australian government (Department of Health): "National physical activity recommendations for children 0–5 years"	[17]	Quantifies limit of screen time
	5–12	Use of electronic media for entertainment should be limited to *less than 2 h/day*.	Australian government (Department of Health): "Australia's physical activity and sedentary behaviour guidelines"	[18]	
	13–17	Minimize the time you spend being sedentary every day by limiting your use of electronic media for entertainment to *less than 2 h/day* and breaking up long periods of sitting whenever possible.		[19]	
	Adults	Minimize the amount of time spent in prolonged sitting. Break up long periods of sitting as often as possible.		[20]	No explicit recommendation for older adults (aged 65+)
Austria	Children + young people	*Break up sedentary periods lasting longer than 60 min* with short bouts of physical activity.	Ministry of Health & Gesundheit Österreich GmbH & Fonds Gesundes Österreich: Austrian recommendations for health-enhancing physical activity	[21]	No recommendations on sedentary behaviour for adults and older adults Document available in German language only

Belgium	Children	<2 years: screen time is not recommended 6–18 years: limit screen time to *no more than 2 h/day* >18 years: break up sitting time every 20 min	Flemish Institute for Health Promotion and Disease Prevention: "Factsheet Sedentary Behaviour"	[22]	
Canada	0–4	Minimize the time infants, toddlers, and preschoolers spend being sedentary during waking hours. This includes prolonged sitting or being restrained (e.g. stroller, high chair) for *more than 1 h at a time*. Screen time: For those under 2 years, *screen time* (e.g. TV, computer, electronic games) *is not recommended.* For children 2–4 years, screen time should be limited to *less than 1 h/day*; less is better.	Canadian Society for Exercise Physiology: "Canadian Physical Activity Guidelines & Canadian Sedentary Behaviour Guidelines"	[23]	Specific and quantified sedentary behaviour guidelines. However, no sedentary behaviour recommendations for adults aged 18–64 years and older adults aged ≥65 years (only physical activity recommendations for adults and older adults)
	5–11	Limit recreational screen time to *no more than 2 h/day*. Limit sedentary (motorized) transport, extended sitting, and time spent indoors throughout the day.			
	12–17	Limit recreational screen time to *no more than 2 h/day*. Limit sedentary (motorized) transport, extended sitting, and time spent indoors throughout the day.			
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/day (maximum)* 6–11 years: *60 min/day (maximum)* 12–18 years: *120 min/day (maximum)*	National recommendations based on expert consensus: "Nationale Empfehlungen für Bewegung und Bewegungsförderung"	[24]	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 1.1 (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"	[25, 26]	Campaign, no official recommendation
	Women	Do stretching exercise while watching television.			
	Elderly	Do muscle training or balancing exercises when watching television.			
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"	[27]	"The National Guidelines on Physical Activity for Ireland" [28] 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"	[29]	
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"	[30]	
New Zealand	5–18	Spend *less than 2 h/day* (out of school hours) in front of the television, computers, and game consoles.	Ministry of Health: website recommendations	[31]	New "Eating and Activity Guideline Series" is currently in process and will include sedentary behaviour recommendations for all New Zealanders, incl. children <5 years and 5–18 years old
	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"	[32]	

	≥65	Limit sedentary behaviour.	Ministry of Health: "Guidelines on Physical Activity for Older People (aged 65 years and over)"	[33]	Explicitly also applies to elderly frail people
Nordic co-operation (incl. 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"	[34]	
Qatar	0–4	Minimize the time children spend being sedentary during waking hours *to no more than 1 h at a time*.	Aspetar Orthopaedic and Sports Medicine Hospital: "National Physical Activity Guidelines"	[35]	
	5–11	Reduce sedentary activities. Reduce the amount of time spent sitting and in front of electronic devices. Take an energy *break after every 1 h of sitting*.			
	12–17	Reduce sedentary activities. *Limit screen time to less than 2 h/day*. Take an activity *break after every 1 h of sitting*.			Screen time explicitly includes TV, computer, iPad, mobile phones, video games, etc.
	Adults with coronary artery disease and heart failure	Limit low-level activities (watching TV, computer work, playing electronic games) to *no more than 2 h/day*.			No sedentary behaviour recommendations for healthy adults

(continued)

Table 1.1 (continued)

Country/Region	Age group	Recommendation	Institution and type of document	References	Comments
Singapore	19–49 and ≥50	*Break up sedentary periods lasting longer than 90 min with 5–10 min of standing*, moving around or doing some physical activity.	Heath Promotion Board (Singapore Government): "National Physical Activity Guidelines"	[36]	
Spain	0–5	Minimize 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 postpartum women (in the absence of any contraindications)
	5–17	Minimize 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. television, 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*.			
UK	<5	Children aged 0–4 years should minimize the amount of time spent being sedentary (being restrained or sitting) for extended periods (except time spent sleeping).	U.K. Department of Health, Physical Activity, Health Improvement and Protection: "Start Active, Stay Active: A report on physical activity from the four home countries' Chief Medical Officers"	[43]	Sedentary behaviour recommendations embedded within physical activity guidelines No quantified recommendation on sedentary behaviour (but quantified recommendation on physical activity)
	5–18	Minimize the amount of time spent being sedentary (sitting) for extended periods. Reduce the time spent watching TV, using the computer, or playing video games. Break up sedentary time, such as swapping a long bus or car journey for walking part of the way.			
	18–64	Minimize the amount of time spent being sedentary (sitting) for extended periods. Reduce the time spent watching TV, using the computer, or playing video games. Take regular breaks at work. Break up sedentary time, such as swapping a long bus or car journey for walking part of the way.			
	≥65	Minimize the amount of time spent being sedentary (sitting) for extended periods. Reduce the time spent watching TV.			

(continued)

Table 1.1 (continued)

Country/Region	Age group	Recommendation	Institution and type of document	References	Comments
		Take regular walk breaks around the garden or street. Break up sedentary time, such as swapping a long bus or car journey for walking part of the way.			
USA	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.
	<2	*No screen time*	Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents: Summary Report	[45]	
	2–17	*Limit sedentary/screen time to* $\leq$*2 h/day*			
	19–21	Discuss sedentary time limits with patient.			
			American College of Sports Medicine "Reducing Sedentary Behaviours: Sitting Less and Moving More"		
WHO Western Pacific Region	18–65	Reduce sedentary activities.	"Pacific Physical Activity Guidelines for Adults"	[46]	

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 can:

- Provide an evidence-based document with public health relevance
- Increase the proportion of health professionals, policy makers, 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 inter-sectoral 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 organizations to provide recommendations aimed at reducing childrens' television viewing time [47]. 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 television viewing in children <2 years of age.

These recommendations were made in order to reduce the potential negative effects of television viewing 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. 4).

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 [48]. 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 [49]. A widely accepted instrument for guideline development, the Appraisal of Guidelines for Research Evaluation (AGREE) II [50], 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 [48].

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 [51].

Box 1.2 The Appraisal of Guidelines for Research Evaluation (AGREE) [50, 52]

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" [52]. The original AGREE instrument comprised 23 items in the following six quality-related domains:

- Domain 1: Scope and purpose (3 items)
- Domain 2: Stakeholder involvement (4 items)
- Domain 3: Rigour of development (7 items)
- Domain 4: Clarity and presentation (4 items)
- Domain 5: Applicability (3 items)
- Domain 6: Editorial independence (2 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

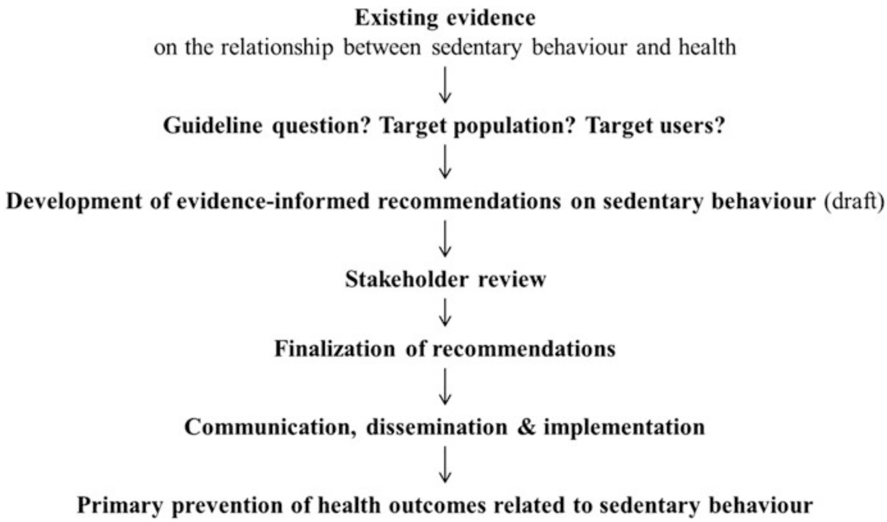

Fig. 1.3 Main steps of the guideline development process

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 pre-existing 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 summarized 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 organizations, governments, and others should be consulted to review the recommendations. Finally, guideline finalization 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 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

Specific Recommendations on Sedentary Behaviour

Table 1.1 provides a summary of existing recommendations on sedentary behaviours. Table 1.2 summarizes practical advice provided by recommendations on how to reduce sedentary behaviour in different age groups and in different domains such as work or leisure time (Fig. 1.4).

Australia provides 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 [17–19]. 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 how to reduce sitting time in children and adolescents are given. For adults, general recommendations on how to reduce sitting time and interrupt prolonged sitting are provided. For older adults, no specific recommendations on sedentary behaviour are supplied.

The Canadian Society for Exercise Physiology (CSEP) provides specific recommendations on sedentary behaviour for children and young people, with quantified time limits for sitting and screen time [23]. The CSEP suggests active transportation, active play, and active family time as key means of how to reduce sedentary behaviour. However, for adults and the elderly, there are no recommendations targeting sedentary behaviour.

Other countries and institutions that currently provide quantified recommendations on the maximum amount of screen time and time spent sedentary are Austria [21], Germany [24], New Zealand [31, 32], Qatar [35], Singapore [36], Spain [37], Turkey [42] and the American Academy of Pediatrics [44] as well as the U.S. 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 [17, 23, 24, 37, 45]. However, specific recommendations for adults and the elderly are sparse.

Table 1.2 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 [23, 43]	Make mealtimes family times and turn off the TV [17, 18] Switch off the TV after a programme has finished [17] Define rules and set limits around screen time [17, 23] Make the children's room a zone free of televisions and computers [18, 23] Reward children with outdoor activities instead of screen time [18] Give presents that can be used for active play (such as skipping ropes, balls) [18] Set an alarm on the computer as a reminder for regular standing up [19] Stand up and move during watching TV [19] Meet friends in person instead of online [19] Play active family games instead of video games [23]	Interrupt long car trips and take a break at a park or rest area for active play [17, 23] Let children walk instead of moving them all the way with the pushchair [17] Let children walk or cycle or use the skateboard or the scooter [17]
	Occupational sitting	Screen time	Sitting during transport
Adults	Stand up whenever possible [53] Visit your colleagues to deliver a message instead of emailing and phoning them [20, 26] Stand up for phone conversations [53] Prefer "walk and talk" meetings instead of sit down meetings [20] Stand up for reading [54] Stand up when you drink water [53] Place your rubbish bin at the other end of the office and get up to go there [54]	Switch off the TV during the day and get out in the garden [20] Set an alarm on the computer as a reminder for regular standing up [20] Meet your friends for a walk instead of sitting to chat [20] Instead of using the remote control, get up and change the channel on the TV [54] During TV time, do muscle training and stretching [29]	Go by bicycle or walk instead of taking the car or bus—at least for part of the way [20, 26, 29, 43]
Older adults		Screen time	
		During TV time, do muscle training or balancing exercises [26]	

Fig. 1.4 Examples of how to reduce sedentary behaviour

General Recommendations on Sedentary Behaviour

Most countries and organizations that provide recommendations on sedentary behaviour issue non-specific guidelines. Those countries and institutions include Hong Kong [25, 26], Japan [29], the Nordic co-operation [34], Sweden [38], Switzerland [39–41], the UK [43], and the World Health Organization of the Western Pacific Region [46], among others. They recommend reducing or minimizing the amount of time spent sedentary or frequently interrupting periods of prolonged sitting. Table 1.2 summarizes practical tips that are part of recommendations on sedentary behaviour.

1.3.6 From Recommendations to Action: Implementing Guidelines into Practice

The goals and aims of sedentary behaviour recommendations–summarized 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 [23], 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" [55]. 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 [55]. 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 1.2). 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 Limitations of Existing Guidelines and Future Needs

Although several countries and institutions have developed guidelines on sedentary behaviour, 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. In line with this, recommendations on sedentary behaviour are often incorporated into physical activity guidelines. Sedentary behaviour recommendations may gain more importance if they existed as standalone recommendations. Second, most existing recommendations target sedentary behaviour in children and young people, and specific recommendations for adults are still sparse. However, the high prevalence of sedentary behaviour is not limited to younger population subgroups but rather, it is highly prevalent across all age groups (as outlined in Chap. 4). Therefore, it is essential to include recommendations targeting sedentary behaviour in adults and the elderly—and in adults with pre-existing diseases or special conditions (e.g. pregnancy)—in existing and upcoming sedentary behaviour guidelines. Third, 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. Furthermore, some countries, such as Spain, Sweden, and Switzerland, publish their recommendations in their respective language only, which makes it difficult to locate them. Therefore, the list of recommendations provided in Table 1.1 may not be comprehensive. In addition, guidelines that are currently in the development or implementation process cannot be accessed prior to publication.

In general, there is a need for scientifically informed recommendations on sedentary behaviour on a global level. In 2010, the World Health Organization (WHO) published the Global Recommendations on Physical Activity for Health [56], which provide age-specific recommendations for the duration, intensity, and frequency of physical activity, but do not include recommendations on reducing sedentary behaviour. Neither do the EU Physical Activity Guidelines provide any recommendation on sedentary behaviour [57]. The Physical Activity Guidelines for Americans (2008) do not include sedentary behaviour recommendations–aside from the sentence "All adults should avoid inactivity" [58]. The "Report of the Commission on Ending Childhood Obesity" published in 2016 by the WHO includes a recommendation that aims at "implement[ing] comprehensive programmes that promote physical activity and reduce sedentary behaviours in children and adolescents" [59]. However, screen-based entertainment is the only target of that recommendation.

A systematic and extensive web search failed to identify recommendations on sedentary behaviour for low and middle income countries. There is a need for sedentary behaviour recommendations in those countries because they are facing a high burden of non-communicable diseases resulting from the epidemiologic transition [60].

1.3.8 Summary

This section shows that several countries and organizations developed recommendations on sedentary behaviour for health to address the public health relevance of sedentary behaviour across all age groups. However, most recommendations target children and young people and do not provide specific guidelines for adults and the elderly. Thus, there is a need for evidence-based, quantified recommendations for adults and the elderly that extend beyond guidelines for TV watching. For guidelines to be successfully implemented, an emphasis on public health and prevention policies is required.

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Chapter 2
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 categorized by energy expenditure and posture. New horizons for subjective methodologies include smartphone applications that allow measurement of the facets and sub-categories 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.

2.1 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 minimizing bias. Epidemiologic studies have traditionally relied on subjective methods to measure sedentary

B. Ainsworth (✉) • F. Rivière • A. Florez-Pregonero
School of Nutrition and Health Promotion, Arizona State University, Tempe, AZ, USA
e-mail: barbara.ainsworth@asu.edu; fbn.riviere@gmail.com; alberto.florez.p@gmail.com

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behaviours (e.g. job classification and questionnaires), whereas more recent of 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 minimized by standardizing 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 [1]. 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. 3. The measure also should have sufficient psychometric properties of validity, reliability, and responsiveness to compute the strength of the association between the sedentary behaviour measure and the outcome. Further, measures should reflect the construct of sedentary behaviours to enhance comparison of studies when evaluating consistency of results.

2.1.1 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 [2].

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 sitting during a day with a questionnaire, items would need to address sitting during transportation, work, during leisure time, and in other relevant areas. 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, c*onstruct 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 behaviour 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 characterized 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 less than $\leq$1.5 METs, including all reclining and sitting activities [3]. Similarly, a questionnaire would need to have a sufficient number of items to reflect relevant behaviours $\leq$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 behaviour 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% [4].

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 $r \geq 0.70$ 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 behaviour 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.

2.1.2 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 project (SIT) [5]. 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. behaviour 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 a relatively new 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.

2.2 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 standardize 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 [6].

With advancements in smartphone technology, EMA methods may 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 [7]. 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.

2.2.1 Types of Questionnaires

Global Questionnaires

Global questionnaires aim to provide a general categorization 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 assesses sitting time in 27,919 respondents from the 28 European Member States [6]. 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 [7]. 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 $\geq$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 [8]. 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 characterize 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 9 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 randomized controlled trials and a prospective study [9] 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 care giving behaviours, during both a weekday and a weekend day. The SIT-Q-7d has been used in a recent one-year follow-up study with 301 adults to examine the relationships of intrapersonal, social-cognitive, and physical environmental variables with context-specific sitting time [10]. The study revealed different correlates of the variables studied depending on the sedentary behaviours, highlighting the interest of using such a questionnaire.

2.2.2 Characteristics of Sedentary Behaviour Questionnaires

A growing number of sedentary behaviour questionnaires with acceptable validity and reliability are currently available (see Tables 2.1 and 2.2). 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 [23]. 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 [24]. The mode of administration also may impact the cost of the study and the responses provided by respondents [25].

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. [26] for a discussion of the factors to consider when selecting a questionnaire for use in physical activity and sedentary behaviours research.

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

Table 2.1 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 [11, 12]	Time sitting in general	1	Interview and self	Typical weekday	1 weekday	Open ended h and min	h/day
Workplace Sitting Time Questionnaire [13]	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 [14]	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 [15]	Time sitting and reclining in various domains	7	Self	Past day	1 weekday	Open ended h	h/day
Sedentary Behavior Questionnaire [16]	Time sitting at home and work	9	Self	Typical weekday Typical weekend day	1 day 1 weekend day	Categorical h and min	h/week
Sedentary Time and Activity Reporting Questionnaire [17]	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
Multi-context Sitting Time Questionnaire [18]	Time sitting in various activities and sleep	14	Self	Average work day and non-work day during a usual week		Open ended h and min	h/day

Recent Physical Activity Questionnaire [19, 20]	Physical and sedentary activities in 4 domains (domestic life, recreation, work, and transport)	~50	Self	Average workday and weekend day last 4 weeks	Frequency of 4 travel modes (always, never, rarely)	Open ended h and min Categorical	MET-time; h/day
Last 7-day Sedentary Time Questionnaire [21]	Sedentary time for meals, transportation, occupation, leisure screen time and other activities, and sleep	~68	Self	Average weekday 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 [22]	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 2.2 Measurement qualities of a sample of sedentary behaviour questionnaires

Name	Validity		Reliability	
	Criterion measure	Coefficient	Test-retest recall frame	Coefficient
International Physical Activity Questionnaire Short Form [11, 12]	ActiGraph CSA 7164 worn for 7 days	Spearman's $r = 0.34$[a]	3–7 days	Spearman's $r = 0.81$[a]
Workplace Sitting Time Questionnaire [13]	ActiGraph GT1M worn for worn 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 [14]	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 [15]	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 [16]	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 [17]	Not reported	Not reported	3 months	Sedentary Time ICC = 0.53 95% CI (0.37, 0.66)
Multi-context Sitting Time Questionnaire [18]	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

(continued)

Table 2.2 (continued)

Name	Validity		Reliability	
	Criterion measure	Coefficient	Test-retest recall frame	Coefficient
Recent Physical Activity Questionnaire [19, 20]	Actiheart, CamNtech Ltd, Cambridge, UK worn a minimum of 4 days	Spearman's correlation $r = 0.21$ and $r = 0.18$ in women and men (both $p < 0.001$)	2 weeks	Sedentary time ICC = 0.76, $p < 0.001$
Last 7-day Sedentary Time Questionnaire [21]	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 [22]	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

sedentary behaviours such as snacking while doing a sedentary behaviour [27]. Table 2.3 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 [26].

Table 2.3 MET values for sedentary behaviours classified by posture from the 2011 Compendium of Physical Activities [28]

	Posture			
Category	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 2.3 (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 and is defined as the ratio of the activity metabolic rate divided by the resting metabolic rate of 1 MET. MET values for sedentary behaviours range from 1.0 to 1.5 and differ by posture and types of activities performed. Multiplication of 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 2.3 provides an example of the MET values for selected sedentary behaviours [11].

Overall, questionnaires are easy to use and give useful information to characterize 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 numerous 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.

2.3 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 [29]. Table 2.4 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 [30–32] and epidemiologic [33–36] 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

Table 2.4 Overview of recommended instruments in epidemiologic studies to measure facets of the Consensus of the Sedentary Behavior Taxonomy [5]

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

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) [37]. For example, the activPAL has demonstrated high accuracy for estimating sitting, standing, and 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 [38]. 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 [39]. This latter approach may be useful for surveillance settings if information about the location and purpose of behaviours are desirable [40]. Since most surveillance and epidemiologic studies use accelerometers and/or pedometers, this discussion will focus on single-unit approaches.

2.3.1 Pedometers

Pedometers are low-cost, battery-operated digital step counters that have gained popularity in surveillance and population study settings [41–45]. 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 [46–49]. 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 (Omron HJ-720I, Fitbit

One, Fitbit Zip) and the wrist (Fitbit Flex, Jawbone UP24), Nelson et al. [50] 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 [51–53], adverse health outcomes [54], and overweight and obesity [55, 56]. In 2013, Tudor-Locke and colleagues [57] 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. [57] 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.

2.3.2 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 [53]. 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 are presented in Table 2.5. Adult population-based studies utilizing accelerometer-based activity monitors typically use a 1-min epoch [64] and 100 counts per minute as the threshold for sedentary behaviours [61].

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 utilizing 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 [64]. Wear time is determined by subtracting non-wear time from total time in the day (wear time = 24 h minus non-wear time). Non-wear time can be estimated by automated

Table 2.5 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 [58]	1 min	ActiGraph	One axis (vertical)	Hip	Not reported
Counts = 8 [59]	10 s	ActiGraph	One axis (vertical)	Hip	Not reported
Counts = 77 [60]	1 min	GENEActiv	Three axes	Hip	AUC[a] (95% CI) = 0.97 (0.96–0.98)
Counts = 217 [60]	1 min	GENEActiv	Three axes	Left wrist	AUC[a] (95% CI) = 0.98 (0.98–0.99)
Counts = 386 [60]	1 min	GENEActiv	Three axes	Right wrist	AUC[a] (95% CI) = 0.98 (0.97–0.99)
Counts = 100 [61]	1 min	ActiGraph	One axis (vertical)		Not reported
Counts = 150 [62]	1 min	ActiGraph	One axis (vertical)	Hip	Bias[b] = −0.9 min SE[c] = 7.7 min
Counts = 500 [63]	1 min	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

processes using published algorithms [30, 65] 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) [30]. 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 [30]. Using the same data, Matthews et al. [61] 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 [32, 66].

The NHANES accelerometer data has been used to study associations between sedentary behaviours and health outcomes to include the metabolic syndrome [67], mobility disabilities [68], type 2 diabetes [69], sleep outcomes [70], and diabetic peripheral arterial disease [71] among other outcomes. Other studies that have used the ActiGraph accelerometer to assess exposure-outcome relations include the 10-country International Physical activity and the Environment Network (IPEN) Adult study [72], Women's Health Study [34], Women's Health Initiative (WHI), Objective Physical Activity and Cardiovascular Health (OPACH) Study, an ancillary study of the WHI 2010–2015 Long Life Study [73], and the British Regional Heart Study [74], 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 [62, 75], 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 [76, 77]. 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 [78, 79]. 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. 3.

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 [40]. Accelerometer-based activity monitors have demonstrated feasibility and utility to assess sedentary time in large-scale surveillance studies [64] 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 [24]. Further, with suitable techniques, obtaining raw data from tri-axial accelerometers makes it possible to perform activity recognition analyses [80].

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. Initializing 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 initialization, monitoring period, and the most appropriate data-processing protocol, despite consensus documents published on this topic [24, 40]. 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 [40]. That said, wrist-worn accelerometers are gaining in popularity for objective, long-term measurement of sedentary behaviours in free-living environments with minimum obtrusiveness [81]. 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 [62]. Healy and colleagues [64] 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 use of the ActiGraph enhances the ability to compare results among studies, it also limits comparability among different activity monitors [82]. 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 [29]. 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. 3.

2.4 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,

> . . .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. [83]

This definition calls for 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 [28], 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. [77] introduced the concept of the *sedentary sphere* as a new name used to describe the energy cost (≤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 [3], 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 [76, 77] and multi-unit [38] 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. [84] 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. This permits 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. 6, 21, and 23.

2.5 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 $\leq$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. 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.

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Chapter 3
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 big 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 in sedentary behaviour research.

3.1 Introduction

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

- "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

W. Zhu (✉)
Department of Kinesiology and Community Health, University of Illinois at Urbana-Champaign, Champaign, IL, USA
e-mail: weimozhu@illinois.edu

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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.

3.2 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, 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 television (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 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.

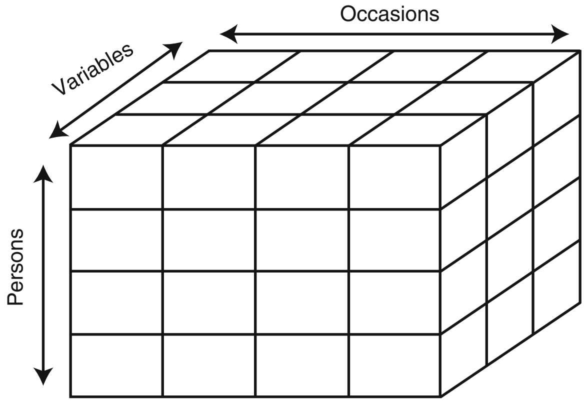

Fig. 3.1 Illustration of Cattell's data box

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. 3.1), from which at least six different structural relationships can be utilized 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 multi-level data structure, with occasion-related variables at the within-person level and persons' demographics or group membership at the person level ([4], pp. 27–39; [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

(continued)

ID_j	O_i	X_{ij}	Y_{ij}	W_j
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 (DV) over time in relation to the independent variable (IV) individually or jointly with other IVs. 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 DV's regular fluctuations or cycle in relation to the IV. Weekday and weekend physical activity is a recognizable 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 in both total physical activity time or total minutes and in the proportion of the total time (see Table 3.1). Researchers have learned, when running statistical analysis, a large variation, expressed in standard deviation for example, often has led to a "non-significant" 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.

Table 3.1 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 min/day	6344	459.20	125.72	1044.86	67.50	48.22% male
	Light PA min/day	6344	344.73	100.30	769.43	16.00	
	Moderate PA min/day	6344	25.53	22.90	307.00	0.00	
	Vigorous PA min/day	6344	5.04	9.96	115.00	0.00	
	MVPA min/day	6344	30.57	28.61	331.00	0.00	
	Sedentary min/day/Total	6344	0.55	0.13	0.98	0.10	
	Light PA min/day/Total	6344	0.41	0.11	0.79	0.02	
	Moderate PA min/day/Total	6344	0.03	0.03	0.32	0.00	
	Vigorous PA min/day/Total	6344	0.01	0.01	0.15	0.00	
	MVPA min/day/Total	6344	0.04	0.03	0.39	0.00	
Adults ≥ 18	Sedentary min/day	4130	478.29	124.97	1044.86	67.50	47.77% male
	Light PA min/day	4130	333.65	105.19	769.43	16.00	
	Moderate PA min/day	4130	22.97	24.71	307.00	0.00	
	Vigorous PA min/day	4130	0.98	3.53	53.00	0.00	
	MVPA min/day	4130	23.95	26.23	331.00	0.00	
	Sedentary min/day/Total	4130	0.57	0.13	0.98	0.10	
	Light PA min/day/Total	4130	0.40	0.12	0.79	0.02	
	Moderate PA min/day/Total	4130	0.03	0.03	0.32	0.00	
	Vigorous PA min/day/Total	4130	0.00	0.00	0.08	0.00	
	MVPA min/day/Total	4130	0.03	0.03	0.39	0.00	
Children < 18	Sedentary min/day	2214	423.61	119.25	965.20	110.71	49.05% male
	Light PA min/day	2214	365.40	86.78	639.43	22.50	
	Moderate PA min/day	2214	30.30	18.13	159.14	0.00	
	Vigorous PA min/day	2214	12.61	13.14	115.00	0.00	
	MVPA min/day	2214	42.91	28.78	252.14	0.00	
	Sedentary min/day/Total	2214	0.51	0.12	0.97	0.14	
	Light PA min/day/Total	2214	0.44	0.10	0.74	0.03	
	Moderate PA min/day/Total	2214	0.04	0.02	0.21	0.00	
	Vigorous PA min/day/Total	2214	0.02	0.02	0.15	0.00	
	MVPA min/day/Total	2214	0.05	0.03	0.33	0.00	

MVPA moderate-to-vigorous physical activity

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. [8], for the youth population alone, there are already 11 sedentary behaviour cut-off scores 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-off scores 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.

3.3 Statistical Analysis of Sedentary Behaviour Data

Currently, most sedentary behaviour data have been analysed using conventional parametric statistics, such as correlation, regression, *t*-test, ANOVA, MNOVA, etc. Unfortunately, due to the structure and characteristics of sedentary behaviour data as described above, these statistics 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 statistics 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 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 have been computed and analysed in reported research studies. In contrast, recent physical activity and sedentary behaviour research indicate 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 both "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-off scores is a concern. While a great deal of attention has been devoted on how to set cut-off scores 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_2max, and % maximal heart rate), there remains the need to further validate the developed cut-offs.

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.

3.3.1 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 at 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 the 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-subjects heterogeneity) and auto-correlated errors, a set of intensive longitudinal methods are available [4].

3.3.2 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 of the development of compositional data analysis, see the good summary by Pawlowsky-Glahn et al. [26]). In addition, a number of text books 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].

3.3.3 Machine Learning

Machine learning is a subset of artificial intelligence, which utilizes 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 recognizing of patterns and classifying outcomes [30]. 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 [31–34]. Some studies to connect physical activity patterns to posture recognition and fall detection were conducted in a controlled environment with known activities [35, 36]. Others focused on activity recognition have been conducted in realistic conditions outside of a clinical environment [31, 37]. 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. [38–40]. A study by O'Connell et al. [41] 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 recognizing patterns in movement that help predict health status. In addition, machine learning algorithms have also been applied to accelerometer 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 [42]. Thus, machine learning methods show promise in recognizing unique movement patterns for classification of disease status.

3.3.4 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 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 [43]) is mostly studied and applied. EGA breaks down a scatterplot of a reference glucose monitor and an evaluated glucose meter into five areas (see Fig. 3.2):

(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

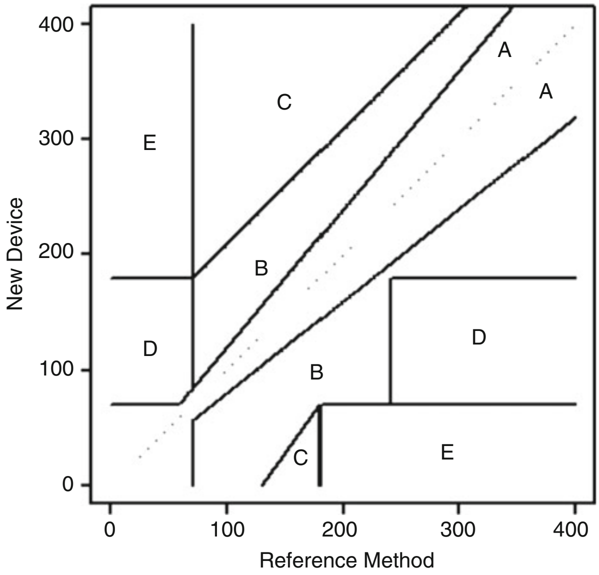

Fig. 3.2 Illustration of Clarke's error grid analysis (EGA)

(d) Where the values indicate a potentially dangerous failure to detect hypoglycemia or hyperglycemia
(e) Where the values could confuse treatment of hypoglycemia for hyperglycemia and vice versa

Many new methods and useful information have been generated since then (see, e.g. [44–47]). 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.

3.3.5 Validating Cut-Off Scores

Because of differences in samples and criterion measures employed in validation studies, it is expected that inconsistency in setting cut-off scores 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-off score is set up so that additional validity evidence can be accumulated and the credibility of the cut-off scores can be further evaluated. When validating a cut-off score or standard, Kane ([48, 49], p. 59) 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-off score 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 [50]. In addition, the role of consequences in standard setting and associated arbitrariness in standards must be examined (see also Zhu [51] for a discussion from the kinesiology's view on standard and cut-off score setting).

3.4 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 .05 *p*-value was achieved. Even though the interpretation of statistical finding based only on *p*-values has long been criticized [52], this practice continues in the field of physical activity and sedentary behaviour research [53]. For correlational and regression research, statistical interpretation should be based on either absolute criteria or the variance percentages explained by the predictors; for inferential statistical findings, the interpretation should be based on the effect size or the confidence intervals [53, 54]. 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.

3.5 Causality in Sedentary Behaviour Epidemiology

Understanding cause–effect relations is essential to any scientific research, which is also true for all epidemiologic studies. Lazarsfeld [55] 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 an empirical 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 [56] is the perhaps 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 change 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 criticized. Interested readers are referred to Kundi [57] for more detail.

A well-controlled experimental design is also very important to establish causality. In epidemiologic studies, the randomized clinical trial (RCT) is the gold-standard research design to provide the most convincing evidence of a relationship between a cause and an 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, non-experimental 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 new statistical methods known as propensity score analysis [58, 59], 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.

3.6 Summary

With the increased awareness of 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 not taken 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. using the wrong methods to analyse compositional data) 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 structure of real-time, long-term physical activity and sedentary behaviour data was explained, and how to select the appropriate statistical method based on the data structure and research interest was described in this chapter. Finally, a number of new statistical methods that could address these problems were introduced, and the principles to establish causality in sedentary behaviour epidemiology were described. The application of these methods and concepts will increase our understanding of physical activity and sedentary behaviour as their data are correctly analysed.

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Chapter 4
The Descriptive Epidemiology of Sedentary Behaviour

Adrian E. Bauman, Christina B. Petersen, Kim Blond, Vegar Rangul, and Louise L. Hardy

Abstract Relative to the overall increase in sedentary behaviour and sitting-related publications, only a small proportion has focused on estimating the prevalence of sedentary behaviour in populations. Although several studies examined the correlates or factors associated with sedentary behaviours, few consistent correlates have been reported. This chapter summarizes recent evidence on the prevalence of sedentary behaviour among adults and children, comprising 39 large and population-representative studies published between 2012 and 2016 for adults and 30 studies for children. Moreover, this chapter describes the correlates of sedentary behaviour for adults, older adults, and children derived from cross-sectional studies.

The median self-report of sedentary behaviours among adults was 5.5 h/day, but was more than 2 h/day longer for objectively measured sedentary behaviours (median 8.2 h/day). Reported television (TV) watching time showed a median of 2.2 h/day. The prevalence of sedentary behaviours among older adults was higher than among adults overall, especially when objectively measured. For children/adolescents, the total time averaged 8.1 h/day and increased from early childhood through adolescence. The average screen time was 2.9 h/day, exceeding recommended levels.

A.E. Bauman (✉) • C.B. Petersen • L.L. Hardy
Charles Perkins Centre, Sydney University, Sydney, NSW, Australia

School of Public Health, Sydney University, Sydney, NSW, Australia
e-mail: adrian.bauman@sydney.edu.au; cbjoerk@hotmail.com; louise.hardy@sydney.edu.au

K. Blond
Charles Perkins Centre, Sydney University, Sydney, NSW, Australia

School of Public Health, Sydney University, Sydney, NSW, Australia

Centre for Physical Activity Research, Rigshospitalet, University of Copenhagen, Copenhagen, Denmark
e-mail: kimblond87@hotmail.com; kim.blond@regionh.dk

V. Rangul
HUNT Study, Department of Public Health and Nursing, Norwegian University of Science and Technology, Trondheim, Norway
e-mail: vegar.rangul@ntnu.no

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Studies on correlates of sedentary behaviour among adults showed that time spent sedentary increased with age, full-time occupation, and higher education. An inverse association was noted with TV time, which was more often reported by least advantaged adults. Sedentary behaviour also showed an inverse association with physical activity time and, for older adults, was associated with current co-morbidity and with perceived safety. Among children, sedentary behaviour increased with age, showed inverse associations with sleep time and physical activity, and was associated with domestic factors, such as parental regulation of screen time and the presence of a TV in the child's bedroom.

In summary, high levels of sedentary behaviour are reported in populations of adults and children, with between a third and two-thirds in the presumed "high sitting" or at-risk sedentary behaviour level. Trend data are limited, but in 27 - European countries, sedentary behaviour declined slightly between 2002 and 2013, indicating that, although high in prevalence, the problem may not be necessarily increasing in high income countries. Self-report estimates tend to underestimate sedentary behaviour time, suggesting the need for consistent objective measures in population studies. The distribution of, and correlates of sedentary behaviour are different to those for physical activities, which means that different population targets and strategies are needed to reduce sedentary behaviour time.

4.1 Introduction

There is increased interest in the relationship between exposure to sedentary behaviour and health and metabolic outcomes. Sedentary time appears to have increased in many countries since the 1960s [1–3]. In the occupational setting in particular, there has been a gradual transition from physically demanding job types to more sedentary occupations [4–6]. In addition to sitting at work or school, adults and children have increasing amounts of discretionary sedentary time, through sitting in their leisure time and during passive transport, the latter especially sitting in the car. The exposure measurement, sedentary behaviour, is usually expressed as total sitting time throughout the day; alternatively, domain-specific sitting time can be estimated for sitting at work, at home, or in travelling from place to place. In addition, some studies used television time as a proxy measure for discretionary domestic sitting time and assessed the relationship between reported TV watching time and health outcomes.

Since 2008, substantial increases have been noted in the published literature on sedentary behaviour (see Fig. 4.1, showing the number of publications with "sitting" or "sedentary behavio(u)r" in the title by year). Data show a marked increase in publications especially from 2008 onwards. In fact, misclassification is likely in the early 2000s, as "sedentary behaviour" was a term then used to describe "low physical activity levels not meeting recommendations or guidelines", but in recent

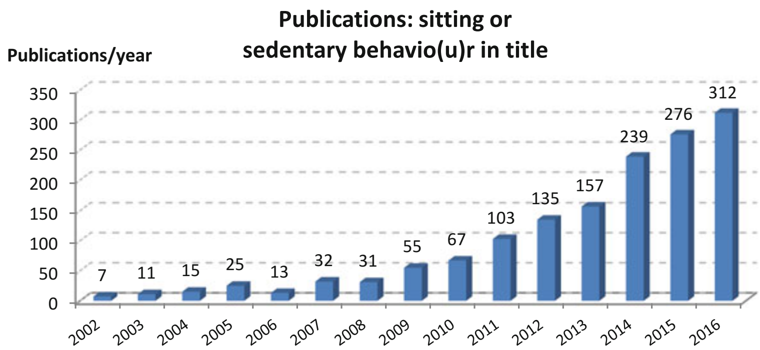

Fig. 4.1 Trends in sitting and sedentary behavio(u)r (Title, Scopus database). Note that data for 2016 are extrapolated from the first 11 weeks of 2016 and are a likely underestimate

years has almost always described sitting time (<1.5 metabolic equivalents (METs) activity of sitting or reclining). In particular, epidemiologic and physiologic 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. Only 6.2% of the 1197 published sedentary behaviour papers had "prevalence" or "correlates or determinants" as title words, suggesting that limited research has reported on the prevalence or distribution of sedentary behaviours in populations.

In order to obtain an overview of the prevalence and distribution of sedentary behaviours, this chapter summarizes recent estimates of sedentary behaviour (sitting) prevalence and explores factors typically associated with sedentary behaviour time in large and population-representative studies. Identifying prevalence and correlates of sedentary behaviour is an important component of population health planning, as it identifies the magnitude of the problem in populations and focuses on identifying characteristics of those that report sitting for prolonged periods.

4.2 Surveillance and Prevalence of Sedentary Behaviour

4.2.1 Surveillance and Population Measurement

Sedentary behaviour is a distinct set of behaviours, not a measure of physical inactivity. It is important to capture the dimensions of sedentary behaviour in the measures used, including low energy expenditure (below 1.5 METs); the sedentary behaviour-relevant posture and position (sitting or reclining); and the different domains of sitting behaviour (at school/work, at home, during transport, and in leisure time) [7].

The descriptive epidemiology of sedentary behaviour requires an assessment of population prevalence, defined as the proportion of people who report information on specific domains or on total sedentary behaviour. Sedentary behaviour in populations is usually measured by self-report or sometimes using objective measures. The aim is to measure sedentary behaviour in the most pragmatic ways for large samples, but to obtain as valid an estimate as possible. Additional measurement information may be obtained by characterising the duration of sedentary behaviours, frequency of interruptions to sedentary behaviour, and the setting or context in which the sedentary behaviours are carried out. These are needed as part of a surveillance system to estimate and monitor sedentary behaviours over time and to identify subgroups at high risk of increased sedentary behaviour.

4.2.2 Measuring Sedentary Behaviours in Populations of Adults and Children

The population prevalence of sedentary behaviours is measured in adults and children using diverse methods, as summarized in Table 4.1. The initial decision is to determine the form of data that are required, whether information is needed on total sedentary time, episodes of sitting time, or on a specific domain of sedentary behaviour, such as work-related sitting, transport-related sitting, or total screen time.

Self-report measures are the most feasible and scalable measures used in large studies and can be incorporated into routine surveillance systems. Questions can be short single items assessing total sitting [12] or can assess domain-specific sitting [13, 14]. Modes of administration include self-report questionnaires, face-to-face interviews, or online surveys. Self-recorded diaries provide better quality information, as behaviour is recorded at regular intervals throughout the day, but a high respondent burden limits their population use for assessing sedentary behaviours. For children aged less than 11 or 12 years of age, proxy reporting of their sedentary behaviour by their parent or teacher is necessary [11].

Objective measures include motion-sensing devices such as accelerometers and inclinometers, and algorithms are used to translate raw movement count data into sedentary time. Accelerometers, which continuously measure movement in one or more planes, can quantify the duration of total daily sitting and the number of breaks in sitting time. More recent advances have included new accelerometers with the capacity for postural measurement which help to identify sit–stand transitions and to differentiate time spent sitting down from time spent standing still [8]. Pedometers, although inexpensive and accurate, only assess step counts and cannot assess sedentary time. Direct or video observations of sedentary behaviours can be used, but are usually limited to small studies. New technologies for observational measurements, such as ecological momentary assessments (EMAs) [15] or direct or video observations, provide precise information but are not yet feasible in

Table 4.1 Summary of objective and self-report population measures of sedentary behaviour among adults and children

	Objective measures			Self-report measures		
	Accelerometers	Posture monitors	Wearable technology	Time-use diary	Self-report	Proxy report
Description	Small usually hip or wrist worn electro-mechanical accelerometer (detects linear movement, vibration, and changes to movements in up to 3 planes.	Small thigh-worn device; accelerometer and gyroscope to measure the angle tilt in real-time (including posture, sit-to-stand transitions).	Are accelerometers usually wrist or hip worn; linked to web Apps; smartphones; measures steps/acceleration; some estimate of sitting time (with feedback).	Participant records all activity at specified intervals over 1 or more days. May include contextual information (place and person).	Questions on sedentary behaviour activities. May be self-completed on paper, by interview or on line.	For children; possibly for the oldest elderly; questions completed by a third party (for example parent or teacher).
Example	Actigraph [8]	ActivPAL, Axivity [9]	Fitbit, Jawbone, Iphone, and Android Apps	National time use diary data [10]	Many sedentary behaviour questionnaires are validated	Pate et al. [11]
Assessment period	Usually 4–7 days to capture habitual sedentary behaviour		May be continuous among users	Variable length of time	Variable: sedentary behaviour in previous day, usual/past week, month, or year	
Advantages for population measurement	• Can estimate sedentary behaviour and duration (identify interruptions to sitting; prolonged sitting periods) • Criterion measure (especially with posture included) • Suitable for use across age groups		• Pervasive in society; high population use • Continuously collects research quality data • Suitable for all age groups	Better validity than self-report questions (related: ecological momentary analysis random contacts through the day to assess sitting/physical activity)	• Low cost, large samples • Can estimate total reported sitting time; can assess intensity, domain of sitting • Can provide information on correlates of sitting • Low respondent burden • Can be easily added to existing physical activity and health surveillance systems	

(continued)

Table 4.1 (continued)

	Objective measures			Self-report measures		
	Accelerometers	Posture monitors	Wearable technology	Time-use diary	Self-report	Proxy report
Disadvantages for population measurement	• High cost • High burden for participants; wear time compliance • No contextual information • Cannot distinguish sitting, standing, lying • No standard data analytic protocols	• High cost • High burden for participants; wear-time compliance • No contextual information	• Sitting assessment using wearable technology not widely validated and varies by device • Transience of devices and Apps, constantly upgraded • Some devices have proprietary data algorithms making it difficult to assess sitting	• High burden; completion may vary by health literacy • Potential for social desirability bias	• Potential for recall or social desirability bias • May under- or overestimate sedentary behaviour time	• Potential for bias (social desirability and recall) • May under- or overestimate sedentary behaviour time • Random error due to opinion of proxy responder

large population studies. Wearable technologies, including rapidly evolving wrist worn devices and smart watches, provide access to data from large numbers of people, but their sedentary behaviour algorithms have not yet been validated [16].

The advantages and disadvantages of different population measures of sedentary behaviour are shown in Table 4.1. Most large studies that assess the prevalence of sedentary behaviours have used self-report measures, although a few have piloted the use of objective motion sensors in population samples. For further details on subjective and objective measurements of sedentary behaviour, please refer to Chap. 2.

4.2.3 Compiling the Prevalence Estimates of Sedentary Behaviour

In order to estimate prevalence of sedentary behaviours across studies, PubMed, EMBASE, and Scopus were searched for articles published in English from the 1 January 2012 through to 27 January 2016. These were used as the most recent years, during which 77% of sedentary behaviour papers to date were published (Fig. 4.1).

The syntax used for searching in PubMed was:

((sitting(Title) OR sedentary(Title)) AND (Prevalence(Title/Abstract) OR public health(Title/Abstract) OR population(Title/Abstract) OR epidemiology(Title/Abstract) OR risk(Title/Abstract) OR correlate*(Title/Abstract) OR association*(Title/Abstract)) AND ("2012"(Date—Publication): "2016"(Date—Publication))).*

This resulted in 1197 publications. Two of the authors reviewed the publications to identify studies that provided prevalence estimates, and only large population-based studies with at least 2000 participants for cross-sectional studies and 500 for analytical studies were included, as these studies were more likely to have more generalizable estimates of sedentary behaviours. Further, we excluded studies that did not report an appropriate and comparable estimate of sedentary behaviour time, defined as providing means and standard deviations (SD) or medians and inter-quartile ranges (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 also excluded.

Prevalence data from the selected studies were examined to produce an overall range and median estimates of sedentary behaviour time. The studies among adults are shown in Table 4.2 (n = 39 studies) and among children in Table 4.3 (n = 30 studies). For each paper, the lead author is reported as well as the country and year of study, age group, and sample size. The prevalence of sedentary behaviour was extracted in three contexts for adults: total sitting time, TV viewing/screen time and work, and in four contexts for children and adolescents: total sitting time, TV viewing, computer use, and screen time. The prevalence of sedentary behaviour is

Table 4.2 Descriptive estimates of the prevalence of sedentary behaviour 2012–2016 (adults)

Study	Country	Year	Age group	Sample size (*N*)	Context of sitting time Mean hours/day (h/d) ± SD if nothing else is stated		
					Total sitting time	TV viewing/ Screen time	Work
Self-reported							
Aadahl et al. (2013) [1]	Denmark	2010	25–79	77,517			4.60 ± 2.79 h/d
Asztalos et al. (2015) [17]	Belgium	Not stated	25–64	4344[a]	4.7 ± 2.3 h/d		
Bennie et al. (2013) [18]	32 countries	2005	15–98	27,637[b]	5.2 ± 3.1 h/d *5 (3–7) h/d*		
Bjork Petersen et al. (2014) [19]	Denmark	2007–2008	18–99	71,363[c]	*6.9 (4.5–8.7) h/d*		
Borodulin et al. (2015) [20]	Finland	2002	25–74	4516[d]	6.4 ± 3.2 *6.0 (4.0–9.0) h/d*		
Chau et al. (2015) [21]	Norway	2006–2008		50,817[e]	7+: h/d: 32.0% 10+ h/d: 13.3%	4 + h/d: 13.3%	
Chau et al. (2012) [13]	Australia	2007–2008	15–69	10,785 working[f]		3.8 ± 3.0 h/d	
Clemes et al. (2016) [22]	UK	2012	18+	4436 [22]	10.4 ± 2.8 h/d	1.5 ± 1.2 h/d	6.3 ± 1.8 h/d
Guallar-Castillon et al. (2014) [23]	Spain	2008–2012	18+	4271 [23]		2.2 ± 1.47	
Hadgraft et al. (2015) [24]	Australia	2011–2012	Mean: 53	1235 working[g]		*1.4 (0.7–2.1) h/d*	*6.0 (3.0–7.6) h/d*
Hamer et al. (2014) [25]	England	2008	16–95	11,658 [25]	4.9 ± 1.5 h/d	2.8 ± 1.6	

Horta et al. (2015) [26]	Brazil	2012–2013	30	1241[h]	Highest quartile: 12.3–15.9 h/d		
Lin et al. (2015) [27]	USA	2002	38–45	5285 working[i]			3.0 ± 1.1 h/d
Matthews et al. (2012) [28]	USA	1995–1996	50–71	240,819[j]	7+ h/d: 23% 9+ h/d: 8.3%	3+ h/d: 62.7% 5+ h/d: 18.9%	
Matthews et al. (2014) [29]	USA	2002–2009	40–79	63,308[k]	Highest quartile: >12.0 h/d		
Mielke et al. (2014) [30] and Munir et al. (2015) [31]	Brazil	2012	20+	2927[l]	5.8 ± 4.5 h/d *4.5 (2.5–8.0) h/d*		
Milton et al. (2014) [32]	27 European countries	2013	15+	27,919[m]	4.9 ± 2.3 *5.0 (3.0–7.0) h/d* 8.5+ h/d: 11.3%		
Mitas et al. (2014) [33]	Czech Republic	2007	15–69	4097	*5.9 (4.0–8.0)*		
Munir et al. (2015) [31]	Northern Ireland	2012	median age 35–44 yrs	4436 [31]			6.4 ± 1.9 h/d
Pinto Pereira and Power (2013) [34]	UK	2003	44–45	6562 working[n]		3+ h/d: 19.9%	3–4 h/d:6.8% 4+ h/d:35.0%
Ryu et al. (2015) [35]	Korea	2011–2013	Mean: 39.9	139,056[o]	7.6 ± 3.8 h/d		
Saidj et al. (2015) [36]	France	2009	18+	35,444 working[p]		2.19 ± 1.62 h/d	4.2 ± 3.1h/d
Saidj et al. (2013) [37] and Saidj et al. (2014) [38]	Denmark	2006	18–69	3544 working[q]	7.2 ± 2.8 h/d		4.1 ± 2.7 h/d
Shih et al. (2014) [39]	Taiwan	2011	40+	10,940[r]	7+ h/d: 31.7%		
Sloan et al. (2013) [40]	Singapore	2010	18–79	4337[s]	*5 (3–8) h/d* Highest tertile: 10 (8–11) h/d		

(continued)

Table 4.2 (continued)

Study	Country	Year	Age group	Sample size (*N*)	Context of sitting time Mean hours/day (h/d) ± SD if nothing else is stated		
					Total sitting time	TV viewing/ Screen time	Work
Sodergren et al. (2012) [41]	Australia	2010	55–65	3644[t]	5.8 ± 2.9 h/d *5.1 (5.0–5.3)*		
Staiano et al. (2014) [42]	USA	2007	20+	4560[u]	*5.7 (5.5–5.8) h/d*		
Stamatakis et al. (2012a) [43]	Australia	2010	>47	26,366 working[v]	5.5 ± 3.1 h/d	2.4 ± 1.4 h/d	
Stamatakis et al. (2012b) [44]	UK	2008	16–65	5948[w]	Highest tertile: >7.8 h/d		
van der Ploeg et al. (2012) [10]	Australia	2006–2010	45+	22,2497[x]	8+ h/d: 25.1% 11+ h/d: 6.4%		
Wallmann-Sperlich et al. (2013) [45]	Germany	2010	Mean: 49.3	2000	5.3 ± 3.1 h/d *5.0 h/d* >6 h/d: 30.1%		
Win et al. (2015) [46]	Singapore	2012	Mean: 43	2319[y]	*6 (3–8) h/d* 8+ h/d: 37%		
Objectively measured							
Barone Gibbs et al. (2015) [47]	USA	2005–2006	38–50	2027[z]	8.1 ± 1.7 h/d		
Carson et al. (2014) [48]	Canada	2009/2011	20–79	4935 [48]	10.8 ± 2.0 h/d		
Hagstromer et al. (2015) [49]	Sweden	2001	18–75	1172 [49]	8.21 ± 1.5 h/d		
Kim et al. (2015b) [50]	USA	2003–2006	18+	5917[aa]	8.1 ± 4.5h/d		
Qi et al. (2015) [51]	USA	2008–2011	18–74	12,083 Hispanic and Latinos[ab]	11.9 h/d		

Stamatakis et al. (2012b) [44]	UK	2008	16–65	1772[ac]	Highest tertile: >10.2 h/d		
Van Dyck (2015) [52]	10 countries	2002–2011	18–65	5712	8.55 ± 1.75 h/d		

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
[e]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]NHANES 2006–2008
[ab]Hispanic Community Health Study/Study of Latinos (HCHS/SOL)
[ac]Health Survey for England (HSE) 2008

Table 4.3 Descriptive estimates of the prevalence of sedentary behaviour 2012–2016 (children and adolescents)

Study	Country	Year	Age group	Sample size (N)	Context of sitting time (h/day) Mean hours/day (h/d) ± SD if nothing else is stated			
					Total sitting time	TV viewing	Computer	Screen time
Self-reported								
Carson et al. (2015) [53]	USA	2007–2012	12–19	3556	7.5 ± 6.5 h/d			
Chen et al. (2014) [54]	Taiwan	2012	9–12	1933	4.7 ± 2.4 h/d			2.9 ± 2.5 h/d
Chen et al. (2014) [55]	China	2011	11–18	9901		> 4 h/d: 1.2%	> 4 h/d: 1.7%	
Babey et al. (2013) [56]	USA	2005	12–17	4029		2.3 ± .04 h/d	1.4 ± .04 h/d	
Baygi et al. (2015) [57]	Iran	2009–2010	10–18	2618		3.5 ± 1.2 h/d	2.0 ± 1.2 h/d	5.56 ± 1.8 h/d
Dadvand et al. (2014) [58]	Spain	2006	9–12	3178				> 1 h/workday and >2 h/weekend day: 28.4%
Duan et al. (2015) [59]	China	2013	12–15	1793		≥2 h/d: 8.3%	≥2 h/d: 22.7%	≥2 h/d: 42.9%
Gopinath et al. (2012) [60]	Australia	2009–2011	17–18	1094		1.34 ± 0.8 h/d	1.54 ± 0.9 h/d	3.27 ± 1.60 h/d
Iannotti and Wang (2013) [61]	USA	2009–2010	11–15	10,848		2.4 ± 0.05 h/d	1.5 ± 0.05 h/d	

Kiefte-de Jong et al. (2013) [62]	The Netherlands	2002–2006	2	2420		≥2 h/d: 9.0%		
Kim et al. (2016) [63]	USA	2012–2013	14–17	12,081		≥3 h/d: 31.8%	≥3 h/d: 41.0%	
Kong et al. (2015) [64]	Korea	2013	12–18	53,769	School time: 6.3 h/d Leisure time: 3.0 h/d			
Leatherdale et al. (2015) [65]	Canada	2012–2013	14–17	23,031	8.2 ± 5.2 h/d[a]	1.95 ± 1.4 h/d	1.4 ± 1.8 h/d	
Lee (2014) [66]	USA	2001–2002	11–21	3717		1.8 ± 1.8 h/d	0.7 ± 1.2 h/d	3.2 ± 3.4 h/d
Loprinzi (2015) [67]	USA	2011–2012	6–17	40,446				2.0 ± 0.02 h/d
van Rossem et al. (2012) [68]	The Netherlands	2002–2006	3	4688		≥2 h/d: 7.8%		
Wijtzes et al. (2014) [69]	The Netherlands	2002–2006	6	5913		≥2 h/d: 19.9%	≥1 h/d: 7.6%	
Zhang et al. (2012) [70]	China	2004	6–18	5497		>2 h/d: 23.1%		
Objectively measured								
Aibar Solana et al. (2015) [71]	Spain and France	2010–2012	Mean age 14.33	829	France: 9.1 ± 1.2 h/d Spain: 9.3 ± 1.2 h/d			
Atkin et al. (2013) [72]	U.K.	2011	9–14	2064	5.8 ± 0.7 h/d			2.2 (1.2–3.7) h/d
Downing et al. (2015) [73]	Australia	2008–2009	3–5	703	10.8 (10.8–10.9) h/d	1.6 ± 1.0 h/d	0.1 ± 0.2 h/d	

(continued)

Table 4.3 (continued)

Study	Country	Year	Age group	Sample size (*N*)	Context of sitting time (h/day) Mean hours/day (h/d) ± SD if nothing else is stated			
					Total sitting time	TV viewing	Computer	Screen time
Herrmann et al. (2015) [74]	Europe[b]	2007–2008 and 2009–2010	2-<6 and 6–10	1512 and 2953	2-<6 years: 4.4 ± 1.5 h/d 6–10 years: 5.7 ± 1.5 h/d			
Hildebrand et al. (2015) [75]	Europe[c]	1997–2007	6–18	10,793	6.2 ± 1.5 h/d[d]			
Katzmarzyk et al. (2015) [76]	ISCOLE Study[e]	2011–2013	9–11	6539	8.55 ± 1.15 h/d[d]			
Loprinzi et al. (2015) [77]	USA	2003–2006	6–17 Children:6–11 Adolescents: 12–17	Children: 1036 Adolescents: 1608	Children: 5.9 (5.8–6.0) h/d[d] Adolescents: 8.0 (7.8–8.2) h/d[d]			
Marques et al. (2016) [78]	Portugal	2010–2011	9–12	1042	9.1 ± 1.2 h/d			≤2 h/d: 20%
Santos et al. (2014) [79]	Portugal	2008	10–18	2506	9.0 ± .03 h/d[d]			
Sherar et al. (2016) [80]	ICAD[f]	1997–2009	10–18	12,770	Boys: 5.9 ± 1.5 h/d[d] Girls: 6.8 ± 1.6 h/d[d]			
Trang et al. (2013) [81]	Vietnam	2009	11–17	585	8.0 ± 1.5 h/d	1.65 h/d (1.0–2.3)		3.4 h/d (2.6–4.4)

Verloigne et al. (2013) [82]	Belgium, Greece, Hungary, the Netherlands, and Switzerland	2010	10–12	672	8.2 ± 1.1 h/d[d]	1.8 ± 1.0 h/d	1.2 ± 0.8 h/d	3.0 ± 1.7 h/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]The cut-off for sedentary/sitting time was ≤100 counts/minute

[e]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

[f]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

expressed as total sitting time (hours/day) or as time spent in specific sitting activities (hours/day).

4.2.4 The Prevalence of Total Sitting Time Among Adults

The purpose of descriptive epidemiology of sedentary behaviour is to estimate the prevalence of sitting time. As can be seen from Table 4.2, the estimates were mostly from high income countries. Across all these studies, the median of the estimates of average total daily sitting time was 6.4 h/day, ranging from a mean of 3.8–11.9 h of sitting/day. When stratifying by studies measuring sitting time that used objectively measured methods, the median was 8.2 h/day (range 4.9–11.9 h/day). This is 2 h more than the median sitting time extracted from studies using self-report measures of sitting, where the median sitting time was 5.5/day (range 3.8–7.6 h/day). Around a third (32%) of the estimates reported sitting for more than 7–8 h/day and one out of four were sitting for 11+ h/day.

The socio-demographic correlates of sedentary behaviours are reasonably consistent across studies. Across studies, those from higher social groups or with higher achieved education are likely to spend more time sitting, mostly driven by high rates of work-related sitting time [18, 30], with highest rates of sitting among working-aged populations. This contributes to the generally higher time spent sitting by men, compared to women, in many countries. The association in adolescents from multiple countries studied also showed similar associations, with higher maternal education associated with higher sitting time among adolescents [80]. However, an inverse association is seen with the component of sedentary time that is time spent on television watching; this is consistently higher among lower socio-economic groups, among migrant populations, and among older adults [83], indicating that different domains of sedentary behaviour show different correlates. Further, multi-country studies indicate geographic differences, with a European north-south gradient noted, demonstrating higher rates of sitting in Northern Europe compared to Mediterranean countries [18, 32]; this is the inverse of leisure time physical activity patterns, which are higher in Scandinavia and Northern Europe. It is not clear whether these differences are true, or result from reporting and language differences across Europe, but warrant further investigation.

The observation that objective measures showed higher sitting estimates was noted in earlier population research [84]; data from the National Health and Nutrition Examination Survey (NHANES) 2003 in the USA showed a mean of 7.7 h of daily sitting when objectively measured. Even higher levels of sedentary behaviour were reported among adult Canadians, showing objectively measured sedentary behaviour for an average of 9.5 h/day, representing 68% of their waking hours [85].

For many adults, three key domains contribute to total sitting time: work, leisure time, and transportation [2, 86]. For working adults, occupational sitting time contributes largely to the total amount of sitting time accumulated during the day.

Today, many adults have sedentary jobs [6, 87]. Based on the estimates in Table 4.1, the overall median occupational sitting time was 4.2 h/day (range 3.0–6.3 h/day). Thus, most working adults spent more than half of their working day sitting. For further details on occupational sitting and interventions targeting sedentary behaviour at work, please refer to Chap. 18. 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 2.2 h/day (range 1.5–2.9 h/day) and overall, 26% reported watching TV for more than 3–4 h/day. Only a few studies have estimated the prevalence of sitting for transportation. In a large sample of the French working population, the mean time spent sitting for transportation was 1.1 h/day [38]. Clearly the amount of time spent sitting for transportation depends on urban and transport planning as well as the transport culture [2]. In Australia, around 60% people drive to work every day with an average driving time of approximately 80 min, which means that the average time spent sitting in a car would be around 50 min/day in the population when including those not driving [88]. Assuming that driving time is normally distributed, roughly, 20% in the general population would spend more than 2 h in the car each day.

4.2.5 Sedentary Behaviour in Older Adults

Few large population-based studies have been conducted in older adults (i.e. >60 years old). Here, we summarize the findings of a comprehensive review reported by Harvey et al. [89]. That review identified 18 studies from 7 countries published to 2012 and used slightly different criteria to the adult review above. Harvey and colleagues used sample sizes of at least 200 older adults, reduced data to hours per day as a common metric, and pooled data by gender to arrive at a total sample average among adults over 60 years. Their paper showed that there was a slight increase in the prevalence of sedentary time with age [89]. Approximately, 60% of older adults report sitting for more than 4 h/day and around a quarter reported more than 7 h sitting per day; further, more than 54% report watching TV for more than 3 h/day. When objectively measured, 77% of the older population were sedentary for more than 8.5 h/day. These pooled estimates are similar to those from representative surveys of American and Canadian older adults. The U.S. NHANES survey showed a mean sitting time of 8.5 h/day for adults aged over 60 years [90], and the Canadian Health Measures Survey showed even higher rates, with a mean of 10 h/day of sedentary behaviour among Canadians aged 60–79 years [91].

4.2.6 Sedentary Behaviour Prevalence Estimates in Children and Adolescents

Table 4.3 shows the prevalence of sedentary behaviour among children and adolescents aged up to 19 years. The average total daily sitting time was 8.1 h and ranged from 4.4 h/day for children age 2–6 to 9.3 h/day for adolescents age 12–18 years. The lower half of Table 4.3 shows estimates of children's sedentary behaviour using accelerometers, where a cut-point of <100 counts/minute was used to define sedentary time.

Unlike physical activity, there has been a lack of a specific guideline for sedentary behaviour, and currently there are no evidence-based international guidelines for limiting sedentary behaviour. In 1986, the American Academy of Pediatrics introduced the first guidelines for sedentary behaviours in children. These were revised by Strong et al. [92] who suggested reducing sedentary behaviours to less than 2 h/day. This was followed by the first evidence-based Sedentary Behaviour Guidelines for Children and Youth in Canada [93], which recommended for children (aged 5–11) and youth (aged 12–17) that they minimize time spent being sedentary each day by limiting the recreational screen time (watching television, computer use, playing video games, etc.) to no more than 2 h/day. For further details on recommendations for sedentary behaviour, please refer to Chap. 1. For the individual studies reviewed in Table 4.3, screen time ranged from 1.6 to 5.6 h/day. The average screen time for the studies that presented prevalence estimates (7 studies) was 2.9 h/day among children and adolescents. One of the studies reported that 28.4% of children aged 9 to 12 years reported more than 3 h/day of screen time. The screen time prevalence was limited to TV watching and computer use, and varied from 0.3 h to 3.5 h/day, and average time for TV watching was 2.1 and 1.1 h/day for computer use.

Few studies have specifically looked at sedentary behaviour in preschool-aged populations. Studies of preschool-aged children report that most of the measureable sedentary behaviour is assessed as TV/video time; a systematic review of 3- to 5-year-old children in childcare suggested that they viewed 0.1–1.3 h/day of television in childcare centres, less than those in home-based child care (1.8–2.4 h/day; [94]). This was similar to estimates in a large Melbourne study of preschoolers, who demonstrated 127 min/day of screen time. [95]. Younger children, aged 0–2 years, were more variable, but a review of 30 estimates from 24 studies in 6 countries found that typically this infant age group had 80–90 min/day of screen time [96].

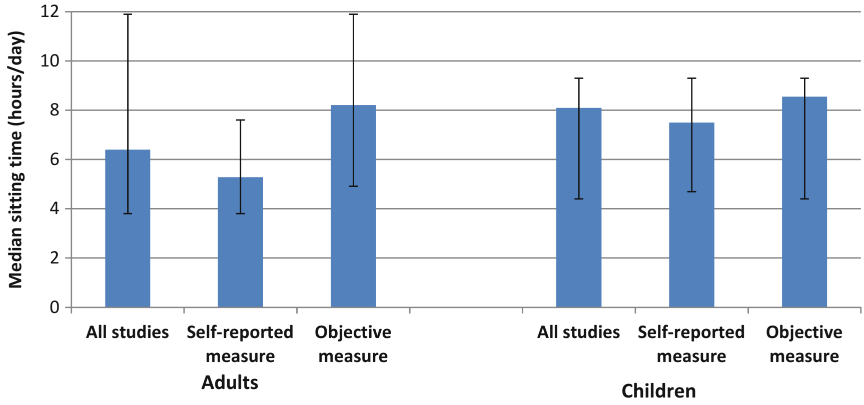

Fig. 4.2 Pooled prevalence of mean sitting time in studies using self-reported and objectively measured methods to estimate sitting time. The estimates present the median of the mean values presented in Tables 4.2 and 4.3, showing the range of mean estimates obtained from the reported studies

4.2.7 Discussion of Sedentary Behaviour Prevalence Estimates

The current review examined sedentary behaviour in studies published between 2012 and 2015 and showed that sedentary behaviour comprises a substantial part of the total day for adults and children. For adults, self-report estimates were just under 6 h/day, which was 2.5 h less than estimates obtained by objective measures (the data are summarized in Fig. 4.2). Although samples were not directly comparable, it suggests that self-report substantially underestimates total sitting time. If the data were normally distributed, the self-report estimate would imply that a quarter of adults sat for 7 or more hours, and the objective measures would suggest that around three quarters sat for 7 or more hours a day. This indicates that there are differences according to the mode of measurement and suggests the need for objective assessments to refine population estimates of sitting time. Rapid changes in technology may improve the measurement of sedentary behaviour and active time, and this may provide better estimates of the distribution of sedentary time in future years. Further, there may be variation in sitting time by weekend and weekday. For example, among working adults, greater sitting time is reported on workdays. Days of the week that are recalled or objectively assessed need to be considered in estimating total weekly sitting time [97].

In addition to these individual sample studies in Tables 4.2 and 4.3, several multi-country studies have compared sedentary behaviour prevalence. These were not included in the single estimate tables earlier. In a 20-country comparison, Bauman et al. [98] presented data on 49,493 adults aged 18–65 years and reported a total sitting median of 5 h/day (interquartile range, 3–6 h; mean of 5.8 h/day). Twenty-five percent reported at least 8 h/day of sitting, with the highest rates of sitting reported in Taiwan, Hong Kong, Saudi Arabia, Japan, Lithuania, and Japan and the lowest rates in Portugal, Brazil, Colombia, India, and China. More recent studies examined total sitting time in the population-based Eurobarometer surveys from Europe [18, 99]. Data from the most recent survey in 2013 indicated a median sitting time of 5 h/day, with 25% reporting more than 7 h/day [99]. Trend data were examined across Eurobarometer surveys in 2002, 2005, and 2013 using comparable sitting measures in 27 countries [32]. "High levels of sitting" were defined as reporting at least 7.5 h of sitting per day. The prevalence of "high sitting" declined across this 11-year period in most countries and, overall, declined from 23% in 2002 to 22% in 2005 and 18% in 2013. This suggests that sitting rates, at least by self-report, are not increasing and may be declining over time in European countries.

For older adults, prevalence data were similar, with a quarter sitting for 7+ h/day and subjective estimates more than 2 h/day lower than objective estimates. Television watching averaged 2.2 h among adults, and appeared to increase through older adult years, contributing to domestic sitting time.

Among children and adolescents, the majority of preschoolers, children, and adolescents in middle and high income countries exceeded the guideline of 2 h of screen time daily. One multi-country estimate reinforced this, using international health survey data [100]; that report noted that globally around two-thirds of adolescents aged 13–15 years exceeded the guideline of watching 2 h/day of screen time.

There are challenges in estimating sedentary behaviour prevalence in adults and in children. These include lack of clear thresholds of prolonged or uninterrupted sitting that pose a health risk. Guidelines for adults refer only to reducing sitting, and for children and adolescents, refer to limiting screen time to less than 2 h per day. For adults, mortality risk seems to increase for sitting times greater than 7 or 8 h/day [101], but the quality of sitting (whether sitting time is broken up, or prolonged continuous sitting) is not reported, which may influence the physiology of sitting-related risk [102]. 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.

4.3 Correlates of Sedentary Behaviour and Sitting

4.3.1 Correlates of Sitting in Adults

Numerous studies have examined factors associated with sitting time amongst 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, TV time, and the correlates of total sitting time [2]. The largest study of sitting correlates was carried out in serial multi-country studies of European adults [18, 99]. Consistent correlates of high sitting time across countries were being a white-collar worker, self-employed, and having higher educational attainment or still being a student [99].

Other correlates were high internet usage, low life satisfaction (depression), and both financial insecurity and unemployment [99]. The inverse, low rates of sitting time were noted for those who were regularly physically active, those with three or more children, and rural or small town residents (compared with those in large cities).

In most research, a strong and consistent positive association is noted between sitting and education attainment, income or measures of social position, or socio-economic status (SES). Those with higher education or SES report sitting for longer, especially at work; this has been noted in German men and women [103]; among Australian adults of middle age [24, 104], and in broader reviews of adults sitting time [98, 105]. Full-time employment is a consistent correlate of prolonged sitting [104], although some studies have reported reduced productivity among those who sit too long [106]. For women, total sitting time was higher among those in full-time employment, in higher income occupations, and those who chose passive recreational pursuits [97]. This direct association between workplace sitting time and higher education is reversed for domestic sitting as measured by television time, which is higher among low SES and least educated populations [107, 108].

There are consistent associations between prolonged sitting and obesity [109, 110] and between prolonged sitting and depression and mental health [40, 106, 111], but these may be merely associations, and the true relationship may be bidirectional [111, 112]. One aspect of the sitting and obesity relationship is the interesting observation among car users who sit in the car for prolonged periods. Previous well-cited studies only examined cross-sectional associations, but more recent research has shown weight gain among daily car commuters; the magnitude of this effect is around 0.2 kg/year, compared to those not engaged in lengthy car commutes or not travelling to work [110]. As with elderly adults, the presence of co-morbidity and chronic health conditions is consistently associated with increased sitting time throughout adult life [104]. 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 [108].

Researchers have investigated environmental correlates of prolonged sitting and identified housing type and size in Denmark [36] and less walkable neighbourhoods and lower community engagement in Western Australia [113]. Bennie et al. [18] showed geographic differences in 2003 in sitting time across Europe, with some evidence of greater reported sitting time in Northern European countries compared to those (with warmer climates and on average, slightly less income) in the southern parts of Europe. Similar surveys repeated in 2012 showed Switzerland, Denmark, and the Netherlands as having the highest sitting rates in both surveys; further, there was up to a three-fold variation in the proportions reaching 7.5 h/day of sitting time across European countries [99].

Finally, psychological factors have been examined, and the psychological habit of usually sitting and intention to sit are both related to sitting behaviour [114]; further, self-efficacy or confidence in being able to build non-sitting behaviours into daily life is also associated with lower sitting time [115].

4.3.2 Correlates of Sitting in Older Adults

Older age groups usually refer to adults approaching or beyond retirement age, typically aged 60 years and older. This section reviews correlate studies among older adults mostly from the period 2012 to 2015. One consistent factor through older adulthood is increased time spent on watching television, partly as a consequence of increased free time and partly contributed to by decreased mobility or increased co-morbidity [116].

Chastin and colleagues [117] carried out a systematic review of 22 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 co-morbidity (including obesity) were more likely to spend time in prolonged sitting. A national health survey of Canadians showed that older adults sat more if they were completely retired (as a proxy for older age), lived in apartments (compared with living in houses or separated dwellings), or if they felt disconnected from their community. Increased rates of prolonged sitting were also seen among widowed or divorced older adults, but showed no clear associations with income or attained education in older age [118]. Co-morbidity was repeatedly associated with prolonged sitting, especially chronic cardiac or pulmonary disease, obesity, low physical activity, or poor self-rated health. Similar associations were seen in a large sample of older adults in southern Brazil, where co-morbidity and low physical activity were correlates of prolonged sitting time [119], as well as in studies of colon cancer patients [120] and older Canadians [121]. An objectively measured sedentary behaviour study of older Canadians showed significant correlates included poor self-rated health status, obesity, smoking, and low physical activity [91]. A study of older Canadians suggested that total sitting was correlated with obesity and with home internet availability [122]. By contrast, an Australian population study did not find specific correlates of sitting in the elderly, except negative associations for those with social supports and friends who discouraged sitting [123].

Kesse-Guyot et al. [124] examined the relationship between sedentary time and cognitive function in a large French cohort aged over 65 years and followed between 2001 and 2007. 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 characterize epidemiological exposure and are more useful in understanding correlates/determinants than simple associations from cross-sectional studies [125].

4.3.3 Correlates of Sitting and Sedentary Behaviours Among Children and Adolescents

The majority of children and adolescents attend school; hence, measurement of their sedentary behaviour focuses on their discretionary (outside of school) time. The proliferation of screen-based devices, including smart phones and tablets, has led to concerns that contemporary generations of young people spend a large proportion of their awake time sedentary. Information on the correlates of sedentary behaviour in children and adolescents, screen time in particular, can inform intervention efforts for children at greatest risk of sitting for periods of time that may impact on their health.

Our understanding of the correlates of sedentary behaviour among children and adolescents is limited by the differences in the measurement across surveys including a failure to measure new small screen devices, which are popular among children and adolescents. Although better measures of sedentary behaviour are required, there have been a number of reviews of sedentary behaviour correlates in children and adolescents which consistently show that socio-demographic and environmental factors influence sedentary behaviour. Temmel and Rhode's recent review [126] based on 181 studies published between 2001 and 2011 shows that age, gender, and socio-economic status are consistently associated with children and adolescent sedentary behaviour.

Age has been the most consistent correlate, with most studies indicating that sedentary behaviour increases as children move into adolescence [126]. 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 [126, 127].

High socio-economic 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 [56, 128]. Some of these aspects of sedentary behaviour were more common among boys than girls [56]. Even within categories of screen time, cultural differences occur, with more television time reported by African American adolescents from low socio-economic backgrounds, and more screen time (computers in particular), more likely among Asian Americans from higher income backgrounds who also reported less physical activity [56].

Globally, social and economic correlates are less clear, with some evidence of increased sedentary behaviour in urban environments, compared with rural children in low and middle income countries [129]. There are added seasonal differences in some countries, with increased sedentary behaviour in the coldest or warmest months [130]. Higher screen time has been reported among migrant children in developed countries, compared with non-migrant children, although this may be due to low socio-economic circumstances, a lack of access to other leisure time facilities, and urban crowding [126].

Psychosocial correlates have been examined in several studies. Self-esteem has been shown to be inversely related to screen time [131], and overall measures of sedentary behaviour are associated with reduced quality of life, and measures of emotional health and well-being [60]. Behavioural correlates of sedentary behaviour also show a mixed pattern. One study of adolescents in eight African countries showed a consistent positive association between increased sedentary behaviour and tobacco, alcohol, and substance use [132]. This was noted in several studies reviewed by Temmel [126], as were inverse associations between healthy diet, measured through indicators of fruit and vegetable consumption and sedentary behaviours.

Sleep is more consistently and inversely associated with sedentary behaviour, as there is a displacement effect of more sedentary behaviour encroaching on sleep time; this was demonstrated in a substitution modelling paper using accelerometer data on American adolescents [133]. There were adverse metabolic consequences if sleep was reduced and compensated for by increased sedentary behaviour time. There are clear and inverse associations between physical activity and sedentary behaviour time, with these associations present for both children and adolescents [126, 134, 135]. Increased sedentary behaviour was also associated with lower participation in physical education classes [136]. The association between sedentary behaviour and obesity may be stronger for TV time compared to other settings for sedentary behaviours [137] and is partly a consequence of food advertising to children on television and the displacement of time that could be spent in physical activity.

Environmental and social factors influence sedentary behaviours and sitting time and may be moderated by culture and economic influences. Outdoor environmental factors such as accessible play spaces and playground density may be associated with decreases in sedentary behaviours and concomitant increases in physical activity [138]. By contrast, low neighbourhood safety is associated with increased sedentary behaviour [126]. Dog ownership and a walkable environment were associated with increased walking, but made no difference to sedentary behaviour or screen time [139].

A longitudinal study of Vietnamese adolescents followed from age 11 to age 16 showed marked increases in screen time through adolescence, especially those from more affluent families, showing a different pattern to developed countries [81]. 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 the television [140, 141]. Studies in 2011 were remarkably consistent in this area, with all 19 studies showing associations between television viewing in the bedroom and increased sedentary behaviour [126].

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 whilst in their care. There is some information on screen time in this age group, and a recent review estimated that preschoolers' screen time ranges from 37 min to almost 6 h a day and the proportion meeting the zero screen time recommendation ranged from 2.3% to 83% [96]. Further, sedentary behaviours among preschool age children differ 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; however, 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.

4.4 Implications of Current Prevalence and Correlates of Sedentary Behaviour

Given the proliferation of research in the area of sedentary behaviour and sitting time, it is interesting to note that relatively little of the published research describes the magnitude of the problem, and its distribution in populations. Although diverse measures are used in assessing sedentary behaviour, these different measures may be needed in different research projects, to assess sedentary behaviours in different contexts, and for population surveillance. We reported on two recent period-defined systematic appraisals of the prevalence of sedentary behaviours in large sample and population studies. Although total sitting was reported for around 6 h/day by adults in many studies, this self-report estimate seemed at least 2 h less than that measured by objective assessment. This indicates the need for objective assessments in population surveillance systems, so that a better estimate of prevalence can be ascertained and be used to identify population groups at risk and inform public health policy and programmes in this area.

For older adults, rates of sedentary behaviour are even higher, with increases in sedentary behaviour in the domestic setting, mostly through TV watching, which consumes more time in the non-working elderly. Objective assessment is again substantially higher than self-report sitting, with estimates from the USA and Canada ranging from 8.5 to 10 h/day of sitting time. Some of this increased sitting time is related to increased co-morbidity (and decreased physical activity with increasing age), suggesting that reducing or interrupting prolonged sitting time may be particularly important for older adults.

A diverse set of sedentary behaviours increase throughout childhood and adolescence, as active play time is replaced by sedentary screen time. This is one area where there are established population guidelines regarding sedentary behaviour, with recommendations to limit screen time to 2 h or less per day. Most children exceed this in countries where it has been measured, as the average time spent in sedentary behaviours is around 3 h, so there are many countries where population-wide efforts are warranted. Increasing numbers and types of screen-oriented devices are pervasive, pointing to sociocultural trends that will make sedentary behaviours more prevalent in many countries unless population-level programmes target reductions in recreational screen time. Increases in sedentary behaviours also reduce physical activity opportunities in children and adolescents, but also in adults, so that efforts to maintain physical activity levels are important.

A fundamental need is for surveillance systems to monitor the prevalence of sedentary behaviours over time, using identical measures and methods to identify population trends. The only trend data available suggest that European adults are reporting less sitting time in 2013 than 12 years earlier [32], but these self-report data may show social desirability bias as the general community becomes aware of the sedentary behaviour and health nexus. Using objective measures is desirable, but would need to be future-proof, to prevent technical advances creating non-comparable objective sedentary behaviour population measurements [142].

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 socio-economic grouping, for both adults and adolescents. For children, the gender, SES, and environmental correlates are different across subgroups. Some correlates are modifiable and therefore of particular 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 is limited by the usual cross-sectional research design, and more longitudinal research will better clarify which factors are more likely to lead 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 subgroup identification in the population. This is needed so that public health strategies can be implemented to reduce hazardous amounts of sitting at all ages. Given the high proportion of the waking day that is spent in sedentary behaviours, accurate identification of population prevalence and trends area merits greater research attention than it currently receives.

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Part II
Health Effects of Sedentary Behaviour

Chapter 5
Physiological Responses to Sedentary Behaviour

Paddy C. Dempsey and John P. Thyfault

Abstract Sedentary behaviours—too much sitting as distinct from too little exercise—are emerging as a ubiquitous, modern-day health hazard. Epidemiological evidence is accumulating that indicates greater time spent in sedentary behaviour is associated with increased cardiometabolic risk, even when controlling for the influence of leisure time moderate-to-vigorous physical activity. Based on these observations and preliminary experimental work, it has been proposed that sedentary behaviour influences health risk in part through some distinct mechanisms that act independently of lack of physical activity. However, the observational evidence is well ahead of evidence on physiological responses and potential biological mechanisms that may underlie the observed associations. Here, we summarize and discuss experimental evidence to date on the physiological effects of sedentary behaviours (prolonged sitting), including potential countermeasures aiming to address too much sitting as a health risk. We also highlight future research that is needed to further ascertain the impact of sedentary behaviour on altering physiology.

P.C. Dempsey (✉)
Physical Activity, Behavioural Epidemiology, and Metabolic and Vascular Physiology Laboratories, Baker Heart and Diabetes Institute, Melbourne, VIC, Australia

Health Sciences, Swinburne University of Technology, Melbourne, Australia

Faculty of Medicine, Nursing & Health Sciences, Monash University, Melbourne, Australia
e-mail: paddy.dempsey@baker.edu.au

J.P. Thyfault
Research Service, Kansas City VA Medical Center, Kansas City, MO, USA

Department of Molecular and Integrative Physiology, University of Kansas Medical Center, Kansas City, KS, USA
e-mail: jthyfault@kumc.edu

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5.1 Introduction

Regular moderate-to-vigorous intensity physical activity, generally 30–60 min continuous exercise (or accumulated in bouts ≥10 min) 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 are based on strong and consistent evidence, the potential health benefits of increasing moderate-to-vigorous physical activity remain largely unrealized at the population level. Indeed, the majority of affluent populations now 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 equivalents (METs); [2]), has emerged as an additional element within concerns about physical activity and health [3, 4]. Consistent epidemiological evidence has reported deleterious associations of sedentary behaviour with cardiometabolic risk and all-cause mortality in adults. Moreover, these associations appear to be largely additional to the risks associated with lack of moderate-to-vigorous intensity physical activity during leisure time [5, 6].

As a result, researchers are now studying moderate-to-vigorous intensity physical activity and sedentary behaviour as distinct but interrelated behavioural attributes (Fig. 5.1), with unique determinants and health consequences [7]. 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 prolonged sitting, or the potential biological mechanisms underlying the associations of sedentary behaviour with adverse health and mortality outcomes. Such knowledge is essential to inform future intervention efforts

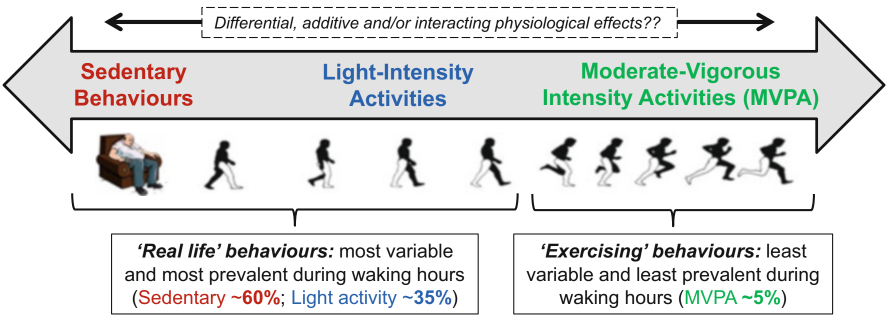

Fig. 5.1 The human movement spectrum—sedentary behaviour, light, and moderate vigorous intensity activities—and their relative contributions to activity levels during waking hours (based on accelerometer data in overweight adults from the *National Health and Nutrition Examination Survey*). Note that, on average, sedentary and light-intensity activities comprise a much larger proportion of total waking time (~95%) compared to moderate-to-vigorous intensity physical activity (~5%). Adapted from Tremblay et al. [7]

aimed at ameliorating the potentially detrimental health impact 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 on a daily basis in large segments of the population. We highlight:

- 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 to be a rather semantic process. Indeed, recent reviews have already summarized the evidence to date on numerous physiological responses as they relate to imposed physical inactivity [8, 9]. These include: muscle atrophy, bone demineralization, reduced cardiovascular function, a reduced capacity to utilize fat as a substrate for adenosine triphosphate (ATP) production, a shift in muscle fibres towards fast-twitch glycolytic type, skeletal muscle insulin resistance, ectopic fat storage, and increased central and peripheral adiposity. However, one must realize that physical activity, light-intensity (non-exercise) physical activity, and sedentary behaviour can all coexist within the spectrum of activities that constitute the waking day [7]. 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 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 has included the development of countermeasures to specifically address sedentary behaviours, with recent experimental studies aiming to *reduce and interrupt prolonged sitting time* providing some important insights.

5.3 Experimental Models Used to Study Sedentary Behaviour and Inactivity Physiology

Physical inactivity and 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, imposed physical inactivity, and prolonged sitting time) are justified depending on the question at hand and can provide complimentary information. However, it is important to recognize and understand the different goals, methodologies, and assumptions made under these models when attempting to interpret and generalize their findings.

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 [10]. 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 (ectopic) fat mass were also reported within 1 week of wheel lock [11, 12]. Interestingly, lowering food intake immediately after the wheel lock protocol did not significantly change fat mass enlargement compared to the rats that were fed *ad libitum*, suggesting that the fat storage was the result of physical inactivity per se, rather than overfeeding or positive energy balance [11].

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 immobilization 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

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

	Training cessation or detraining	Enforced bed rest or spaceflight	Imposed physical inactivity	Interrupting sitting time
Participants level of baseline physical activity or capacity	Extremely active (i.e. trained)	Usually physically active (meeting physical activity guidelines)	Usually physically active (meeting physical activity guidelines)	Usually not physically active
Participants level of sedentary behaviour	Not specified	Not specified	Not specified	Goal is generally to target more sedentary individuals (usually >5 h/day total sitting), but not always specified
Participant characteristics	Healthy-young	Healthy-young	Usually healthy-young or sometimes middle age or overweight	Mixture of healthy-young or "at risk" overweight/obese or with chronic disease
Modality focus	Abrupt reduction in high training/exercise load	Imposed lying down (head-tilt)	Abrupt reduction in physical activity levels or step counts	Imposed prolonged uninterrupted sitting (usually ~3–8 h)
Reference comparator	Prior training activity	Prior habitual activity	Prior habitual activity	Non-exercise activities (e.g. standing, light ambulation)
Change in intervention activity level	Very active (trained) → Inactive (detrained)	Active → Immobilized	Active → Inactive	Inactive/"sedentary" → More standing or light activity
Inconvenience or burden/disruption for study participants	High	High	Moderate-low	Moderate-low
Potential scientific insights provided	Effects, adaptations, and potential mechanisms related to reduced training load	Effects, adaptations, and potential mechanisms related to short- or long-term microgravity and physical inactivity	Effects, adaptations, and potential mechanisms related to reduced physical activity	Effects, adaptations and potential mechanisms related to prolonged sitting and non-exercise activity

1 day of unloading [13]. 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 seemed to remain largely unaffected by moderate-to-vigorous intensity physical activity [14].

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 [14, 15]. This point was further highlighted in a global gene-expression profiling study, which identified 38 genes in muscle that were upregulated by just 12 h of hind limb unloading, 27 of which remained above control levels after returning to normal standing and ambulation for 4 h [16].

Low levels of LPL (the rate-limiting enzyme that facilitates the breakdown of triglycerides and uptake of free fatty acids into skeletal muscle and adipose tissue) have been associated with decreased HDL cholesterol, increased circulating triglyceride levels, and an increased risk of metabolic syndrome and cardiovascular disease (CVD) [15]. The relatively rapid time frame for the LPL protein reductions is an interesting finding, as this likely rules out any generalized effects that occur in concert with muscle atrophy or body fat accumulation over longer periods. In addition, these studies highlight the large and persistent metabolic disturbances that can occur with reduced contractile activity at the muscle and gene-expression level. 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.

5.3.2 Human Models

Training Cessation and Detraining Models

Training cessation and 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 [17], detraining is characterized 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 [17, 18]. 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, as measured by hyperglycaemic–euglycaemic clamps, is reduced to the level measured in non-exercising age-matched controls after only 2 days of training cessation [19, 20]. 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 and Spaceflight Models

Enforced bed rest and spaceflight models are characterized by a lack of muscle activity and postural change, accomplished via immobilization and elimination of gravitational stimuli (head tilt) for extended periods of time (ranging from days to multiple months). Similar to detraining, these studies typically include young, healthy-active individuals and impose extreme immobility that is unlikely to be representative of daily living. Therefore, they require cautious interpretation, as they can cause distinct 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 models can provide important mechanistic hints, illustrating the fundamental physiological adaptations and potential mechanisms to short- or longer-term immobilization. For example, 5–10 days bed rest has been shown to induce dysglycaemia and dramatic reductions in whole-body, muscle, and vascular insulin sensitivity in healthy populations [21–23]. Bed rest also induces changes in fat oxidation capacity and storage, muscle atrophy, and shifts towards more fast-twitch muscle fibre type—mimicking the trajectory of pathways observed in the metabolic dysregulation associated with obesity [8].

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 levels around the US average (<5000 steps/day) [9]. Imposed physical inactivity models are more pragmatic than bed rest and detraining 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 what is commonly observed in population-based surveys. Moreover, they tend not to measure or focus specifically on sedentary (sitting) behaviours per se. Imposed physical inactivity studies have reported that transitioning from high to low activity patterns for only 3–5 days reduces insulin sensitivity, glycaemic control [24, 25], and endothelial function [26], with notable restorations in insulin sensitivity once activity levels are returned back to normal. A longer duration study where participants lowered their step count from >10,000 to <1500 steps/day for 2 weeks showed even more robust changes, including reduced skeletal muscle insulin sensitivity and signalling, increased central adiposity, and reduced lower limb muscle mass [27].

For more information on experimental studies that used models of bed rest, detraining, 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. 14.3.

5.4 Physiological Responses to Sedentary Behaviour in Humans

5.4.1 Characterizing Prolonged Sitting in Humans

Physiologically, sitting postures are associated with low energy expenditure demand, as measured by indirect [28, 29] and whole-room calorimetry, where the average energy cost of common sedentary behaviours (reclining, watching television, reading, and typing on a computer) are narrowly banded around ~1.0 METs at various times of the day, even in the postprandial state [30]. 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 [15, 31]. These key energetic and postural features of prolonged sitting are what define the control groups of experimental studies examining the impact of reducing and interrupting prolonged sitting.

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 physical activity and health. In these studies, 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

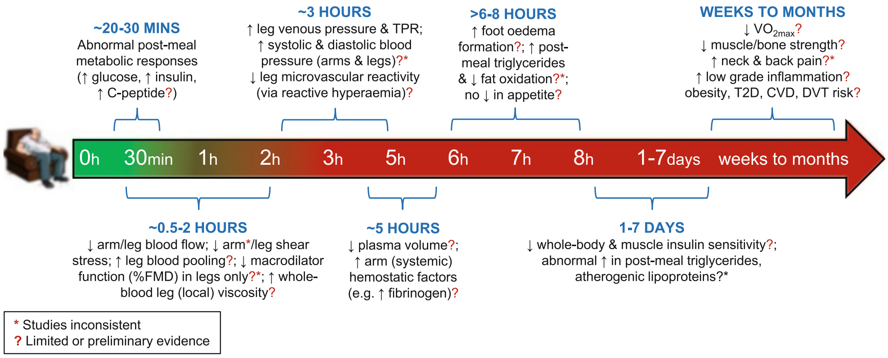

Fig. 5.2 A conceptual timeline of the various physiological alterations induced by acute and more prolonged sedentary behaviour. This is based on evidence from a variety of studies and population subsets that have included prolonged sitting exposures or interventions to reduce or interrupt prolonged sitting. Changes beyond one day imply approximately >6–8 h/day spent sedentary over consecutive days. *FMD* flow-mediated dilatation, indicative of macrovascular dilator function; *Reactive hyperaemia*, hyperaemic blood flow responses to cuff occlusion, indicative of microvascular reactivity; *TPR* total peripheral resistance; VO_{2max}, cardiorespiratory fitness

non-sitting) states [32]. Importantly, unlike detraining and bed rest models, and imposed physical inactivity models to a lesser extent, reducing and interrupting sitting time interventions target the large proportion of the population in which sitting time, not active time, is the predominant behaviour [33].

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, and, if addressed:
2. The physiological impact of reducing or interrupting sitting exposures with various forms of physical activity

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 epidemiological and meta-analytic evidence on the deleterious associations of sedentary time have been reported for metabolic risk markers and for risk of developing type 2 diabetes [5, 6]. 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. The acute duration of these sitting exposures (mostly <1 day but some up to 5 waking days) provides greater assurances that the 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 [34, 35]. The studies are summarized in more detail in Table 5.2 and are discussed below.

5.5.1 Glucose and Insulin Responses

Glycaemic benefits have been observed when prolonged sitting is reduced or interrupted with light-intensity bouts of post-meal walking, ranging from 15 to 40 min in length [48, 53, 57]. More recently, prolonged sitting interrupted by brief (<5 min) intermittent bouts of light- [37, 39, 40, 47, 49] or moderate-intensity [40, 54] ambulation have also demonstrated improved glycaemic control in both active-healthy, overweight/obese-sedentary, and dysglycaemic populations. However, findings from studies in which sitting was replaced with standing-only bouts have been less consistent for glucose and insulin responses, with some showing significant reductions [38, 44, 56] and others not [37, 49]. 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.

There is some evidence to suggest that alterations in markers of insulin action may also be an early response to prolonged sedentary behaviour [34, 35, 55, 59]. This evidence corroborates with reports of reduced glycaemic control and insulin action observed following longer periods of bed rest [8, 60–62] and 3–14 days of reduced stepping [24, 27]. However, three days of interrupting prolonged sitting with regular light-intensity activity bouts (2 min every 20 min) showed no sustained benefit for postprandial glucose and insulin responses beyond the first day [47]. More recent work has reported differences in the molecular signalling pathways in skeletal muscle (*vastus lateralis*), with one day of interrupting prolonged sitting associated with an upregulation of the contraction-stimulated, Adenosine Monophosphate-Activated Protein Kinase (AMPK)-mediated glucose uptake pathway, while 3 consecutive days of interrupting sitting demonstrated a transition towards upregulation of the Akt-mediated insulin-sensitive glucose uptake pathway [59]. These initial mechanistic findings provide a basis by which interrupted sitting time improves glucose metabolism and insulin sensitivity. However, whether these acute physiological changes are sustained following several weeks/months of

Table 5.2 Summary of studies examining metabolic responses to acute prolonged and interrupted sitting

References	Population/Setting	Study design/Outcomes	Experimental conditions	Results
Altenburg [36]	11 (5 men, 6 women) Age: 18–24 years BMI: mean (range) 23 (20–26) kg/m^2 Healthy Activity level—not reported Setting: laboratory	Randomized crossover Washout between conditions: ≥7 days Outcomes: – Fasting/postprandial capillary plasma glucose and C-peptide, triglycerides, and HDL/LDL/total cholesterol, measured hourly	1. *Sitting (SIT)*—7 h 2. *Sitting + moderate-intensity activity breaks (CYCLE)*—7 h (6 × 8 min bouts of cycling at hourly intervals—total 48 min cycling—each about 40–60% heart rate reserve) Diet: Two standardized "high-fat" mixed meals provided at 1 and 5 h consisting of 843 and 1190 kcal, 92 and 102 g carbohydrate, 29 and 28 g protein, respectively	*CYCLE vs. SIT* – ↓ C-peptide – No significant differences for glucose, triglycerides, or HDL/LDL/total cholesterol
Bailey [37]	10 (7 men, 3 women) Age: 24 ± 3 years BMI: 27 ± 4 kg/m^2 Healthy Activity level—not reported Setting: laboratory	Randomized crossover Washout between conditions: ≥6 days Outcomes: – Finger prick plasma glucose (fasting/postprandial—hourly), total cholesterol, HDL-C, triglycerides (fasting and 5 h)	Duration of experimental conditions—5 h post-meal (plus initial 1 h sitting state prior to meal) 1. *Sitting (SIT)*—5 h 2. *Sitting + light-intensity activity breaks (LW)*—5 h (14 × 2 min bouts of light walking at 20 min intervals—total 28 min light walking) 3. *Sitting + standing breaks (STAND)*—5 h (14 × 2 min bouts of standing still at 20 min intervals—total 28 min standing) Diet: 2 × meal replacement beverages at start of 5 h (total of 80.3 g carbohydrate, 50 g fat, nil protein)	*LW vs. SIT* – ↓ 5 h blood glucose iAUC by 15.9% *STAND vs. SIT* – No significant differences *LW vs. STAND* – ↓ 5 h blood glucose iAUC by 16.7% – No significant differences for total cholesterol, HDL-C, SBP and DBP

(continued)

Table 5.2 (continued)

References	Population/Setting	Study design/Outcomes	Experimental conditions	Results
Buckley [38]	10 (2 men, 8 women) Age: women 22–59 years Age: men 21 and 62 years BMI: all <30 kg/m^2 Healthy Activity level—not reported Setting: workplace	Non-randomized, repeated measures design Washout between conditions: 24 h Outcomes: – Continuous glucose monitoring (postprandial and overnight)	Duration of experimental conditions—185 min 1. *Seated desk work (SIT)*—185 min 2. *Standing desk work (STAND)*—185 min Diet: Participant asked to eat exact same food (volume, type, time), with a standardized buffet lunch provided on condition days	*STAND vs. SIT* – ↓ 185 min AUC by 43% – No significant differences for overnight glucose
Dempsey [39, 74]	24 (14 men, 10 women) with type 2 diabetes Age: 62 ± 6 years BMI: 33 ± 3 kg/m^2 HbA1c: 7.2 ± 0.7 % Sedentary and insufficiently active Setting: laboratory	Randomized crossover Washout between conditions: 6 to 14 days Outcomes: – Fasting/postprandial venous plasma glucose and triglycerides, serum insulin, and c-peptide. Measured every 30 min – Energy expenditure of activity bouts estimated (indirect calorimetry) during separate visit – Blood pressure (hourly)	Duration of experimental conditions—7 h post-meal (plus initial 1 h sitting state prior to meal) 1. *Sitting (SIT)*—7 h 2. *Sitting + light-intensity walking bouts (LW)*—7 h (12 × 3 min bouts of light walking at 30 min intervals—total 36 min light walking) 3. *Sitting + simple resistance activity bouts (SRA)*—7 h (12 × 3 min bouts (body-weight half squats, calf raises, gluteal contractions) at 30 min intervals—total 36 min) Diet: Dinner standardized night before trial. Standardized breakfast and lunch meals during trial to meet estimated energy requirements (all both 50% carbohydrate, 35% fat, 15% protein, ~823 kcal/meal)	*LW vs. SIT* – ↓ glucose iAUC by 39% – ↓ insulin iAUC by 36% – ↓ c-peptide iAUC by 27% – triglycerides trended lower (non-significant) – ↓ SBP by 14 mmHg – ↓ DBP by 8 mmHg *SRA vs. SIT* – ↓ glucose iAUC by 39% – ↓ insulin iAUC by 37% – ↓ c-peptide iAUC by 30% – ↓ triglycerides iAUC by 40% – ↓ SBP by 16 mmHg –↓ DBP by 10 mmHg *SRA vs. LW* – ↓ triglycerides iAUC – ↑ energy expenditure – ↓ respiratory exchange ratio – ↓ in glucose iAUC for LW vs. SIT was greater for women (↓58%) compared to men (↓26%) – ↓ SBP by 2 mmHg – ↓ DBP by 2 mmHg

Dunstan [40], Howard [41], Larsen [42]	19 (11 men, 8 women) Age: 54 ± 5 years BMI: 31 ± 4 kg/m^2 Sedentary occupation Insufficiently active Setting: laboratory	Randomized crossover Washout between conditions: 7–12 days Outcomes: – Venous plasma glucose and serum insulin (fasting/postprandial) – Haemostatic parameters (baseline (−2 h)/post-intervention (5 h) –Blood pressure (hourly)	Duration of experimental conditions—5 h post-meal (plus initial 2 h sitting state prior to meal) 1. *Sitting (SIT)*—5 h 2. *Sitting + light-intensity walking bouts (LW)*—5 h (14 × 2 min bouts of light walking at 20 min intervals—total 28 min light walking) 3. *Sitting + moderate intensity walking bouts (MW)*—5 h (14 × 2 min bouts of moderate walking at 20 min intervals—total 28 min moderate walking) Diet: Standardized test drink (75 g carbohydrate, 50 g fat)	*LW vs. SIT* – ↓ 5 h glucose iAUC by 24% – ↓ 5 h insulin iAUC by 23% – ↓ plasma fibrinogen – ↓ haematocrit, haemoglobin, red blood cell count – ↑ plasma volume – ↓ SBP by 3 mmHg – ↓ DBP by 3 mmHg *MW vs. SIT* – ↓ 5 h glucose iAUC by 30% – ↓ 5 h insulin iAUC by 23% – ↓ 2 h insulin – ↓ haematocrit, haemoglobin, red blood cell count – ↑ plasma volume, mean platelet volume, white cell count – ↓ SBP by 2 mmHg – ↓ DBP by 2 mmHg *MW vs. LW* – No significant differences
Duvivier [34]	18 (2 men, 16 women) Age: 21 ± 2 years BMI: 23 ± 3 kg/m^2 Insufficiently active Setting: Free living	Randomized crossover Days 1 to 4: Experimental conditions Day 5: Testing in laboratory after overnight fast (OGTT) Washout between conditions: >10 days Outcomes: – Venous plasma glucose (fasting, postprandial), total cholesterol, HDL-C, LDL-C,	Duration of experimental conditions—4 days 1. *Sitting (SIT)*—instructed to sit 14 h/day, walk 1 h/day, 8 h/day sleeping or supine 2. *Exercise* [43]—instructed to replace 1 h sitting by 1 h vigorous supervised cycling per day, with rest of the day similar to sitting condition 3. *Minimal intensity PA (MIPA)*—	*EX vs. SIT* – ↓ 2 h insulin AUC by 7% *MIPA vs. SIT* – ↓ 2 h insulin AUC by 13.2% – ↓ fasting plasma triglyceride by 22% – ↓ fasting plasma non-HDL-cholesterol by 10% – ↓ fasting plasma Apo B by 8% *MIPA vs. EX* – ↓ 2 h insulin AUC by 19%

(continued)

Table 5.2 (continued)

References	Population/Setting	Study design/Outcomes	Experimental conditions	Results
		non-HDL cholesterol, triglycerides, insulin (fasting, postprandial), C-peptide (fasting, postprandial), apo A-I, apo B, insulin sensitivity index	instructed to replace 6 h of sitting with 4 h of walking at a leisure pace and with 2 h of standing Diet: Participants maintained usual dietary habits during the three conditions (not controlled)	– ↑ insulin sensitivity index (ISI) by 15% – ↓ fasting plasma triglyceride by 17.6% – ↓ fasting plasma non-HDL cholesterol by 6.7%
Henson [44]	22 post-menopausal dysglycaemic (impaired glucose tolerance) women Age: 67 ± 5 years BMI: 33 ± 5 kg/m^2 Insufficiently active Setting: Laboratory	Balanced incomplete block design (participants randomized to complete 2 of the 3 conditions) Day 1 ($n = 22$): Experimental condition (1, 2 or 3) in laboratory Day 2 ($n = 17$): Experimental condition (7.5 h prolonged sitting) in laboratory Washout between conditions: 7–22 days Outcomes: Fasting/postprandial venous plasma glucose, insulin, NEFA, triglycerides	Day 1: 1. *Sitting (SIT)*—6.5 h 2. *Sitting 5.5 h + 12 standing bouts (STAND)*—5 min every 30 min, total 60 min 3. *Sitting 5.5 h + 12 light-intensity walking bouts (LW)*—5 min every 30 min, total 60 min Day 2: Sitting (*SIT*)—6.5 h Diet: Standardized breakfast and lunch mixed meals during experimental conditions (both 58% fat, 26% carbohydrate, 16% protein)	*DAY 1:* *STAND vs. SIT* – ↓ 6.5 h glucose iAUC by 34% – ↓ 6.5 h insulin iAUC by 20% – ↓ 6.5 h NEFA suppression iAUC by 33% – *LW vs. SIT* – ↓ 6.5 h glucose iAUC by 28% – ↓ 6.5 h insulin iAUC by 37% – ↓ 6.5 h NEFA suppression iAUC by 47% – No significant differences between LW and STAND *Day 2:* *STAND day 1 vs. SIT* – ↓ 6.5 h glucose AUC by 19% *LW day 1 vs. SIT* – ↓ 6.5 h glucose AUC by 17% – ↓ insulin AUC by 24% – No differences in triglycerides between conditions on either day

Holmstrup [45]	11 (8 men, 3 women) Age: 25 ± 3 years (SE) BMI: 36 ± 3 kg/m^2 All had impaired fasting glucose Activity level—light to moderate walking ≤ 5 times per week Setting: laboratory	Randomized crossover Washout between conditions: Not reported Outcomes: – Venous serum glucose, insulin, c-peptide (fasting/postprandial—10 min intervals), total peptide YY (PYY) – Appetite perceptions (feelings of hunger and satiety/fullness) using visual analogue scales. Measured fasted and every 20 min.	Duration of experimental conditions—12 h (meals—every 2 h) 1. *Sitting (SIT)*—12 h 2. *Sitting + regular-activity breaks (LW)*—12 h (5 min moderate walking bout @ 60–65% VO_2max every hour—total of 60 min walking, 660 min sitting) 3. *Sitting + one continuous physical activity bout* [43]—12 h (60 min moderate walking bout @ 60–65% VO_2max, then sit 660 min) Diet: Six small liquid meals consumed every 2 h (~1046 kJ/meal; 65% carbohydrate, 20% fat, 15% protein) across each condition	*LW vs. SIT* – ↓ 12 h insulin iAUC by 15% – ↓ 2 h insulin iAUC across all time blocks – ↓ 2 h c-peptide iAUC across all time blocks – ↑ insulin production rate 20% *EX vs. SIT* – ↑ 12 h glucose iAUC by 13% – ↑ glucose concentrations for ~150 min – ↓ 12 h insulin iAUC by 15% – ↓ 2 h insulin iAUC across all time blocks – ↓ 2 h c-peptide iAUC across all time blocks – ↓ satiety in afternoon *LW vs. EX* – ↓ 12 h glucose iAUC by 15% – ↓ glucose concentrations for ~240 min – ↑ insulin production rate 20% – ↓ hunger and ↑ satiety in afternoon – No differences in total PYY between conditions

(continued)

Table 5.2 (continued)

References	Population/Setting	Study design/Outcomes	Experimental conditions	Results
Kim [46]	9 men Age: 24 ± 4 years BMI: all <30 kg/m^2 Recreationally active Setting: laboratory	Randomized crossover Day 1–2: Stabilization period, low level of physical Activity (7000–7500 steps/day) Day 3: Experimental condition in laboratory Day 4: High-fat tolerance test (HFTT) Washout between conditions: >7 days Outcomes: – All measurements conducted during HFTT. Venous plasma glucose, insulin, triglycerides, free-fatty acids (FFA) and substrate oxidation.	Duration of experimental conditions—9 h period 1. *Sitting (SIT)*—7 h 2. *60 min of moderate intensity running + sitting (MOD)*—6 h min (65% VO_{2peak}) at the end of sitting 3. *9 walking bouts at self-selected pace (~25% VO_{2max}) but energy matched to the MVPA condition via indirect calorimetry + sitting (LOW)*—260 min Diet: Days 1–2 based on total energy intake. Day 3 based on sedentary activity, so a net energy balance for SIT but a net negative energy balance for MOD and LOW. Low-fat meal the evening before HFTT	*MOD vs. SIT* – ↓ triglyceride iAUC by 33.6% – ↑ fat oxidation, ↓ carbohydrate oxidation, ↓ glucose, ↑ FFA *LOW vs. SIT* – ↓ triglyceride iAUC by 19.8% – ↑ fat oxidation, ↓ carbohydrate oxidation, ↓ glucose *MOD vs. LOW* – ↓ triglyceride iAUC by 17.2% – ↑ fat oxidation, ↓ carbohydrate oxidation, ↓ glucose, ↑ FFA – No significant treatment differences for insulin.
Larsen [47]	19 (11 men, 8 women) Age: 57 ± 2 years (SE) BMI: 33 ± 1 kg/m^2 Sedentary (>5 h/day sitting) and insufficiently active Setting: Laboratory	Randomized crossover Three consecutive days per condition with assessment days on day 1 and 3 Washout between conditions: ≥12 days Outcomes: – Venous plasma glucose, insulin, and triglycerides (fasting/postprandial)	Duration of experimental conditions—6 h post-meal (plus initial 1 h sitting state prior to meal) 1. *Sitting (SIT)*—6 h 2. *Sitting + light-intensity activity breaks (LW)*—17 × 2 min bouts of light walking at 20-min intervals (total 34-min light walking Diet: Meal tolerance test completed on day 1 and 3 of each condition (75 g carbohydrate, 50 g fat) and a snack (filled roll) at 4 h	*SIT and LW* – No effect of time (temporal change from day 1 to day 3) for any outcomes *LW vs. SIT* Day 1 and 3: – ↓ glucose iAUC by ~32% – ↓ insulin iAUC by ~15% – No significant differences for triglycerides

Lunde [48]	11 women Pakistani Immigrants Age: 44 ± 9 years BMI: 31 ± 7 kg/m^2 Activity level—not described Setting: laboratory	Randomized crossover Washout between conditions: 7 days Outcomes: – Capillary glucose (fasting/postprandial)—15 min intervals – Blood pressure	Duration of experimental conditions—120 min post-meal (plus initial 30 min sitting) 1. *Sitting (SIT)—rest* 120 min 2. *Slow walking 20 min (W20)*, 100 min sitting (rest) 3. *Slow walking 40 min (W40)*, 80 min sitting (rest) Diet: Test meal was Cornflakes and milk consisting of 50 g carbohydrate	*W20 vs. SIT* – ↑ time to peak glucose – ↓ 2 h glucose iAUC by 31% *W40 vs. SIT* – ↓ 2 h glucose iAUC by 39% – ↑ time to peak glucose – ↓ postprandial glucose peak – ↓ 2 h SBP *W40 vs. W20* – ↓ postprandial glucose peak
Lyden [35]	10 (4 men, 6 women) Age: 25 ± 6 years BMI: 25 ± 4 kg/m^2 Recreationally active ≥150 min MVPA/week Setting: Free living	Crossover (not randomized or counterbalanced) Washout between conditions: ≤24 h Outcomes: 2 h OGTT (venous) completed after each condition: – fasting and 2 h glucose and insulin and iAUC – fasting triglycerides, total cholesterol, HDL and LDL – Insulin action or composite insulin sensitivity index (Matsuda index)	Duration of experimental conditions—7 day period 1. 7 d of *normal daily activities, including exercise* (*BASELINE*) 2. 7 d *sedentary* (↑*SIT*)—instructed to ↑ sitting time and not engage in exercise or physical activity (accumulate ≤ 5000 steps/day using pedometers for feedback) Diet: Maintained normal dietary habits during each condition, asked to keep food standardized the day before each OGTT	*BASELINE vs.* ↑*SIT* – insulin 2 h and iAUC ↑ – insulin action ↑ by ~17.2% – Insulin action correlation with ↓ accelerometer assessed light-intensity physical activity and ↑ sedentary time in prolonged bouts (>30 and >60 min) – No significant differences for any other outcomes
Miyashita [49], Takahashi [50]	15 men Age: 27 ± 2 years BMI: 23 ± 3 kg/m^2 Insufficiently active Setting: laboratory	Randomized crossover Day 1: Experimental condition in laboratory Day 2: Testing in laboratory after 10 h overnight fast Washout between conditions: >7 days	Duration of experimental conditions—7.5 h (plus initial 15 min resting prior to venepuncture); meal provided at 3.5–4.5 h 1. *Sitting (SIT)*—7.5 h 2. *Sitting + standing (STAND)*—7.5 h (6 × 45-min standing bouts—	*Metabolic responses:* *STAND vs. SIT* – No significant differences *EX vs. SIT* – ↓ 6 h serum triacylglycerol AUC by 18% – ↓ 6 h glucose AUC by 7%

(continued)

Table 5.2 (continued)

References	Population/Setting	Study design/Outcomes	Experimental conditions	Results
		Outcomes: – Venous serum triacylglycerol, inactive monomeric lipoprotein lipase protein, apolipoprotein C-II, apolipoprotein C-III, non-esterified fatty acids, 3-hydroxybutyrate, plasma insulin, plasma glucose (fasting, postprandial) – Markers of postprandial oxidative stress: Serum derivatives of reactive oxygen metabolites (d-ROMs, BAP and plasma TBARS, SOD, CAT, GPX, and TRX).	total standing duration: 4.5 h) 3. *Sitting + one continuous walking bout* [43]—7.5 h (30 min brisk walk at self-selected pace) Diet: Weighed food diaries completed before and on day 1 and replicated on subsequent trials (amounted to approximately 8.4 MJ/day; 59% carbohydrate, 29% fat, 12% protein)	*EX vs. STAND* – ↓ 6 h serum triacylglycerol AUC by 18% *Oxidative stress markers:* *Day 1* – SIT ↑ SOD compared to EX *Day 2* – SIT ↑ d-ROMs over time, but STAND and EX did not – Trial x time interaction effect for d-ROMs, GPX and TRX (only d-ROMs remained statistically significant after post-hoc tests)
Miyashita [51]	15 post-menopausal Japanese women Age: 69 ± 2 years BMI: 24 ± 3 kg/m^2 Healthy and physically inactive (self-reported) Setting: Laboratory	Randomized crossover Washout between conditions: ≥7 days Outcomes: – Venous plasma glucose and insulin and serum non-esterified fatty acids (NEFA), 3-hydroxybutyrate (3-OHB) and triglycerides (fasting/postprandial)	Duration of experimental conditions—8 h period 1. *Sitting (SIT)*—8 h 2. *Sitting + one continuous exercise bout* [43]—8 h (first 1 h sit, then 30 min walking bout, then sit 6.5 h) 3. *Sitting + regular-walking bouts (LW)*—8 h [(first 1 h sit, then 20 × 1.5 min walking bouts at ~15 min intervals (7 × post breakfast, 13 × post lunch)—total of 30 min walking] Diet: Standardized breakfast and lunch mixed meals during experimental conditions (both 50% carbohydrate, 35% fat, 15% protein)	*EX vs. SIT* – ↓ triglycerides AUC by 12% *LW vs. SIT* – No significant differences *LW vs. EX* – ↓ glucose iAUC – ↓ triglycerides AUC by 14% – ↑ 3-OHB iAUC – No significant differences for insulin and NEFA

Newsom [52]	11 (3 men, 8 women) Age: 28 ± 2 years (SE) BMI: 37 ± 1 kg/m^2 Healthy and physically inactive (self-reported) Setting: Laboratory	Randomized crossover Day 1: Experimental condition in laboratory followed by meal tolerance test (MTT) 1 h after trial condition for glucose and insulin. Day 2: Hyperinsulinaemic euglycaemic clamp (insulin sensitivity), whole body fatty acid uptake and muscle biopsy ~19 h after experimental condition Washout between conditions: ≥7 days Outcomes: – Fat oxidation, glucose and insulin (during MTT), hepatic glucose production, whole body insulin sensitivity, fatty acid mobilization and uptake.	Duration of experimental conditions—8 h period 1. *Sitting (SIT)*—8 h 2. *Sitting + one continuous exercise bout* [~70 min @ 50% VO_{2peak} (EX50)] 3. *Sitting + one continuous exercise bout* [~55 min @ 65% VO_{2peak} (EX65)] Diet: Standardized breakfast, lunch, MTT and dinner meals to meet daily estimated energy requirements adjusted for energy expenditure (~20% daily energy requirements; 55% carbohydrate, 30% fat, 15% protein).	*EX50 vs. SIT* – ↑ Insulin sensitivity by 35% ($P = 0.01$) *EX65 vs. SIT* – ↑ Insulin sensitivity by 20% (non-significant; $P = 0.17$) – ↓ Muscle glycogen content *EX50 vs. EX65* – ↓ Mean fatty acid uptake *ALL TRIALS* – Change in fatty acid uptake negatively correlated with changes in insulin sensitivity ($r = 20.60$, $P = 0.003$). – Both EX conditions tended to improve acute glucose and insulin responses to MTT, but difference was non-significant.
Nygaard [53]	13 women Age: > 50 years BMI: 24 ± 3 kg/m^2 Sedentary workers Setting: workplace	Randomized crossover Washout between conditions: 5–30 days Outcomes: – Capillary glucose (fasting/postprandial)	Duration of experimental conditions—120 min post-meal 1. *Seated office work*—120 min 2. *Slow walking 15 min*, 105 min seated office work 3. *Slow walking 40 min*, 80 min seated office work Diet: Test meal was Cornflakes and milk corresponding to 1 g carbohydrate per kg body mass	*W15 vs. seated work* – ↑ time to peak glucose *W40 vs. seated work* – ↓ 2 h glucose iAUC by 31.2% – ↑ time to peak glucose

(continued)

Table 5.2 (continued)

References	Population/Setting	Study design/Outcomes	Experimental conditions	Results
Peddie [54]	70 (28 men, 42 women) Age: 25.9 ± 5 years BMI: 24 ± 4 kg/m^2 Sedentary occupation Insufficiently active Setting: laboratory	Randomized crossover Washout between conditions: >6 days Outcomes: – Venous plasma glucose, plasma insulin, plasma triglyceride (fasting/postprandial—hourly between baseline and 9 h; additional samples 30 and 45 min after each meal)	Duration of experimental conditions—9 h 1. *Sitting (SIT)*—9 h 2. *Sitting + one continuous exercise bout* [43]—9 h (first 15 min sit, then 30 min walking bout, then sit 8.25 h) 3. *Sitting + regular-walking bouts (LW)*—9 h [(first 15 min sit, then 18 × 1:40 mm:ss moderate walking (60% maximal aerobic capacity) equally spaced over 9 h period—total of 30 min walking] Diet: Meal replacement beverages provided at 1, 4, & 7 h (each meal consisting of 1.12 g carbohydrate, 0.46 g fat, 0.54 g protein per kg body mass)	*EX vs. SIT* – No significant differences *LW vs. SIT* – ↓ 9 h glucose iAUC by 39% – ↓ 9 h insulin iAUC by 26% *LW vs. EX* – ↓ 9 h glucose iAUC by 37% – ↓ 9 h insulin iAUC by 18% – ↓ 9 h triglyceride iAUC by 31%
Stephens [55]	14 (7 men, 7 women) Age: 26 ± 5 years BMI: 24 ± 3 kg/m^2 Sufficiently active Setting: laboratory	Randomized crossover Day 1: Experimental condition in laboratory Day 2: Testing in laboratory after 13–14 h overnight fast Washout between conditions: >7 days Outcomes: – Venous plasma glucose and plasma insulin (whole body insulin action determined from continuous infusion of [6,6-^{2}H]-glucose	Duration of experimental conditions—see below, conducted over a 24 h period 1. *Active condition with reduced sitting (NO-SIT)*—5.8 h sitting, 9.8 h standing, 2.2 h stepping 2. *Prolonged sitting (SIT)*—16.9 h sitting, 0.2 h standing, 0.1 h stepping 3. *Prolonged sitting + reduced energy intake (SIT-BAL)*- 16.8 h sitting, 0.3 h standing, 0.1 h stepping	*SIT vs. NO-SIT* – ↓ insulin action (whole-body rate of glucose disappearance normalized to mean plasma insulin) by 39% *SIT-BAL vs. NO-SIT)* – ↓ insulin action (whole-body rate of glucose disappearance normalized to mean plasma insulin) by 18%

		– Glucose Ra, Glucose Rd, Non-oxidative glucose disposal, oxidative glucose disposal, hepatic glucose production, fat oxidation	Diet: Standardized breakfast and lunch mixed meals during experimental conditions (58% fat, 26% carbohydrate, 16% protein), with dinner having less carbohydrate (43% fat, 29% carbohydrate, 16% protein); energy content adjusted according to the conditions	
Thorp [56]	23 (17 men, 6 women) Age: 48 ± 8 years BMI: 30 ± 4 kg/m^2 Sedentary (desk-bound occupation) Insufficiently active Setting: laboratory designed to simulate office work conditions	Randomized crossover Days 1–5: Experimental conditions Days 1 and 5: Testing in laboratory after overnight fast Washout between conditions: >7 days Outcomes: – Venous plasma glucose, serum insulin, plasma triglycerides (fasting, postprandial)—0, 60, 120, 180, and 240 min post-meal)	Duration of experimental conditions—5 days 1. *Seated only work (SIT)*—instructed to sit to perform computer-based work tasks for 8 h (480 min) each day 2. *Seated and standing work (STAND)*—instructed to perform computer-based work tasks using a height-adjustable workstation, systematically interchanging between sitting and standing postures every 30 min over each 8 h workday—sitting: 240 min, standing: 240 min Diet: Participants provided with standardized energy balanced mixed meals (breakfast, lunch, snack) daily (~55% carbohydrate, ~30% fat, ~15% protein)	*STAND vs. SIT* – ↓ 4 h glucose AUC by 11.1% – No significant differences for insulin and triglycerides

(continued)

Table 5.2 (continued)

References	Population/Setting	Study design/Outcomes	Experimental conditions	Results
Van Dijk [57]	20 men with type 2 diabetes Age: 64.0 ± 1 years (SE) BMI: 30 ± 1 kg/m^2 HbA1c: 6.9 ± 0.1 % Activity level—not reported Setting: laboratory	Randomized crossover Washout between conditions: >7 days Outcomes: – Venous plasma glucose, plasma insulin (fasting/post-prandial—9 samples), 24 h glycaemic profiles (continuous glucose monitoring) – Glucose 3.5 h iAUC (after each meal) – Glucose 10.5 h iAUC (cumulative across all 3 meals) – Insulin 10.5 positive iAUC	Duration of experimental conditions—12 h 1. *Sitting (SIT)*—12 h 2. *Sitting + ADL bouts (ADL)*—11.25 h (3 × 15 min bouts of slow paced strolling @ 3 METS, 45 min after each meal– total 45 min) 3. *Sitting + Exercise Bout* [43]—11.25 h (1 × 45 min bouts of moderate intensity cycling @ 6 METS, 45 min after breakfast meal—total 45-min moderate intensity exercise) Diet: Standardized mixed meals provided at 08:30, 12:30, & 17:00 h (~9.8 MJ/day; 50% carbohydrate, 35% fat, 15% protein)	*ADL vs. SIT* – ↓ 10.5 h glucose iAUC by 19% – ↓ 10.5 h insulin positive iAUC by 14% *EX vs. SIT* – ↓ 24 h prevalence of hyperglycaemia by 30% – ↓ 10.5 h glucose iAUC by 36% ↓ 10.5 h insulin positive iAUC by 32% *EX vs. ADL* – ↓ insulin positive iAUC – No significant differences for total cholesterol, HDL-C, SBP, and DBP

Data represent means ± SD or mean (range) for study described unless otherwise stated
↑ increased significantly ($P < 0.05$); ↓ decreased significantly ($P < 0.05$); iAUC, net or positive incremental area under the curve; AUC, total area under the curve; NEFA, non-esterified fatty acids. SBP, systolic blood pressure; DBP, diastolic blood pressure. Note: Some information is adapted from Dempsey et al. [58] with permission

sitting displaced by standing or light-intensity physical activity bouts remains unclear at present.

5.5.2 Lipid Responses

Findings from experimental studies examining the effects of interrupting prolonged sitting on fasting [34, 35] and postprandial plasma lipid responses [37, 39, 44, 46, 47, 49, 51, 54, 56] have been less consistent than that of glucose/insulin responses (see Table 5.2). In healthy young adults, a 30-min 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 min walking bouts every ~15–20 min) [51, 54] or with intermittent standing bouts (6 × 45 min) [49]. This lack of effect on triglycerides for brief activity bouts was also observed in interventions switching between sitting and standing every 30 min in overweight/obese sedentary adults [56], or interspersing sitting with brief standing or walking bouts every 20–30 min in normal-weight adults [37] or overweight/obese sedentary postmenopausal women [44]. However, Henson et al. [44] also observed that interrupting prolonged sitting with hourly standing and walking bouts attenuated the suppression of non-esterified fatty acids. Dempsey et al. [39] and Kim et al. [46] also 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, respectively. Findings from repeated- or multi-day exposures to sedentary behaviours [34, 35, 47, 56] have so far largely observed minimal effects 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 [34]. In this study, participants were instructed to replace 6 h of sitting with 4 h of walking at a leisurely pace and with 2 h of standing on each of 4 consecutive days.

Discrepancies in results from animal and bed rest studies and between studies utilizing a prolonged sitting approach for lipid responses are unclear. Findings appear to be influenced by the populations studied, as well as the experimental designs (i.e. concurrent vs. next-day effects), meals, and/or interventions utilized, 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 [14], 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 [62]. 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 may vary depending upon the meal composition (i.e. high fat vs. high glucose) [63, 64] or the population studied (i.e. healthy vs. obese vs. type 2 diabetes) [65].

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 [5]. For further details, please refer to Chaps. 9 and 14. However, compared to the number of acute experimental studies on postprandial metabolism, there are far fewer randomized experimental studies that have examined the physiological effects of prolonged sitting on cardiovascular function or its antecedent risk biomarkers (see Table 5.3) [37, 42, 43, 66–70]. Nonetheless, experimental studies that have included prolonged sitting exposures are starting to provide an interesting picture concerning the marked vulnerability of the vasculature to prolonged sitting.

5.6.1 Haemodynamics

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 [72, 73]. 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. Increased hydrostatic pressure within the leg vasculature due to prolonged gravitational forces may also cause blood to pool within the venous circulation [68]. Indeed, in healthy populations, brachial artery shear rate (an estimate of shear stress without adjustment for blood viscosity) is reduced after only 30 min of sitting [67]. After 1–2 h, thigh blood flow decreases along with both brachial and popliteal artery shear rate. By ~2 h, blood pools in the calf and whole-blood leg viscosity are reduced [66]. Greater than 3 h of continuous 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) [67, 69, 74]. 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 [75]. Interestingly, these latter effects were shown to be largely attenuated with modest leg activity while seated for 8 h [76].

Five experimental studies to date have examined the impact of interrupting sitting time on blood pressure responses [37, 42, 43, 71, 74]. In a young-healthy population, Younger et al. observed significant increases in mean arterial pressure and post tibial artery blood velocity over 5 h of prolonged sitting. However, neither Younger et al. [43] nor Bailey et al. [37] showed significant blood pressure changes when sitting was interrupted with 2 minute intermittent walking/standing bouts or a continuous 30 min bout of exercise. In contrast, Larsen et al. [42] recently reported, in inactive overweight/obese adults, that interrupting sitting time with brief bouts of

Table 5.3 Summary of studies examining cardiovascular responses to acute prolonged and interrupted sitting

Reference	Population/Setting	Study design/Outcomes	Experimental conditions	Results
Hitosugi [66]	9 healthy men Age range: 20–22 years BMI: "non-obese" Activity level—not reported Setting: laboratory	Experimental study conducted over 1 day Washout between conditions: N/A Outcomes: – Blood viscosity, blood count, and blood chemistry (plasma total protein, albumin, blood urea nitrogen, erythrocyte sedimentation rate, haematocrit)	Duration of experimental condition—*2 h sitting* Blood obtained from the arm (cubital vein) and foot (superficial dorsum vein) before and after sitting period Diet: Participants did not eat but consumed 100 mL of water (total 500 mL)	*Responses during 2 h sitting* – ↑ mean blood viscosity in foot vein by ~17% (local), but not for arm vein (systemic) – ↑ mean haematocrit in both arm (~1%) and leg (~6%) – ↑ total protein in leg only – ↑ blood urea nitrogen in leg only – No significant changes in other outcomes
Padilla [67]	8 healthy men Age: 24 ± 2 years (SE) BMI: 24 ± 1 kg/m^2 Physically active Setting: laboratory	Randomized crossover Washout between conditions: <7 days Outcomes: – Lower leg (popliteal artery) blood pressure, arterial diameter, shear rate, time-to-peak dilation, mean arterial pressure, heart rate, and flow-mediated dilatation (FMD)—measured in the prone position.	Duration of experimental conditions—5 h period (with initial 1 h and 30 min in supine and prone positions, respectively, and an additional 30 min prone in final 30 min) 1. S*itting (SIT)*—3 h 2. *Supine control (LYING DOWN)*—3 h Diet: Experimental day completed in fasted state.	*SIT vs. LYING DOWN* – ↑ SBP – ↑ DBP – ↓ mean, maximum and minimum shear rate – No significant differences in FMD or other variables.
Restaino [68]	11 healthy men Age: 27 ± 1 years (SE) BMI: 25 ± 0.4 kg/m^2 Recreationally physically active Setting: laboratory	Experimental study conducted over 1 day (measurement order randomized at baseline but not post-SIT and post-WALK) Washout between conditions: N/A Outcomes: – Lower leg and forearm reactive hyperaemia, popliteal and brachial artery flow-mediated dilatation (FMD), mean blood flow (BF—calculated from	Duration of experimental conditions—6 h period Experimental procedures/order: 1. *PRE-SIT* measures (order randomized) 2 h after meal → 6 h sitting with meal at 3.5 h 2. *POST-SIT* measures (starting with lower limb) → 10-min walking @ self-selected pace (intensity not measured, ~1000 steps)	*POST-SIT vs. PRE-SIT* – ↓ mean popliteal and brachial BF, blood velocity, shear rate – ↑ calf circumference – ↓ popliteal and brachial microvascular reactivity – ↓ popliteal %FMD but not brachial *POST-WALK vs. PRE-SIT* – ↔ mean popliteal and brachial

(continued)

Table 5.3 (continued)

Reference	Population/Setting	Study design/Outcomes	Experimental conditions	Results
		continuous artery diameter and mean blood velocity), mean shear rate (defined as 8 × mean blood velocity/ diameter)	3. *POST-WALK* measures (starting with lower limb) Diet: Standardized mixed meals 2 h prior to arriving at laboratory and at 3.5 h during 6 h sitting period	BF, blood velocity, shear rate – ↔ popliteal hyperaemic BF, but not brachial – ↔ popliteal % FMD (microvascular dilator function), but not brachial (↔ = restored to PRE-SIT levels)
Shvartz [69]	8 healthy men Age range: 19–30 years BMI: ~25 kg/m^2 (data not specifically reported) Activity level—not reported Setting: laboratory	Experimental study conducted over 1 day Washout between conditions: N/A Outcomes: Blood pressure (BP), cardiac output, stroke volume, heart rate, total peripheral resistance (TPR), calf and thigh blood flow (BF), and venous pooling (via electrical impedance plethysmography).	Duration of experimental conditions—*5 h sitting* period with initial 30 min and 20 min in supine and standing positions, respectively Diet: Participants did not eat but consumed 100 mL of water (total 500 mL)	*Responses during 5 h sitting* – ↑ TPR by 5% – ↑ DBP by 9 mmHg (1 h vs. 5 h) – ↑ mean arterial BP (7.3 mmHg) – ↓ calf BF by 13% – ↑ calf pooling by 17% – Non-significant changes in SBP, thigh BF, cardiac output, stroke volume, and heart rate
Thosar [70]	12 healthy men Age: 24 ± 4 years BMI: 24 ± 3 kg/m^2 Insufficiently active Setting: laboratory	Randomized crossover Washout between conditions: 2–7 days Outcomes: – Mean shear rate, antegrade shear rate (forward flow), and retrograde and SRauc shear rates (hyperaemic stimulus), superficial femoral artery flow-mediated dilatation (FMD)—measured in the seated position.	Duration of experimental conditions—3 h period 1. *Sitting (SIT)*—3 h 2. *Sitting + light-intensity walking bouts (LW)*—3 × 5 min bouts (3.2 km/h) at 0:30, 1:30 and 2:30 mm:ss—total 15-min light walking Diet: Experimental day completed in fasted state; participants asked to maintain their regular dietary patterns throughout the study duration	*SIT (vs. baseline)* – ↓ mean and antegrade shear rates at 1 and 2 h – No change in SRauc and retrograde shear rates – ↓ FMD at 1, 2 and 3 h *LW (vs. baseline)* – No significant differences *SIT vs. LW* – ↓ FMD at 1, 2 and 3 h

Younger [43]	10 (6 men, 4 women) Age: 22 ± 1 years (SE) BMI: 25 ± 2 kg/m^2 Convenience sample, healthy normotensive, and physically active Setting: laboratory	Counterbalanced (non-randomized) crossover Washout between conditions: ≤7 days Outcomes: – Capillary glucose (fasting/postprandial), blood pressure (hourly), heart rate, post-tibial artery blood velocity (PTABV)	Duration of experimental conditions—5 h period 1. *Sitting (SIT)*—5 h 2. *30-min MVPA* (cycling) + 5 h sitting Diet: Meal replacement beverage at start of 5 h (post-MVPA)	*BOTH SIT and MVPA* – ↓ PTABV by 14% – ↑ Mean arterial pressure by 5% over 5 h *MVPA vs. SIT* – ↑ Heart rate in h 1 and 2 – No significant differences for glucose, SBP, or DBP
Zeigler [71]	9 (2 men, 7 women) Age: 30 ± 15 years BMI: 29 ± 3 kg/m^2 Insufficiently active 7 participants pre-hypertensive Setting: laboratory	Randomized crossover Washout between conditions: 7 days Outcomes: – Ambulatory blood pressure	Duration of experimental conditions—11 h 1. Sitting (SIT)—8 h 2. Sitting + accumulated standing bouts (total 2.5 h) STAND—8 h (2 × 10, 2 × 15, 2 × 20, 2 × 30 at ~hourly time points) 3. Sitting + accumulated walking bouts @ 1.6 km/h (total 2.5 h) WALK (accumulated same as 2.) 4. Sitting + accumulated cycling bouts @ ~20 watts and same cadence as 3.) (total 2.5 h) CYCLE (accumulated same as 2.) Diet: Standardized meals during trial (400 ± 80 kcal for breakfast, 590 ± 25 kcal for lunch, and 780 ± 23 kcal for dinner)	*STAND vs. SIT* *↓SBP by 5 mmHg* *↓SBP load by 4%* *WALK vs. SIT* *↓SBP by 4 mmHg* *↓SBP load by 4%* *CYCLE vs. SIT* *↓SBP by 7 mmHg* *↓SBP load by 13%* *↓DBP by 2 mmHg* *CYCLE vs. STAND* *↓SBP by 2 mmHg* *↓DBP by 3 mmHg* *CYCLE vs. WALK* *↓SBP by 3 mmHg* *↓DBP by 2 mmHg*

Data represent means ± standard deviation (SD) or mean (range) for study described unless otherwise stated
↑ increased significantly ($P < 0.05$); ↓ decreased significantly ($P < 0.05$); ↔ restored to PRE-SIT levels; SRauc, shear rate area under the curve; FMD, flow-mediated dilatation; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; MVPA, moderate-to-vigorous physical activity

either light- or moderate-intensity walking significantly lowered resting systolic and diastolic blood pressure by ~2–3 mmHg. Further, overweight/obese adults that accumulating 2.5 h of standing or light-intensity physical activity during an 8 h workday equally improved ambulatory blood pressure during and after work hours, compared to prolonged sitting [71]. Lastly, Dempsey et al. observed marked reductions in resting systolic and diastolic blood pressure and plasma noradrenaline levels when sitting was interrupted with light-intensity walking or simple resistance activities in adults with type 2 diabetes [74]. The latter three studies are suggestive that interrupting prolonged sitting may disturb the haemodynamic and potentially hypertensive impact of prolonged sitting in older, more at-risk populations. However, further studies are warranted, particularly in individuals with hypertension, type 2 diabetes, and cardiovascular disease.

5.6.2 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) [77–80] and more recently to people in office environments [81–83]. The mechanisms for the relationship of prolonged sitting with deep vein thrombosis, while unresolved, are likely related to alterations in venous haemodynamics, 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 [84–86]. Venous stasis is also characterized by alterations in key blood viscosity parameters that influence blood flow, including plasma fibrinogen, haematocrit, haemoglobin, red blood cell count, and reduced plasma volume [87, 88]. 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 pro-thrombotic and pro-inflammatory lysophospholipids [89]. Interestingly, despite limited evidence of preventive effects from exercise training *per se*, recent studies suggest that frequent localized muscle contractions, simple foot movements [89–93], or brief walking interruptions in prolonged sitting time [41, 70] may play an important role in improving leg blood flow, haemostatic gene expression, and pro-coagulant risk factors.

5.6.3 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 [94, 95]. Persistent inactivity over time may mediate oxidative stress and endothelial dysfunction [50, 96]. 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 [26]. Three recent well-controlled studies have also provided evidence on the potential effects of prolonged sitting on vascular function [67, 68, 70]. Padilla et al. [67] observed that 3 h 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. [70] 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 h 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 min bouts of light-intensity walking.

Using both FMD and reactive hyperaemia to isolate the effects on macro- and microvascular function, Restaino et al. [68] provided further insights, demonstrating that prolonged sitting differentially influences vascular function in a limb-specific manner. They showed that 6 h 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 finding 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 competed after participants had walked for 10 min at a self-selected pace. The 10-min walk fully reversed sitting-induced vascular impairments in the lower limbs; however, no effect was observed for upper limb microvascular reactivity. This suggests that local increases in blood flow and shear rate to exercising tissue may be necessary to reverse these microvascular impairments, an important finding since impaired forearm microvascular function is a predictor of cardiovascular events in participants, with and without cardiovascular disease [97, 98].

5.6.4 Cardiovascular Structural Adaptations and 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}) [99, 100]. However, limited interventional evidence exists for changes in these longer-term cardiovascular outcomes in relation to prolonged sitting. In a small, 12-week, four-condition, pilot intervention study in 57 sedentary, overweight/obese men and women, Keadle et al. [101] 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 (exercise): 40 min moderate exercise session 5 days/week; (2) rST (reduced sedentary time): 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 [27, 102]. 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. While more data are certainly needed, given that VO_{2max} is a strong predictor of early mortality and disease risk [103, 104], these findings may hold important relevance for the ageing population with low levels of moderate-to-vigorous intensity physical activity.

In summary, prolonged sitting appears to be linked with a number of factors that may predispose to thrombotic and cardiovascular disease risk, including a tendency for low blood flow and vascular shear stress; decreased endothelial dysfunction; 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, along with a more detailed examination of the integrated mechanisms that may underlie the associations between sedentary behaviour and CVD risk.

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 [105–107]. 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) [108–113], 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 [114, 115]. 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 the relatively crude assessments 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 [116], which has been linked with inactivity and sedentary behaviour in numerous observational studies [117–120]. Data from bed rest studies are also somewhat mixed. For example, 14 days of bed rest in young volunteers resulted in increased circulating levels of CRP and IL-6 [121]; however, 7 days of bed rest in elderly individuals appeared only to influence local (muscle) pro- and anti-inflammatory cytokines, but not systemic inflammatory markers [122]. Therefore, whether there is any meaningful adiposity-dependent or independent link between sedentary behaviour, immunology, and cardiometabolic health remains equivocal at present.

Longer-term intervention studies examining sedentary behaviour and inflammatory outcomes are needed to elucidate the mechanisms specifically linking sedentary behaviour to chronic inflammatory-related disease, 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, particularly given the longer observation periods required to observe changes, the numerous potential influences on inflammatory markers over time, and the relatively subtle/variable stimuli 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 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 [123, 124].

The inter-relationships between sedentary behaviour, physical activity, and appetite regulation have 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 [125]. A recent meta-analysis [126] indicated that young-healthy populations tend not to compensate for the energy expended by altering food intake in the immediate hours after physical activity, suggesting it subsequently induces a 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 [127]. However, again, 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. [128] 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. [129], 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 weeks, where energy balance was maintained due to a lowering of energy intake to match lower expenditure [8].

At present, we are aware of only two randomized crossover studies that have examined appetite and appetite-regulating hormone responses when interrupting prolonged sitting [45, 130]. In young obese participants with impaired fasting glucose, Holmstrup et al. [45] compared objective measures of satiety when participants consumed liquid meals every 2 h over a 12 h period and completed hourly 5 min 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. In a shorter duration trial (5 h) with a single test drink, Bailey et al. [130] observed no significant differences between conditions for hunger, satiety, or circulating gut hormone concentrations (total PYY and acylated ghrelin) when sedentary participants interrupted prolonged sitting time with 2 min bouts of light- or moderate-intensity walking every 20 min. 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. However, implications with regard to weight management are likely oversimplified. Longer-term studies would be required to elucidate this.

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 [131, 132] 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 [132–137]. 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 activity could help lessen/maintain ageing-induced bone loss [138]. 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 disc herniation during sitting [139], a systematic review found no evidence for an association between leisure time sitting and low back pain [140].

Findings are also mixed in the occupational setting, with some systematic reviews [141, 142] showing associations between occupational sitting and musculoskeletal issues (e.g. neck and back pain) while others have shown no association [143–146]. 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 [147–149]. In summary, there is at present preliminary but inconsistent observational evidence that prolonged sitting is associated with musculoskeletal issues. High-quality evidence from longitudinal and interventional studies using both valid and context-specific measures of sitting patterns and musculoskeletal health is still required.

5.10 Conclusions: Research Needs and Future Opportunities

The science of sedentary behaviour, while in its infancy, 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 a number of 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 activity can inform innovative and pragmatic interventions and public health recommendations. Hereafter, we provide a perspective on some of the priority areas for future work to inform sedentary physiology.

5.10.1 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 [15]. Thus, understanding the specific physiologic mechanisms underlying the associations between sedentary behaviour and adverse health outcomes would be informative. Importantly, there remains a critical need for longer duration studies to improve our causal understanding on both the acute and longer-term effects of exposures to prolonged sitting and 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 the underlying 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), and not only surrogate markers. As examples, alterations in skeletal muscle insulin signalling [59] and gene expression associated with tissue-specific and small-molecule biochemistry, cellular development, growth and proliferation, and carbohydrate metabolism [150] were observed in overweight/obese adults when prolonged sitting was interrupted with regular activity bouts. Further analyses of this nature will provide valuable insights on the site-specific regulatory systems and molecular processes underlying the physiological effects of prolonged sitting.

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

Based on acute evidence to date, it is likely that the associations between sedentary behaviours and health outcomes will be dependent upon the specific outcomes measured and the populations involved, meaning future sedentary behaviour interventions and guidelines may have to be 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. These could include integrative studies across metabolism, vascular physiology, molecular mediators, “omics” technologies, central and peripheral neural effects, inflammation, musculoskeletal, bone health, and cognitive effects. Such collaborations would allow for the integrated assessment of novel markers of ageing and musculoskeletal and brain health, along with other clinically relevant outcomes.

In the initial phases, some investigations of novel outcomes and potential modulators of sedentary behaviour will probably only be feasible using animal models, particularly when invasive procedures are required. An intriguing example in the animal model space involves studies that have focussed on the potential neural mediators of spontaneous, light-intensity physical activity, such as hypothalamic orexins (neuropeptides also known as hypocretins). Surgical removal of these orexin neurons caused narcolepsy and obesity [151], but also decreased spontaneous movements [152–154]. Age-related decline in orexin receptor messenger-RNA levels in rats has also been shown to correlate with decreased ambulatory activity [155], while biochemically elevated orexin levels increased daily ambulatory activity [156]. These studies suggest that lower orexin levels may mediate lower incidental activity, energy expenditure, and obesity. How neuro-mediators interact with other environmental cues, behavioural factors and relate to humans remains speculative; however, these investigations illustrate the potential for integrated mechanistic insights from unique outcomes or paradigms related to health, and the possibilities for informing or identifying new therapeutic targets.

5.10.3 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, important unresolved questions at the core of sedentary behaviour research include: (1) what duration of sitting is too much? And, equally, (2) how often and with what activities should prolonged sitting time be replaced? Furthermore, 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?

These questions are inevitably complex, as the “ideal” patterning of sedentary and physical activity behaviours is likely to be based on the requirements, context, and activity/health status of the subpopulation, rather than a “one size fits all” approach. However, in terms of potential countermeasures applicable to the population, it may be that certain minimal combinations or criteria 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 or moderate-to-vigorous intensity physical activity), or patterning (e.g. activity bout, active around meals, or standing length/accumulation) of physical movement are all that is required to derive physiological benefit.

As examples, 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 optimize glycaemic control [33]. However, one must also be cognizant that each physiological outcome measure may require different doses and types of intervention. Whereas replacing sitting behaviour with more light-intensity activity may improve glycaemic control, it seems less likely to influence outcomes that rely on "working the system" at higher intensities, such as cardiorespiratory fitness. Integrating such information, ideally from randomized controlled trials and longer-term interventions, is especially critical for developing an evidence-base for quantitative and context-specific sedentary behaviour guidelines. Such information will also provide healthcare professionals with more information to begin providing personalized lifestyle prescriptions tailored to deliver optimum health benefit.

5.10.4 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 in relation to key factors, including but not limited to: gender, medications, menopausal status, age, ethnicity, genetic profiles, dietary habits, cardiorespiratory fitness and baseline exercise levels, sleep duration and quality, and populations with or at increased risk of various chronic diseases (see Fig. 5.1). Identifying whether such factors hold significant importance will also help identify more "at risk" populations that may derive greater benefits from reductions in sedentary behaviour.

As an example, acute experimental studies suggest that regular interruptions in prolonged sitting may be particularly beneficial for postprandial glucose responses in those with or at high risk of developing type 2 diabetes relative to healthy individuals [58], suggesting dysregulated metabolic responses to prolonged sitting in these individuals. Moreover, individuals with type 2 diabetes are more likely to be overweight/obese, deconditioned and to be managing 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, or tolerance 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 to those who need them most, or who are most likely to derive benefit, would minimize the likelihood of unhelpful intervention.

5.11 Summary

Excessive sitting is a ubiquitous, modern-day behaviour, co-existing alongside poor adherence to structured exercise in most of the population. Consistent evidence from epidemiological and experimental studies suggests that sedentary behaviour contributes to excess morbidity and mortality. However, as our evidence synthesis shows, the physiological mechanisms underlying the deleterious effects of sedentary behaviour per se (see Fig. 5.2) and the most effective countermeasures to ameliorating its detrimental effects requires further research.

Reducing and interrupting prolonged sitting with light-intensity activities may be a practical strategy to improve health outcomes, particularly in those who are very physically inactive and are at increased risk of type 2 diabetes / cardiovascular disease. However, further evidence from longer-duration and more ecologically relevant free-living intervention studies is still required to confirm this. While recent experimental findings are promising and have provided important physiological insights, they have mostly focussed on changes in glycaemic control, insulin sensitivity, and vascular function. The integration of physical activity and sedentary behaviour models, ideally in parallel with high-quality physiological measurements across a range of populations, will help add further specificity to sedentary behaviour and physical activity recommendations. In the meantime, it remains appropriate and prudent for healthcare professionals—in the interest of "doing no harm"—to promote the statement: "Sit less, move more, more often".

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Chapter 6
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. Numerous cross-sectional studies, prospective studies, and randomized 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. Results suggest that prolonged time spent sedentary is positively associated with adiposity in children and adolescents. The association may be partly explained by unhealthy eating behaviour associated with television viewing. By comparison, the current literature provides insufficient evidence for a positive relation between sedentary behaviour and adiposity among adults. Future prospective studies and randomized controlled trials using objective measures to monitor sedentary behaviour are needed to clarify the role of obesity in the sedentary behaviour context.

6.1 Introduction

Globally, the prevalence of overweight and obesity in young people and adults is alarmingly high, with approximately 41 million overweight children under 5 years of age and 1.9 billion overweight adults, of which over 600 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. Globally, 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 [1].

C. Jochem • D. Schmid • M.F. Leitzmann (✉)
Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany
e-mail: carmen.jochem@ukr.de; daniela.schmid@ukr.de; michael.leitzmann@ukr.de

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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].

Being overweight or obese causes an estimated 35.8 million (2.3%) global disability-adjusted life-years (DALYs) and is responsible for at least 2.8 million deaths. 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 [4, 5].

Overweight and obesity during childhood are associated with adult adiposity [6]. 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 [7] 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 Sects. 4.2.6 and 4.3.3 (children and adolescents) and Sects. 4.2.4 and 4.3.1 (adults).

6.2 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 [8–27]. A selection of studies that have summarized the available information on sedentary behaviour and adiposity in childhood and adolescence published since 2010 is presented in Table 6.1.

6.2.1 Cross-sectional Studies of Sedentary Behaviour in Relation to Adiposity

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

Table 6.1 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 published since 2010

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
Van Ekris et al., 2016 [8]	Meta-analysis including nine 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 five 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 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 [9]	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 [10]	Meta-analysis including 67 randomized controlled trials and non-randomized controlled trials (6 SB only interventions; 10 SB + PA	0–17 years	SB intervention	Objectively measured	SB intervention	Pooled mean reduction in BMI and BMI *z*-score in mixed-weight populations: standardized mean difference = −0.060 (95% CI = −0.098 to −0.022). Pooled estimate for an overweight or obese population: standardized mean

(continued)

Table 6.1 (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; 51 SB + other behaviour interventions)					difference = −0.255 (95% CI = −0.400 to −0.109).
Zhang et al., 2015 [11]	Meta-analysis including 14 cross-sectional studies	1–18 years	Self-reported	Objectively measured or self-reported	TV watching	OR of childhood obesity for highest vs. lowest time of TV watching 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 [13]	Review including three 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 three underlying studies)
Liao et al., 2014 [14]	Meta-analysis including 25 randomized 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 interventions ($g = -0.060$, $p = 0.214$).

Pate et al. 2013 [15]	Review including four 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 [16]	Review including nine prospective cohort studies + one randomized 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 [17]	Review including nine 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 [18]	Review including 18 intervention studies measuring BMI	<12 years	Self-/parent-reported	Objectively assessed	TV viewing; video games; computer use; internet use	Nine studies reported reductions in BMI for the intervention group compared to the control group.
Leung et al., 2012 [19]	Review including 12 intervention studies (3 SB only interventions; 1 PA intervention; 6 SB + PA interventions; 2 SB + PA + diet interventions)	6–19 years	Self-reported	No detail reported	Media use; other SB	One of the 3 SB intervention studies reported 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

(continued)

Table 6.1 (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
van Grieken et al., 2012 [20]	Meta-analysis including 34 intervention studies (4 controlled trials; 30 randomized 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 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 [21]	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 [22]	Review including seven 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 [23]	Review + meta-analysis including 8 randomized controlled trials, 10 intervention studies, 33 longitudinal studies, 119 cross-sectional studies	5–17 years	Self-/parent-reported or objectively measured	Self-/parent-reported or objectively measures	TV watching; overall screen time; playing electronic games; PC use	Effect of -0.89 kg/m^2 (95% CI = -1.67 to $-.11$, $p = 0.03$) decrease in mean BMI in the intervention group. > 2 h 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 h/day significantly increased risk for overweight/obesity.

Chinapaw et al., 2011 [24]	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 [25]	Meta-analysis including 6 randomized 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).

BMI body mass index, *CI* confidence interval, *PA* physical activity, *SB* sedentary behaviour risk of adiposity in school-aged children and adolescents [23]. Based on a dose–response analysis of television watching time and overweight/obesity, the review concluded that >2 h of sedentary behaviour per day is associated with an increased risk for developing adiposity. Similarly, a review by Costigan et al. found evidence for 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 h per day [21].

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) [11]. 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, the 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 [9]. 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. [17] 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 summarized the sparse data on sedentary behaviours other than television viewing such as playing video games, internet use, and cell phone use [17]. According to that review, three studies revealed a positive association between playing video games and adiposity [28–30], whereas one study found no association between PC use and weight [31]. One study also reported that cell phone use was not associated with adiposity, unless cell phones were used to play video games [32]. That study [32] also showed a positive association between internet use and body mass index (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 manner in which 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 [9]. However, one cross-sectional study [33] 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.

Taken together, findings from cross-sectional studies suggest a positive association between sedentary behaviour—particularly television watching in excess of 2 h 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, reverse causation cannot be ruled out. 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 synthesize the results.

6.2.2 Prospective Cohort Studies of Sedentary Behaviour in Relation to Adiposity

Prospective data on sedentary behaviour in relation to adiposity are less abundant than cross-sectional data, but a sizeable number of longitudinal studies have been conducted in this area. 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 [23]. 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 [21]. A more recent meta-analysis by van Ekris et al. of studies in children $\leq$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 estimate from five prospective studies yielded no relation with 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 [8].

A number of studies prospectively examined the association between television watching and adiposity in toddlers and preschoolers. One systematic review by LeBlanc et al. [16] and another by te Velde et al. [22] summarized 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 [34] 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 evident after controlling for baseline body fat and level of physical activity. Similarly, a prospective study found that television viewing among 3–4 year olds was positively related to BMI assessed at 3 years of follow-up [35]. In contrast, a prospective study of children aged 0–6 years [36] found that increased television watching was related to increased adiposity, but that association was no longer apparent when commercialized television viewing was controlled for, suggesting that the increase in adiposity was explained by the content of the television (i.e. advertising) and not the sedentary behaviour. As summarized 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 [24]. 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. [13] and the other by Pate et al. [15], summarized the data from prospective studies that used objective measures of sedentary behaviour. Two individual studies [37, 38] 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 [39]. In contrast, one prospective study found a 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 [40]. Another prospective study reported a borderline significant relation of increased time spent sedentary to increased BMI in girls but detected no association in boys [41]. 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. 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.

6.2.3 Intervention Studies of Sedentary Behaviour in Relation to Adiposity

Several meta-analyses summarized the effect of sedentary behaviour interventions on BMI change in children [10, 14, 18–20, 23]. A recent meta-analysis by Azevedo et al. [10] included 67 trials and found that sedentary behaviour interventions led to a small but statistically significant reduction in BMI (standardized mean difference = −0.060 (95% CI = −0.098 to −0.022), with a more pronounced BMI reduction in overweight or obese children (standardized mean difference = −0.255, 95% CI = −0.400 to −0.109). A meta-analysis by Liao et al. [14] 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. [20] 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. [23] 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. [18] reported that 9 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. [19] of 12 intervention studies that reported a positive impact of decreasing sedentary behaviour on markers of adiposity in school-age youth.

It is important to note that most of the individual studies summarized 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. [25] included six RCTs on the effect of sedentary behaviour reduction on BMI change, five of which did not have co-interventions, 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 significantly decrease BMI 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.

6.3 Sedentary Behaviour and Adiposity in Adults

The volume of information from reviews and meta-analyses of sedentary behaviour in relation to adiposity in adults [42–49] is less abundant than that in children and adolescents. A selection of studies that summarized the available information on sedentary behaviour and adiposity in adults published since 2010 is presented in Table 6.2.

6.3.1 Self-Reported Assessments of Sedentary Behaviour in Relation to Adiposity

A systematic review by Thorp et al. [47] of 24 prospective studies used TV viewing, watching videos, using a computer, playing video games, or riding in a car as an exposure and used BMI, obesity, weight gain, weight maintenance, or a measure of body fat distribution (i.e. waist circumference) as an endpoint. Results showed that only 6 of 11 prospective studies reported a positive relation of self-reported time spent in sedentary behaviour to risk of 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. Another review by Proper et al. [46] 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. Specifically, Thorp et al. [47] 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.

Several individual studies investigated the potential obesogenic effect of television viewing specifically. For example, the Nurses' Health Study [50] found that each 2 h per day increase in television viewing was associated with a 23% increased risk of obesity in women over 6 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 [51]. Some studies showed a positive association between television viewing and BMI or waist circumference [52–55] that was attenuated after controlling for BMI [53], physical activity [54], dietary factors [55], and other covariates [55].

Table 6.2 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
Wirth et al., 2016 [42]	Review including 3 randomized controlled trials, 1 prospective study, 11 cross-sectional studies	Older adults (mean age of study sample ≥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 randomized 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., 2015 [43]	Review including one longitudinal study and eight cross-sectional studies	Adults	Self-reported or objective	Self-reported or objective	Sedentary behaviour; TV watching	Seven studies found that obese adults reported greater levels of sedentary behaviour or TV viewing. Estimated effect size reported: 2.5% and 3.5% more sedentary time and 50% higher odds ratio of TV time for obese individuals.
de Rezende et al., 2014 [44]	Review including six cross-sectional studies	≥60 years	Self-reported or objective	Overweight/obesity	Sedentary behaviour; TV watching; sitting in cars	Five studies showed a positive association 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.

(continued)

Table 6.2 (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
Rhodes et al., 2012 [45]	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 [46]	Review including four prospective studies	Adults	Self-reported	Self-reported	TV viewing; occupational sitting; sedentary behaviours	Insufficient evidence for a positive relation between sedentary behaviour and risk of overweight or obesity.
Thorp et al., 2011 [47]	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 [48]	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.

BMI body mass index, *WC* waist circumference, *WHR* waist-to-hip ratio, *CI* confidence interval, *MET* metabolic equivalent

The Coronary Artery Risk Development in Young Adults (CARDIA) study prospectively examined television viewing in relation to BMI and waist circumference among 3269 men and women over 15 years of follow-up [56]. Results showed that a greater volume of television viewing predicted higher BMI and waist circumference in young adults. However, the association diminished as individuals aged over the following decade. The authors reasoned that such weakening of the relation between television viewing and BMI with age may be partly explained by a lower susceptibility of middle-aged persons to the seduction of television advertising and, hence, decreased likelihood of consuming energy-dense snacks while watching television. Supportive data come from a previous analysis from the CARDIA study showing that diet quality increased with age [57].

One review by Rhodes et al. [45] summarized the data from 42 studies (32 cross-sectional studies and 10 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, general 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 general screen viewing to BMI in adults, but the associations with other sedentary behaviours appear weak.

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. [47] consistently found that sedentary behaviour during childhood or adolescence was positively associated with BMI in adulthood, independent of childhood/adolescent BMI and physical activity.

6.3.2 Occupational Sitting in Relation to Adiposity

A systematic review by van Uffelen et al. [48] examined the relation between occupational sitting time and BMI based on 12 observational studies (9 cross-sectional studies, 2 prospective studies, and 1 study with 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 2 h 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 h per week as compared with less than 1 h sitting. It is worth noting that a large proportion of studies included in the review [48] 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 [58].

6.3.3 Objective Assessments of Sedentary Behaviour in Relation to Adiposity

One recent cross-sectional study of 82 overweight and obese adults [59] found no relation of accelerometer-derived sedentary behaviour to visceral adipose tissue measured by magnetic resonance imaging. Another study [60] using data from the National Health and Nutrition Examination Survey (NHANES) reported inconsistent results for an association between objectively quantified sedentary behaviour and measures of adiposity. Whereas sedentary time was unrelated to BMI, waist circumference, waist-to-height ratio, and percent total body fat in the ordered logistic regression model, a positive association between sedentary time and percent total body fat was noted in the linear model.

One prospective study of healthy middle-aged adults [61] examined objectively quantified time spent sedentary in relation to body weight, BMI, fat mass, and waist circumference. Sedentary time was estimated by individually calibrated heart rate monitoring, and fat mass was measured using bioimpedance. Sedentary behaviour and adiposity-related measures were assessed both at baseline (1994–1996) and during follow-up (2001–2003), with a median interval of 5.6 years between the two time points. Results showed that time spent sedentary at baseline was not predictive of body weight, BMI, waist circumference, or fat mass at follow-up. In contrast, all measures of adiposity significantly predicted sedentary time at follow-up, independent of baseline sedentary time, physical activity energy expenditure, and other covariates. Compared with individuals who lost weight between baseline and follow up, those who gained weight spent significantly more time sedentary at follow-up. These findings indicate that adiposity is predictive of increased time spent sedentary, but that sedentary time is not predictive of subsequent adiposity. The possibility of a bidirectional association between sedentary behaviour and adiposity requires further research attention. Taken together, there is limited evidence for a positive relation of sedentary behaviour to weight gain and obesity in adults.

6.4 Sedentary Behaviour in Relation to Adiposity in the Elderly

Despite a high prevalence of sedentary behaviour among the elderly [62], the relation between sedentary behaviour and adiposity among people of advanced age has not yet been extensively studied. A recent systematic review of 12 cross-sectional studies by de Rezende et al. [44] 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. [42] 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 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 [63].

A recent systematic review by Chastin et al. investigated determinants of sedentary behaviour in the elderly [43]. Seven studies (six cross-sectional studies and one prospective study) on self-reported or accelerometer-based sedentary behaviour in relation to obesity that were included in that report found greater volumes of sedentary time or television viewing among obese individuals [43]. Clearly, there is a need for further prospective studies using objective measures to explore whether sedentary behaviour is related to obesity in the elderly.

6.5 Limitations of Existing Reviews and Meta-Analyses

Although the existing literature points towards a positive association between sedentary behaviour and adiposity among children, the findings need to be interpreted in the context of certain limitations. Most of the available data are based on cross-sectional studies, which pose a challenge regarding inference about causality of the relation. In addition, the evidence is mainly based on television viewing time, which may not be representative of total sedentary time, particularly not in children [64]. Also, the strength of the association sedentary behaviour and adiposity may vary according to the type of sedentary behaviour (e.g. watching television, playing video games, using the computer), which has not always been taken into account. Furthermore, the majority of studies on sedentary behaviour in relation to adiposity are based on self-reports. Findings from studies using objective assessments of sedentary time and measures of adiposity are less prone to measurement error and exposure misclassification [65]. 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 analytical level.

6.6 Biologic Mechanisms

Obesity may arise from several factors, including heritability and genetic factors; hormonal conditions; and appetite and satiety disorders [66]. 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 [67]. This leads to a positive energy balance and subsequent weight gain and obesity over time [68]. Moreover, it is likely that the association between sedentary time and weight gain is influenced by dietary intake. One study [69] found that increased energy intake, particularly energy from carbohydrates, mediated the association between television viewing and BMI in adolescents. Another study in adolescents [70] 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 [71]. Exposure to food advertising during television viewing time has been suggested to prime food consumption [72].

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 [73]. A line of research indicates that physically active persons have better control of appetite than sedentary individuals [74]. A recent experimental study [75] 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 [76].

Obesity is thought to represent an intermediate variable in the relation between sedentary behaviour and various disease outcomes, although this hypothesis needs to be clarified further. While some studies noted attenuation in the magnitudes of associations between sedentary behaviour and obesity-related diseases in models that were adjusted for BMI [77–79], other studies found that adjustment for BMI did not materially affect the results [80, 81]. Obesity induces chronic inflammation [82] and insulin resistance [83], which represent risk factors for cardiovascular disease [84] and cancer [85]. Likewise, postmenopausal oestrogen production in adipose tissue through aromatization of androgens may increase risk of hormone-related female cancers [86, 87]. Further, obesity is related to dyslipidaemia and hypertension [88], which pose risk for cardiovascular disease [89, 90].

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.

6.7 Summary

A multitude of studies 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 2 h per day in children and adolescents appears to be a sound conclusion that can be drawn from the current scientific evidence base. In order to prevent the development of obesity it is crucial to minimize modifiable risk factors such as sedentary behaviour and to encourage protective factors such as physical activity and a healthy diet in both children and adults.

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Chapter 7
Non-Exercise Activity Thermogenesis (NEAT) and Adiposity

James A. Levine and Shelly K. McCrady-Spitzer

Abstract The human being is designed to walk. Over a miniscule, in genetic terms, period of time, a mere 200 years, human have been compressed into chairs. Education, work, and home environments promote sedentariness in susceptible people. In those individuals, non-exercise activity thermogenesis (NEAT) is suppressed and health is harmed. Overall the strength of the evidence regarding sedentary behaviour and obesity suggests that NEAT has declined with urbanization and modernization—in general, modern people living in cities and working in offices are sedentary. Low NEAT (sedentariness) is associated with lower daily energy expenditure than a person of similar size with high NEAT. A person who does not increase NEAT during a period of overfeeding is likely to gain greater adipose tissue than a high-NEAT responder and so people with obesity are more prone to low NEAT and sedentariness. It is clear that central mechanisms exist to regulate NEAT. Solutions exist to measure NEAT and reverse sedentariness in schools and workplaces. It is recommended that a comprehensive societal approach is necessary to reverse sedentariness in homes, schools, offices, and cities.

7.1 Introduction

Obesity is an epidemic with already catastrophic consequences [1]. When a doctor sees a patient with obesity, not only does the doctor need to be cognizant that obesity affects every organ system, but the doctor also needs to be aware that it affects the patient's self-perception [2]. Patients think about their obesity and the discrimination they feel from it approximately five times every hour [3, 4]. It is unfortunate because it is the combination of the patient with not only their inbuilt

J.A. Levine (✉)
Department of Endocrinology, Mayo Clinic, Scottsdale, AZ, USA
e-mail: levine.james@mayo.edu

S.K. McCrady-Spitzer
Department of Endocrinology, Mayo Clinic, Rochester, MN, USA
e-mail: mccradyspitzer.shelly@mayo.edu

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genetic makeup but also the environment in which they find themselves [5] that is preventing the patient from moving and has precipitated their obesity.

There is debate regarding the evolutionary steps that resulted in bipedalism [6]; suffice it to say, the human evolved over hundreds of thousands of years to be upright, two-legged, walking beings [7–11]. Over time, people evolved to explore by foot, to manually invent tools and weapons and to think while upright and responding to environmental cues, perceived threats, and calculated opportunities [12]. Thousands of years ago, living was dynamic. Compare chasing a bison over a cliff to choosing a meat package at the supermarket and contrast hand-chipping a flint for a spear versus engineering a cyber attack. Prior to the industrial revolution 200 years ago, 90% of the world's population lived in agricultural communities where shelter, nutrition, and reproduction all required physical exertion. Data from agricultural communities suggest that, prior to the industrial revolution, people sat for 300 min per day and lived actively [13]. From 1760 onwards, the industrial revolution precipitated urbanization; it was the predominant demographic shift into modern history [14–16]. Now more than half the world's population live in cities, and urbanization continues to grow worldwide [17]. In industrializing countries, 1908 saw the introduction of factories that used conveyor belts, and in the 1940s, modern chair-based offices were developed. In both cases, the environments and furnishings were designed to promote productivity and limit movement by having people sit. Walking around factories or offices was perceived as wasted time. Fast-forward to the present day, and office workers can sit for up to 15 h in a single day! [18]. For a basic description of evolutionary and sociocultural aspects of human sedentary behaviour, please refer to Sect. 1.3.

People are designed to work and socialize while on their legs and to sit in order to rest; the default position for people is to be up and moving. Is it a surprise that modern people who default to sitting (e.g. "take a seat") experience negative physical, medical, and psychological consequences? Do modern environments, however, give us any other choice except to sit? Sedentariness combined with poor food quality and positive energy balance has precipitated obesity.

Obesity not only results in the patient experiencing medical issues—diabetes, hypertension, cardiovascular disease, depression, high cancer risk, joint problems, lymphedema, to name a few [19]—but also discrimination and negative feelings, and the costs to corporate America are staggering. Obesity alone raises annual per capita medical costs by $2741 (in 2005 dollars) [20]. However, a patient can with obesity with multiple complications cost a company $7000–$10,000 per person per year more than their lean counterpart [21].

Worldwide, one and one half billion people have obesity [1]. One-half of children in Beijing are obese [22]. The rate of accentuation of obesity in India is so rapid that it has the capability of slowing its growing economy. The rapid increase in obesity is a global issue [23]. For more details on obesity prevalence, please refer to Chap. 6.

There is debate as to whether it is the chair or the knife and fork that has caused the increase in obesity rates. During the past 150 years, data from multiple studies have shown food intake has remained relatively constant. The UK data have suggested that as the obesity rates have doubled since the 1980s [24], the caloric intake actually declined. However, concomitantly with that there has been a progressive and systematic decline in energy expenditure, first with urbanization and now with the computer and car revolutions. Obesity occurs in the persistence of positive energy balance, such that energy intake is consistently greater than energy expenditure. The National Health and Nutrition Examination Survey (NHANES) has shown that the combined effect of access to low-priced food, concomitantly with an inactive lifestyle, has resulted in sustained positive energy balance and obesity [25]. With this realization, it becomes of great interest to examine the progressive decline in daily energy expenditure.

7.2 Energy Expenditure and Non-Exercise Activity Thermogenesis (NEAT)

Energy expenditure [26] is composed of the basal metabolic rate, thermic effect of food, and activity thermogenesis. The basal metabolic rate accounts for approximately 60% of the total energy expenditure in a sedentary individual. Approximately, 73% of the variance in basal metabolic rate is determined by body size, with the lean body mass positively correlated with the basal metabolic rate. Thermic effect of food accounts for about 11% of the total; this is the energy expenditure associated with the ingestion and absorption of food and its conversion into intermediary metabolites. The remainder of energy expenditure is physical activity.

The energy expenditure associated with physical activity is either associated with purposeful exercise, accounting for 20% of Americans who participate regularly, or non-exercise activity thermogenesis (NEAT), the energy expenditure of everyday living [27]. The energy expenditure of everyday living is of great interest because the vast majority of individuals with obesity have no exercise activity thermogenesis; thus, their entire bout of activity-associated energy expenditure is NEAT. People with high NEAT have active work and leisure; people with low NEAT are sedentary—a.k.a. “couch potatoes”.

Data from the UK display the vast distribution in total daily energy expenditure across an industrialized population [28]. Thus, if body size accounts for basal metabolic rate and the thermal effect of food is small, the only explanation for how one individual of similar body size can expend 2000 kcal/day more than another individual of similar body size is through the variability in their activity energy expenditure.

Similar to the USA, the majority of people in Britain do not utilize fitness centres [29, 30]. Most people do not exercise regularly; thus, the only way to explain why, across a population, some people can expend 2000 kcal/day more than other individuals of similar size is because their NEAT is so variable. How can NEAT vary by 2000 kcal/day between two individuals of similar size both living in civilized countries? Well, the answer is because work practices differ greatly between individuals, and leisure time activities also differ tremendously between individuals.

If one looks, using calorimetry equipment, at the energy expenditure of work, one sees that a chair bound job can be associated with a NEAT of 300 kcal/day [28]. If one were to take, theoretically at least, a group of individuals working in a modern office and transfer them into an environment whereby agriculture was the primary work-related endeavour, energy expenditure theoretically associated with work would increase from 300 kcal/day of NEAT to 2300 kcal. Work is a tremendous driver of the energy we expend through non-exercise activity. The energy expenditure of leisure time activities also has great variance [31–33]. Of course, an activity that many of us engage in for most of our days is gum chewing [34]. Such an activity is associated with an excursion of energy expenditure over resting of about 20 kcal an hour; the point being not necessarily that one should chew gum all day, but to make the point that trivial activities actually have a significant thermogenic impact [35]. When a person engages in multiple low-level activities throughout the day this can aggregate to a significant amount of energy expended [36].

Conversely, there are NEAT activities that can be considered high impact activities. These high impact activities occur when an individual becomes upright. As soon as one starts to walk, even at 1 mile an hour, which is equivalent to "shopping speed", a person doubles their metabolic rate [37]. At two miles an hour, which is equivalent to purposefully walking to a meeting, a person increases their metabolic rate by about 150 to 200 kcal/h, depending upon their size. Rushed walking, which is equivalent to racing to an airport gate, can triple one's metabolic rate above basal. So what a person does in their leisure time can dramatically impact total daily energy expenditure. For instance, a person could return from work at 5:00 in the evening and sit in front of the television until one falls asleep at 11:00 at night. That entire evening of leisure activity will expend approximately 50 kcal. Conversely, a person could return from work at 5:00 in the evening and start raking leaves or paint one's basement, and in so doing, one can expend 100 to 150 kcal an hour. For that evening of avid home redecoration, one can expend 500 to 600 kcal a night, as opposed to sitting in front of the television for 50 kcal. It is that combined impact of what one does during one's day as an obligate job combined with what chooses to do in the evening that can account for why one individual of similar size can burn 2000 kcal more through NEAT than another individual of similar size [38].

7.3 NEAT and Body Weight

If so much variability exists in NEAT, is that variability relevant in weight gain? In a previous research study, we studied a group of lean individuals and determined exactly how much energy each individual required to remain weight stable. Each individual was then overfed by an excess of 1000 kcal/day for 8 weeks [39]. That degree of overfeeding was maintained for 8 weeks, resulting in each individual receiving 56,000 excess kcal for that period. Although the degree of overfeeding was the same for each participant, the variability in how much fat each person gained was great. As shown in other studies [40], individuals appear to gain weight at variable levels, regardless of the amount of energy consumed in excess. Those people who store excess energy as body fat are those who do not activate their NEAT with overfeeding [39]. Those who eat 56,000 kcal greater than their energy needs and do not gain body fat appear to expend it through NEAT.

To understand the mechanism of NEAT activation, the experiment was repeated with different subjects by our laboratory [41]. The results were reaffirmed. The reason, however, an individual can consume 56,000 kcal and not gain excess weight is because this individual intuitively begins to walk [41]. As an individual is overfed an excess of 1000 kcal a day, they take it on themselves, without necessarily realizing it or joining the gym, to increase their walking. The median free-living velocity of walking is 1.1 mile/h, and overfed individuals increase walking by ~2.5 extra hours a day. Thus, individuals who do not respond with changes in NEAT to overfeeding gain excess body fat. Individuals who activate NEAT stay lean, even when they are overfed.

7.4 NEAT: Potential Biologic Mechanisms

Our next question was, are there drivers that stimulate the NEAT response? To address this, our laboratory conducted studies on rats in which putative chemicals were injected into the paraventricular nucleus of the hypothalamus [42, 43]. The rats where then placed inside a calorimetry chamber where movements were monitored continuously in the X, Y, and Z axis, in all axes of movement.

Similar studies have been conducted using numerous different chemicals that potentially drive NEAT. One chemical that became of particular interest to our laboratory was orexin, an arousal protein [42, 43]. In one study, we compared rats that were inbred for leanness over multiple generations to those that were inbred for obesity [43]. Before the orexin injections, the baseline measurements of physical activity for the animals inbred for obesity showed they had lower NEAT than the animals inbred for leanness. Even more intriguing is when progressive doses of orexin were injected, the response of the animals with obesity was far less than the animals injected with similar doses who are lean. The brains of the obese animals appear to have a diminished responsiveness to the same dose of chemical as those animals inbred for leanness. Other neuromodulators have also been similarly implicated in the integration of NEAT into energy balance [44]. It is intriguing to conjecture, therefore, that neuromodulators link NEAT to appetite and thus adiposity and metabolic syndrome.

7.5 Physical Activity Monitoring System (PAMS) and Innovative Technologies for the Assessment of NEAT

If NEAT is variable, centrally regulated, and implicated in fat gain, is NEAT important in obesity? To understand the role of NEAT in daily living, our laboratory developed a physical activity monitoring system (PAMS) [45, 46]. This system enables us to track all movements and postures of free-living individuals. Using this system, we are able to ascertain body posture. When an individual is standing, the body posture sensors indicate a vertical/vertical position; when sitting, the sensors indicate a horizontal/vertical position and when lying, the sensors indicate a horizontal/horizontal position. Because the motion sensors are associated with all posture senses, PAMS allows for all movements of a person in a 24-h period to be captured by the laboratory.

In an analysis of PAMS data from free-living individuals while they were awake, we examined every walk that a free-living person took. A walk was defined as a standing posture that involved movement for at least half a second. This analysis allowed for a unique glimpse into how individuals choose to move throughout their day. This study showed that most walks taken by free-living people were of short duration, with the average walk lasting under 12 min [41]. Similarly, the walks are of low velocity. Thus, the average walk of a person is about 1.1 miles/h, and it lasts for just under 12 min. Therefore, it is the sum of all the different walks that explains how one person can expend by walking 850 kcal/day more of NEAT than another person who is taking slightly shorter, slower walks.

Our movements throughout the day may not therefore be purely volitional but might be underpinned by a deep biology that determines movement. Perhaps some people choose jobs as post office workers and others choose sedentary jobs. Such decisions may be driven by subtle brain mechanisms.

An individual with obesity, living in the same environment as an individual with more NEAT, is seduced into a chair for 2.25 h/day more than their lean counterpart [47]. A lean individual, living in the same environment as a person with obesity, is exploiting opportunities to be up and walking for 2.25 h/day [45, 48]. Somehow subtle “be active” responses in the obesity-prone person might differ from those of lean-prone individuals whose brains are responding to the same signals differently.

How can one take advantage of this information to help individuals with obesity who might want to lose weight? The first question is what are the maximum capabilities of the human to move? In order to address this question, we conducted similar studies utilizing the PAMS technology in Jamaica [13]. We were interested in individuals working in agriculture and in individuals who had migrated into urban Kingston who now worked in offices. We found ambulation in the rural, lean Jamaican individuals to be twice as great as lean individuals living in Kingston or lean individuals living in the USA [13]. Similarly, people who were lean, working in the agricultural communities in Jamaica were seated for half the amount of time as lean Americans. Thus, people in the USA are capable of potentially moving twice as much. Thus, here is the putative therapeutic window, an opportunity to increase calorie expenditure 350–750 kcal more daily—if only we can get people out of their chairs.

To exploit this 350–750 kcal window, we started to examine how we might build high-volume, low-cost sensors that would be amenable to a wider audience. We took the Micro Electro-Mechanical Systems (MEMS) accelerometer technology and integrated it into a MP3 player earpiece [49]. We then took that technology and linked it with a cellular telephone, which would enable people to start competitively "gaming" with respect to physical activity [50]. Next, we built a standalone device for consumers to use throughout their day [51]. As all of this was being done, however, there was a significant advance in the technology. Both the iPhone (Apple Computer, Cupertino, CA) and smartphone platforms incorporated a 3-axis Micro ElectroMechanical Systems accelerometer. These accelerometers are inside cellular telephones to rotate the screen as the machine is rotated. Suddenly, we had a mass marketed technology that enabled daily physical activity to be measured. These technologies have been validated in the laboratory [50] with energy expenditure, and these devices are precise and accurate physical NEAT sensing devices. We deployed an application (App), and 28,000 users used it within 6 months [50] which provided data similar to that of Westerterp [52] (Fig. 7.1). This demonstrated the feasibility of using accelerometers for population-wide assessment of energy expenditure.

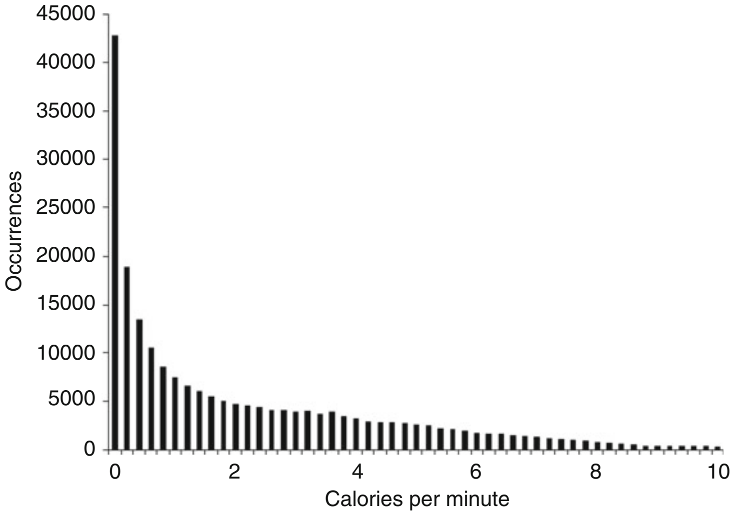

Fig. 7.1 The distribution of physical activity (shown as calories per minute) for 7346 cellular telephone users using a cellular telephone application for monitoring activity

7.6 Work- and School-Based Approaches Aimed at Increasing NEAT

Once we had the capability of measuring NEAT and access to the behavioural techniques to promote it [53–55], we wanted to design environments that were permissive to movement. Our first office of the future was developed in 2005. It was a standard office space populated with treadmills, bicycles, and a walking track. Three hundred and four people worked there temporarily. There were desks; however, they were least favourably positioned in the space. This environment heralded the concept of walk whilst you work.

However, the treadmill desk was only a visual representation of the concept [48, 56]. A person does not need a treadmill desk to be active during the workday. A stepping device with the same technology integrated into it [57] will also allow for increased physical activity while at work. It is placed under a desk and can be pulled out and used at will, for instance during a telephone call. The technology intergraded into the device can provide a daily printout of how many miles a person has stepped. This technology cost just under US $50.

Less expensive and ubiquitously successful is the lanyard worn around the neck, "Walk and Talk Meeting in Progress" [48]. In each company in which it has been deployed, a protocol is put in place such that employees know not to interrupt people who are conducting walking meetings. Other office elements include moving printers away from where things are printed from (this is rarely popular), moving trash cans further away, and having walking tracks laid out with floor tape. Importantly, each of these intervention elements has been validated in the laboratory and assessed for safety and utility by people with obesity. These interventions have therefore been validated and are accessible by most people. For instance, most people, regardless of weight, can complete a 30-min walk-and-talk meeting and use a stepper during phone calls. We have focused on designing, testing, and validating all-inclusive methods of promoting daily physical activity.

Moreover, we have validated comprehensive programmes to promote office-based health and optional weight loss by building laboratories inside office complexes [58]. Subjects generally reach their weight goals and fat mass decreases while the lean mass increases. Full-scale deployments, however, require the need, not only for behavioural scientists but also lawyers, company economists, healthcare providers, information technology personnel, janitorial staff, and managers.

Having developed these approaches for adults in offices, it was important to take them into schools [59]. We interviewed focus groups of 11-year-old children and asked them to design their own school. The students devised this school environment akin to a Socratic village-style living environment (Fig. 7.2). We examined the impact of the re-designed school using validated physical activity sensors. Students, in the re-designed school moved twice as much as in a traditional classroom [60]. In another classroom in Idaho Falls, the entire classroom was re-designed; mobile desks and measurement matrices were put in place by a

Fig. 7.2 Example of design of school of the future

student's mother—Community Based Participatory Research. In this example, the entire process, therefore, was internally driven and successful.

As school-based activity and nutrition programmes expanded, it proved to be a challenge to validate these programmes using robust measures. Thus, we built a bus containing a DEXA scanner and a host of activity sensors and educational materials (Fig. 7.3). Thus, we can drive the laboratory to assess any given programme's efficacy.

However, the most important metric for school-based health programmes is oftentimes educational attainment (much like productivity is in offices). In schools which engage in active learning programmes, educational attainment improves.

7.7 Summary

Overall the strength of the evidence regarding NEAT and obesity can be summarized as follows:

1. NEAT has declined with urbanization and modernization—in general, modern people living in cities and working in offices are sedentary

Fig. 7.3 Example of a mobile dual-energy X-ray absorptiometry unit

2. Low NEAT (sedentariness) is associated with lower daily energy expenditure than a person of similar size with high NEAT
3. A person who does not increase NEAT during a period of overfeeding is more prone to greater adipose tissue gain than a high responder
4. People with obesity are more likely to have low NEAT and sedentariness
5. Central mechanisms exist to regulate NEAT
6. Solutions exist to measure NEAT and reverse sedentariness in schools and workplaces.

Recommendation: A comprehensive societal approach is necessary to reverse sedentariness in homes, schools, offices, and cities.

The human being, in conclusion, was designed over 2.5 million years to walk. It was a feat of glorious engineering. Over a miniscule, in genetic terms, period of time, a mere 200 years, humans have been compressed into chairs. It is an unnatural position for this version of *Homo sapiens*. Sitting is an unhealthy way of spending our days, and simply put, we are not designed to do it. There is a calling, to raise the sedentary from their chairs and let good health abound.

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Chapter 8
Sedentary Behaviour, Diabetes, and the Metabolic Syndrome

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

Abstract Over the past decade, several reviews have pooled the expeditious accumulation of epidemiologic evidence to indicate that the time spent in sedentary behaviour is a distinct risk factor for several metabolic outcomes. Many of these associations persist after adjustment for important confounding variables (moderate-to-vigorous physical activity and adiposity), with the strongest and most persistent associations seen between sedentary time and type 2 diabetes. Epidemiologic evidence has also shown that the number of breaks in sedentary time have been linked to improved metabolic health. Nevertheless, few examples exist of human experimental models that specifically address the impact of prolonged sedentary time, standing, and low level walking on cardiometabolic health parameters. Those that have been conducted demonstrate that breaking up bouts of prolonged sitting with standing, light, and moderate activity elicit significant benefits upon traditional markers of cardiometabolic health (glucose, insulin, non-esterified fatty acids). This chapter highlights some of the key evidence underpinning the link between sedentary behaviour, type 2 diabetes, and the metabolic syndrome in order to reiterate the importance of incorporating reduced sitting time into prevention pathways and public health initiatives.

J. Henson • C.L. Edwardson • M.J. Davies • T. Yates (✉)
Leicester Diabetes Centre, Leicester General Hospital, University of Leicester, Leicester, UK

National Institute for Health Research (NIHR) Leicester Biomedical Research Centre, University of Leicester, Leicester LE1 7RH, UK
e-mail: jjh18@leicester.ac.uk; ce95@leicester.ac.uk; melanie.davies@uhl-tr.nhs.uk; ty20@leicester.ac.uk

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8.1 Type 2 Diabetes Mellitus: Prevalence, Trends, Economic Burden, Definition, and Prevention Strategies

Over the past three decades, the number of people with diabetes has more than doubled and this has been epitomized by the fact that high glucose levels are now the third leading cause of mortality globally [1]. Type 2 diabetes mellitus, a complex heterogeneous disease, is the most prevalent form, affecting around 90% of those individuals with diabetes, while the remaining 10% mainly have type 1 diabetes or gestational diabetes [2]. Type 2 diabetes is a condition characterized by hyperglycaemia, resulting from defects in hepatic and peripheral glucose uptake, insulin secretion, or both [3]. Broadly, the injurious effects of hyperglycemia are separated into microvascular complications (nephropathy, neuropathy, and retinopathy) and macrovascular complications (coronary artery disease, peripheral arterial disease, and stroke) [4]. As advances in clinical sciences have allowed its complex pathophysiology to be explored, its prevalence has exponentially increased. In 2015, the global prevalence of type 2 diabetes was estimated to be 415 million (8.8%) [2]. This figure is expected to rise further to 642 million by 2040, which represents 10.4% of the total adult population aged 20 to 79 [2].

In the UK alone, diabetes is amongst the most common chronic illnesses, with 1 in 10 of all hospital admissions having diabetes, causing approximately 15% of all deaths per year [5]. The 'epidemic' label attributed to type 2 diabetes is further justified when the current and future economic burdens are examined. In the UK during 2010/2011, type 2 diabetes incurred direct costs of £8.8 billion (£1.5 million per hour) and indirect costs of £13 billion [5]. Type 2 diabetes currently accounts for approximately 10% of the total health resource expenditure and if it were to continue on the same trajectory, this figure is likely to rise to 17% by 2035 [5], therefore representing a serious clinical and financial burden in the UK's already stretched healthcare system. Worldwide, the severity of the economic burden varies between countries and is largely dependent upon the healthcare system in place. For example, in high income countries, the burden often affects government or public health insurance budgets whereas in poorer countries the financial onus falls on the person with diabetes [6].

Type 2 diabetes is at one end of a continuous glucose control spectrum, with normal glucose control at the other end. In between, there exists a condition called impaired glucose regulation, defined as a composite of impaired fasting glucose (fasting plasma glucose >6 mmol/l and <7 mmol/l) and/or impaired glucose tolerance (2-h post-challenge plasma glucose ≥ 7.8 mmol/l and <11.1 mmol/l) [7]. More recently, guidelines have also been introduced that allow a diagnosis of impaired glucose regulation or type 2 diabetes to be derived from HbA1c (6.0 to 6.4% and $\geq 6.5\%$, respectively) [8].

Despite both falling under the term impaired glucose regulation, impaired glucose tolerance and impaired fasting glucose appear to have different phenotypes: impaired fasting glucose is associated with hepatic insulin resistance and a defect in insulin secretion while impaired glucose tolerance is strongly associated with peripheral insulin resistance [9–11]. Those with impaired glucose tolerance tend to have higher triglyceride levels, lower high density lipoprotein (HDL) cholesterol, larger waist circumference, and a higher prevalence of the metabolic syndrome when compared to those with impaired fasting glucose [12]. Approximately, 318 million adults (6.7%) are estimated to have impaired glucose tolerance, with that figure likely to rise to 481 million (7.8%) by 2040 [2]. This dramatic escalation is visible worldwide, where the increase has paralleled the rise in obesity [13].

Given these factors, individuals with impaired glucose tolerance are an important population in the prevention of type 2 diabetes. This stage of intermediate hyperglycaemia provides a potential window of opportunity to identify elevated blood glucose levels early, as individuals will have been exposed to less hyperglycaemia and fewer co-existing abnormalities.

Previous lifestyle interventions have been shown to be effective at slowing progression to type 2 diabetes in those with impaired glucose regulation, particularly impaired glucose tolerance. Efficacy trials conducted in the USA, Finland, India, China, and Japan have consistently demonstrated that lifestyle intervention reduces the risk of type 2 diabetes by 30 to 60% in those with impaired glucose tolerance [14]. Importantly, such programmes have also been shown to still yield benefits well after the cessation of the intervention. For example, the Da Qing Diabetes Prevention trial demonstrated that a relative risk reduction of 43% was maintained at 20 years (14 years after the intervention ended) [15].

As a result, both national and international recommendations and policies specify that chronic disease prevention strategies should include targeted interventions aimed at the identification and management of high risk individuals [8, 16–19]. The success of prevention programmes have been underpinned by relatively modest changes in lifestyle that include adopting a healthy diet, maintaining a healthy body weight, and increasing levels of physical activity. Whilst these large efficacy studies were successful at initiating weight loss, the impact on physical activity levels is more equivocal. Indeed, there is little evidence that diabetes prevention trials result in clinically meaningful changes to physical activity [20]. This highlights the difficulty of promoting activity driven behaviour change in high risk/newly diagnosed populations and given this weakness, there is a need to develop novel ways to try and increase movement. The challenge remains to implement the systematic translational research gained from epidemiologic and experimental evidence into real-world diabetes prevention trials, whilst still harnessing the behavioural and physiological adaptations that underpin their success. Significant progress addressing the implementation process has been made through the design of the IMAGE[1] toolkit, which provides the latest evidence in the science of diabetes prevention and practical information regarding how to translate this knowledge into practice [21]. However, much work is required to continually implement these recommendations in the future, particularly around the promotion of physical activity.

[1]IMAGE: The development and Implementation of A European Guideline and training standards for diabetes prevention.

One plausible method may be placing an emphasis upon reducing sedentary behaviour. This is important as excessive sitting has become the default setting for many individuals. As such, reducing sedentary behaviour requires an innovative approach, so that individuals think about the balance of sedentary behaviour and activity in all aspects of daily life. The clinical importance and implication of this new paradigm are summarized in this chapter.

8.2 Metabolic Syndrome: Definition and Prevalence

Epidemiologically, the metabolic syndrome consists of a constellation of related physiological, biochemical, clinical, and metabolic factors that directly increases the risk of cardiovascular disease, type 2 diabetes, and all-cause mortality. From a pathophysiological perspective, it is characterized as a state of chronic low grade inflammation underpinned by a complex interplay between genetic and environmental factors. Several factors of which include (but are not limited to) visceral adiposity, atherogenic dyslipidaemia, endothelial dysfunction, genetic susceptibility, elevated blood pressure, and insulin resistance [22–24].

To date, several different definitions exist from various organizations including the International Diabetes Federation, World Health Organization, and National Cholesterol Education Program [22–24]. Although the definitions differ slightly, diagnosis generally occurs when an individual presents with any three of the following: increased waist circumference, elevated blood pressure, raised triglycerides, high fasting blood glucose, or low high-density lipoprotein levels. Unsurprisingly, metabolic syndrome represents an escalating public health and clinical challenge, particularly given the issues around a sedentary lifestyle, urbanization, and surplus energy intake.

The worldwide prevalence of metabolic syndrome is largely dependent upon the region, environment, and demographic (age, sex, ethnicity) under investigation but the estimates range from 10 to 84% [25]. Metabolic syndrome confers a fivefold increase in the risk of type 2 diabetes and twofold risk of developing cardiovascular disease over 5–10 years [26]. Therefore, the high prevalence of the metabolic syndrome and the associated health consequences demonstrate the importance of understanding the determinants in order to implement successful prevention strategies. However, there is still no universally accepted pathogenic mechanism or clearly defined diagnostic criteria, meaning its value in clinical medicine has not been fully articulated or accepted. Furthermore, there is still debate as to whether it represents a specific syndrome or is a surrogate of combined risk factors that exacerbate risk.

To discuss the evidence linking sedentary behaviour to individual components of metabolic syndrome is beyond the scope of this chapter. However, we will mainly focus upon sedentary behaviour and its role within the underlying pathophysiology of type 2 diabetes and metabolic syndrome, which principally includes insulin resistance, in order to reiterate the importance of incorporating reduced sedentary time into prevention pathways and public health initiatives.

8.3 Sedentary Behaviour, Type 2 Diabetes, and Metabolic Syndrome: Epidemiologic Evidence

8.3.1 Type 2 Diabetes

To date, three meta-analyses have examined the association between sedentary behaviour and type 2 diabetes [27–29]. Within these reviews, the size of the predicted effect ranged from 1.20 to 2.19. One of these meta-analyses reviewed 18 studies (16 prospective, 2 cross-sectional) with 794,577 participants and found a significant positive association between sedentary time and type 2 diabetes risk [29]. Comparing the highest vs. the lowest sedentary time increased the relative risk of type 2 diabetes by 112%, and this was not substantially altered by adjusting for physical activity levels.

Grontved and Hu (2011) also demonstrated that the estimated absolute risk differences for 2 h of television (TV) viewing per day were 176 cases of type 2 diabetes per 100,000 individuals per year. Of the 8 studies included, 4 reported results on type 2 diabetes (175,938 individuals, 6428 incident cases during 1.1 million person-years of follow-up). The relative risk increased by 20% for each 2 h of TV viewing per day, with dose–response analysis revealing a linear increase in risk with the number of hours per day of TV viewing for type 2 diabetes [28].

More recently, a meta-analysis conducted by Biswas et al. (2015) examined the association between sedentary time and the risk for disease incidence, mortality, and hospitalization. Although significant effects were observed for all-cause mortality (pooled HR = 1.22, 95% CI = 1.09 − 1.41), cardiovascular disease mortality (pooled HR=1.15, 95% CI = 1.11 − 1.20), cancer mortality (pooled HR = 1.13, 95% CI = 1.05 − 1.21), and cancer incidence (pooled HR = 1.13, 95% CI = 1.05 − 1.21), the largest statistical effect estimate was associated with the risk for type 2 diabetes, which included 5 studies and 26,700 participants (pooled HR = 1.91, 95% CI = 1.64 − 2.22) [27].

Despite the associations observed between sedentary behaviour and type 2 diabetes, the risk estimates generated by many of the meta-analyses may not accurately reflect the effect that can be attributed to sedentary behaviour. This is largely due to the ambiguity and complexity of defining sedentary behaviour. For example, the subsequent heterogeneity derived from variations in assessing sedentary behaviour has resulted in the pooling of risk estimates from self-reported television viewing time, daily sitting time, and occupational sitting time. The comparison of the highest and the lowest categories of sedentary behaviour within each study may also serve to attenuate the overall effect as there is inter-study variation in the upper and lower values of the sedentary behaviour categories. Another major limitation in many of the reviews is the use of self-reported measures of sedentary time, which have often used only single items assessing daily TV viewing time or overall hours of sitting. These are open to bias and often exhibit only modest levels of validity.

However, at the time that these studies were conducted, these were the only realistic methods available in order to quantify sedentary time. Nevertheless, recent advances in measurement technology mean that sedentary behaviour can now be quantified objectively using inclinometers or accelerometers.

Individual studies that have used objective measures of sedentary behaviour have found associations with glucose and insulin levels [30–33]. Such findings were also populated in a recent systematic review which concluded that sedentary behaviour is detrimentally associated with HOMA-IR,[2] insulin, and insulin sensitivity [34]. The evidence appears particularly compelling for those with a high risk of, or diagnosed, type 2 diabetes where objectively measured sedentary behaviour quantified using an accelerometer is also strongly associated with markers of insulin resistance [32, 35, 36], interleukin-6 (IL-6) [37], and markers of regional adiposity, when assessed by magnetic resonance imaging [38]. Importantly, the majority of these observations persisted after further adjustment for body mass index (BMI) and moderate-to-vigorous physical activity [35, 37, 38]. More recently, cross-sectional analysis in 2497 adults has also shown that an extra hour of objectively measured sedentary time is associated with 22% increased odds of developing type 2 diabetes and 39% increased odds of metabolic syndrome [39]. Again, these results were independent of purposeful physical activity. We have also shown that the association between sedentary time and insulin resistance in a high risk cohort remains consistent across a common genetic polymorphism in the *PPARG2*[3] gene [40]. This is significant because the polymorphism imparts a strong modifying effect on the effect of moderate-to-vigorous physical activity with the wild type displaying only weak associations between moderate-to-vigorous physical activity and insulin resistance [40]. These results, coupled with those discussed above, further support the independent role of sedentary behaviour in regulating metabolic health.

Nevertheless, not all studies have found a link after adjusting for key lifestyle confounders (adiposity and/or moderate-to-vigorous physical activity) [41–46]. These discrepancies may be partly explained by the population under investigation (high risk of type 2 diabetes vs. general population), the potential interaction with physical activity, the measure of exposure (self-report vs. objective), or the statistical methods employed. In addition, it is possible that reductions in sedentary behaviour without changes to moderate-to-vigorous physical activity are insufficient to influence markers of cardiometabolic risk, an issue that is discussed in more detail in the experimental evidence section.

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[2]HOMA-IR: homeostasis model assessment of insulin resistance. The HOMA-IR is used as a surrogate measure for insulin resistance and is calculated as [fasting insulin (mU/mL) $\times$ fasting glucose (mmol/L)]/22.5.

[3]PPARG2 gene: Peroxisome Proliferator-Activated Receptor Gamma-2; a protein coding gene primarily expressed in adipose tissue.

8.3.2 Metabolic Syndrome

Despite the growth of investigations examining the association between sedentary time and individual markers of health, only one meta-analysis has examined the association with metabolic syndrome [47]. That review included 10 studies and 21,393 participants (studies ranged from 358 to 6162 participants) and metabolic syndrome was found in 5585 (26.1%) of subjects. Results showed that greater time spent sedentary increased the odds of metabolic syndrome by 73%. In addition, the observed associations were not influenced by the sex of participants, the type of measurement of sedentary behaviour, or metabolic syndrome definition employed. A sensitivity analysis also suggested that the relationship between sedentary behaviour and metabolic syndrome may be independent of physical activity. However, as mentioned previously, most of the included studies ($n = 8$) used self-reported television viewing as a surrogate marker of sitting.

Individual studies using objective measures of sedentary time have also shown associations with metabolic syndrome. For example, Bankoski et al., examined 1367 individuals (men and women), $\geq$60 years, and found that people with metabolic syndrome spent a greater percentage of their time sedentary, in addition to having longer sedentary bouts. Furthermore, following adjustments for key confounders (age, sex, ethnicity, BMI, physical activity, diabetes status), a higher percentage of time spent sedentary was also associated with a 58% greater likelihood of developing metabolic syndrome (quartile 2 vs. quartile 1) [48].

More recently, prospective epidemiologic studies have also focused upon clustered metabolic risk (incorporating indicators of central obesity (waist circumference), dyslipidaemia (triacylglycerol and HDL cholesterol), hypertension (systolic and diastolic blood pressure), and hyperglycaemia (fasting plasma glucose and serum insulin). They demonstrated that in individuals at high risk of type 2 diabetes, greater increases in sedentary time (measured objectively over 6 years) were associated with larger increases in clustered cardiometabolic risk, independent of baseline sedentary time and moderate-to-vigorous physical activity levels [49]. Such studies examining longitudinal relationships are important as they begin to provide an insight into the potential impact of changing sedentary behaviour and the subsequent influence upon markers of cardiometabolic risk.

8.3.3 Isotemporal Substitution Studies

Most previous investigations have examined each domain (sedentary, light activity, moderate-to-vigorous physical activity) without considering the time-dependent behaviours that are being displaced. Isotemporal substitution was developed as a methodology to study the time-substitution effects of one type of activity for another in a dataset consisting of continuous outcomes [50, 51]. This process is tantamount to energy substitution models used in nutritional epidemiology studies and the heterogeneous effects of an activity undertaken at a certain time point will be largely driven by the other activities being displaced.

Individuals are consistently encouraged to engage in a minimum of "150 min of moderate-intensity aerobic physical activity or 75 min of vigorous-intensity aerobic physical activity throughout the week" (in bouts of at least 10 min) [52, 53]. As such, these definitions are focused upon behaviour undertaken for a small fraction of the week (1.25 to 2.5% of total waking hours, assuming 8 h of sleep daily) and are unaffected by the type of behaviour conducted throughout the rest of waking hours. As the number of waking hours in a day is not infinite, lower sedentary time must equate to higher time spent in light-vigorous intensity physical activity. The intensity of activity that counterbalances the time spent being sedentary is an important consideration for understanding the specific health benefits of reducing sitting time. Given that there are simply too many hours in the day for moderate-to-vigorous physical activity to replace sedentary time, the vast majority of sedentary time is counterbalanced with standing activity or low-grade ambulation. These incidental bouts of non-exercise physical activity, both of which fall under the category of light activity, show a strong inverse correlation with sedentary time [30, 54].

Previous studies employing this method have found that reallocating time from sedentary time into physical activity (either light or moderate intensity) is associated with improvements in insulin sensitivity [55], glucose [56], HbA1c [57], triglycerides [50, 57], markers of adiposity [57–59], and all-cause mortality risk [60, 61]. In particular, the study conducted by Yates et al. (2015) found that reallocating 30 min of sedentary time into light-intensity physical activity was associated with a 5% difference in insulin sensitivity in individuals at high risk of type 2 diabetes. Moreover, the results were modified by glycaemic status, with stronger associations seen in those with impaired glucose regulation. Reallocating time from sedentary behaviour into moderate-to-vigorous physical activity was also associated with a 15% difference in insulin sensitivity [55]. This study further reiterates the dose–response association between moving from sedentary behaviour into more active domains.

Studies that have been able to isolate the effect of displacing sitting with standing using inclinometers (a thigh-worn activity monitor that accurately discriminates between sitting/lying and non-sitting/lying postures) have also shown beneficial associations with markers of diabetes risk [56]. This is important as such devices have been shown to have almost perfect correlation with direct observation for sitting, sitting to upright transitions, and for detecting reductions in sitting [62–64]. Additionally, they are able to accurately distinguish between standing and stepping [65]. Healy et al. (2015) suggested that moving from sitting to standing (2 h per day) may result in lower fasting glucose (2%), triglycerides (11%), and total/HDL-cholesterol ratio (6%). Conversely, reallocating time from sitting to stepping resulted in 11% lower BMI, 7.5 cm lower waist circumference, 11% lower 2-h plasma glucose, and 14% lower triglycerides [56].

Findings from these studies provide further encouraging evidence that simply substituting sitting for standing throughout the day may improve markers of health involved in the underlying pathophysiology of type 2 diabetes. That said, stronger and more consistent associations are observed when transitioning from a sitting position into physical activity (light or moderate-to-vigorous physical activity), thus highlighting the continued importance of more intense physical activity. Despite the limitation inherent in the design (not based on actual behavioural reallocation), these findings compliment the current epidemiologic evidence whilst allowing the formulation of hypotheses to be tested in an experimental, prospective, or interventional context, which includes elucidating potential mechanisms mediating the effect of low stimulus activities, such as standing.

8.3.4 Breaks in Sedentary Time

The sedentary behaviour paradigm is conceptualized around two constructs: total time spent sedentary and the number of breaks in sedentary time (e.g. rising from a sitting/lying position to a more active state, including standing). It has been previously demonstrated that accelerometer derived breaks in sedentary time, which are inferred from a time-stamped transition between a lack of movement (typically <100 counts/min) to relatively more movement (>100 counts/min), are associated with health benefits. From epidemiologic data it is known that, independent of the total time spent sedentary and in moderate-to-vigorous physical activity, increased breaks in sedentary time are associated with favourable outcomes for 2 h glucose values, triglycerides, HDL cholesterol, and C-reactive protein (CRP) [31, 32, 66, 67]. However, with the exception of CRP, all associations were attenuated after further adjustment for adiposity (either BMI or waist circumference). The attenuation and subsequent nullifying of results is consistent with other studies that have shown no or weak associations between breaks in sedentary time and markers associated with type 2 diabetes and metabolic syndrome (insulin, HOMA-IR) [36, 39].

Interestingly, the association between markers of health and breaks in sedentary time appears to be strongest when examining measures of adiposity, most notably in those at high risk of/recently diagnosed type 2 diabetes [32, 36]. Consequently, breaks in sedentary time, rather than total sedentary time per se, may be an important factor in the regulation of body weight. This is consistent with a small intervention study which suggested that regular variations in posture allocation may be an influential factor in the regulation of energy homeostasis [68].

The findings for breaks in sedentary time and biochemical markers associated with type 2 diabetes and metabolic syndrome are less consistent than those observed for total sedentary time. This may be partly due to the crude method used to quantify breaks in sedentary time which may have attenuated the associations, particularly as the duration and intensity of each break is often not reported. Furthermore, given the fact that all of these studies used accelerometers, the results are not necessarily driven by changes in posture, a tenet which is fundamental when investigating the potential effects of breaking up prolonged sitting.

8.3.5 Can Fitness or Moderate-to-Vigorous Physical Activity Moderate Findings?

Despite many of the associations between sedentary behaviour and health persisting after adjustment for moderate-to-vigorous physical activity, there is emerging evidence that levels of fitness or physical activity may actually modify the associations, particularly in those who are inactive or unfit [35, 37, 69, 70]. Indeed, we recently examined accelerometer data from 2131 participants, aged ≥18 years, and demonstrated that in comparison to adults who are physically inactive with high sedentary time, those who are physically active have a more desirable health profile across multiple cardiometabolic markers (BMI, A1c, HDL cholesterol, and waist circumference) even when combined with high sedentary time [69].

In addition, cross-sectional analyses in high risk of type 2 diabetes individuals has demonstrated that after stratifying by moderate-to-vigorous physical activity levels, the detrimental effects of sedentary time on IL-6 were stronger in those individuals who were classified as inactive, again suggesting that the effects of sedentary time may be more relevant in those individuals who do not engage in sufficient levels of moderate-to-vigorous physical activity [37]. Similar results have also been shown in individuals recently diagnosed with type 2 diabetes, where results were suggestive of a stronger association between sedentary time and subcomponents of metabolic risk among individuals below the median for cardiorespiratory fitness [35]. Shuval et al. also demonstrated that after adjusting for physical activity and other key covariates, sedentary behaviour was significantly associated with a range of cardiometabolic outcomes (BMI, waist circumference, triglycerides, % body fat, and triglyceride-high-density lipoprotein ratio). However, after adjustment for fitness and other covariates, sedentary behaviour only remained associated with a higher triglyceride-high-density lipoprotein ratio [70].

More recently, a harmonized meta-analysis, which included more than 1 million males and females, found that high levels of moderate physical activity seem to negate the increased risk of death associated with high sitting time [71]. More specifically, when compared to the referent group (<4 h of sitting per day, ~60–75 min of moderate intensity activity per day), there was no increased risk of mortality during follow-up in those who sat for more than 8 h per day but also engaged in ~60–75 min of activity (HR 1.04, 95% CI 0.99–1.10). Conversely, those who sat the least (<4 h/day), who were also in the lowest active quartile (~5 min per day), had a significantly increased risk of dying during follow-up (HR 1.27, 1.22–1.30) [71].

Taken together, these studies begin to suggest that being physically active may confer some protection from the potentially deleterious impact of high sedentary behaviour. Furthermore, they also reiterate the independent importance of cardiorespiratory fitness as well as all aspects of the daily physical activity pattern for metabolic outcomes. However, given the observational nature of the evidence, these findings need to be explored through experimental research in order to better inform public health policy and guidance.

8.4 Sedentary Behaviour, Type 2 Diabetes, and Markers of Metabolic Syndrome: Experimental Evidence

It would be easy, given the strength of the cross-sectional epidemiologic research, to assume that sedentary behaviour causes cardiometabolic disturbance. Although the aforementioned epidemiologic studies have received considerable media attention, many may be prone to confounding and/or reverse causality. As such, there is a fundamental need to establish a meaningful, statistically valid connection between the two phenomena, in line with Sir Austin Bradford Hill's hypothesis, which delineates nine criteria needed for determining causality [strength, consistency, specificity, temporal relationship, biological gradient (dose–response), plausibility, coherence, experiment, consideration of alternate explanations] (please also refer to Chap. 3) [72].

Sedentary behaviour interventions frame the research question in relation to the environmental "norms" placed on human behaviour. This puts exorbitant sitting as the default setting for the majority of modern society. Therefore, it is particularly important to investigate the metabolic responses that accrue if we disrupt this norm.

Bed rest studies are considered the primitive models in which to investigate the deleterious effect of inactivity. Contrary to sedentary behaviour interventions, they place an active state as our biological or evolutionary "norm" and examine the effects of imposed sedentary conditions (moving from regular moderate-to-vigorous physical activity to bed rest). Therefore, they do not mimic sedentary behaviour as they are extreme experimental models that are quantitatively and qualitatively different from the level of physical inactivity observed in the general population. Prolonged sitting introduces distinctly different physiological mechanisms (e.g. low shear stress, pooling of blood) when compared to traditional physical inactivity models [73]. That said, bed rest studies still remain a unique model to investigate the basic mechanisms of adaptation to short- or long-term physical inactivity.

In essence, either approach (sedentary intervention vs. bed rest) is justified depending on the question asked, but in the context of this chapter, only the sedentary behaviour approach has the ability to influence future behavioural therapies. Moreover, sedentary behaviour is comparatively easy to simulate in the laboratory and may represent the best inactivity model due to its simplicity and practical application.

As such, intervention studies in which participants are confined to sedentary pursuits begin to provide some of the strongest mechanistic evidence that sedentary behaviours are indeed harmful to metabolic health. To date, few examples exist of human experimental models that specifically address the impact of reducing prolonged sedentary time with standing or low level walking on cardiometabolic health parameters. Those that have been conducted demonstrate that breaking up bouts of prolonged sitting with standing and light and moderate activity elicit significant benefits upon markers of metabolic health [74–78].

8.4.1 Breaking Prolonged Sitting with Light or Moderate-to-Vigorous Physical Activity

Dunstan and colleagues were one of the first to investigate the acute effects of breaking up prolonged sitting on glucose and insulin incremental area under the curve (iAUC). That study employed a cross-over design and included 19 overweight/obese adults (age 53.8 ± 4.9) [75]. Participants were assigned to uninterrupted sitting, sitting interrupted by light-intensity (3.2 km/h) treadmill walking, or sitting interrupted by moderate-intensity (5.8–6.4 km/h) treadmill walking (both conducted for 2 min every 20 min). Each condition lasted for 7 h (including an initial 2 h steady state period). Participants were also provided with a standardized meal (200 ml, 75 g carbohydrate, 50 g fat) at 2 h, with the iAUC measured over the remaining 5 h. Results showed that postprandial glucose and insulin area under the curves were significantly reduced by 24% and 23%, respectively, with light intensity walking breaks, with similar results seen for moderate walking [75].

Similarly, a recent randomized controlled cross-over study [76], conducted in 70 healthy, normal weight adults (mean age 25.9 ± 5.3), compared the effects of prolonged sitting (9 h), continuous physical activity combined with prolonged sitting (1 × 30 min bout of walking), and regular activity breaks on postprandial metabolism (walking for 1:40 min every 30 min). The results showed that regular activity breaks (39% reduction in glucose iAUC) were more effective than continuous physical activity at decreasing postprandial glycaemia levels.

The hypothesis that repeated light bouts of physical activity throughout the day provide a similar level of acute benefit as one long bout of exercise was further supported by a recent study conducted in 10 inactive, older (>60 years) adults with impaired glucose tolerance, where 15 min of walking (performed 3 times a day, 30 min after each meal) significantly improved 24-h glycaemic control and was equally as effective as a 45 min bout of walking [79]. Despite not imposing a bout of uninterrupted sitting, this study shows that similar to pharmacological treatments, a smaller physical activity dose repeated several times per day may provide greater overall benefits than a single large dose taken once per day.

A study carried out in 14 middle aged women (aged>50) also demonstrated that 15 and 40 min bouts of light intensity walking (heart rate ~10% above rest, carried out immediately after a meal) stimulated reductions in the acute blood glucose response to a carbohydrate meal, relative to 2-h sitting [80]. Therefore, even slow post-meal walking can attenuate the increase in blood glucose levels normally observed after a carbohydrate-rich meal, whilst only eliciting minor increases in heart rate.

Newsom et al. (2013) also demonstrated in 11 sedentary, obese adults (mean age 28 years; BMI 37 ± 1 kg/m^2) that a relatively modest bout of exercise (conducted at 50% of VO_2 peak; expending 350 kcal) following a prolonged bout of sitting can improve insulin sensitivity for up to 19 h after cessation, when compared to a sedentary, control condition [81]. Importantly, the observed improvement (35%) in whole-body insulin sensitivity was due to enhanced peripheral glucose uptake. The subsequent improvement also correlated with a change in fatty acid removal from plasma. Interestingly, exercising at 60% of VO_2 peak (whilst keeping the energy expenditure constant) did not yield any metabolic benefits above and beyond those seen when exercising at 50% VO_2 peak [81].

Duvivier et al. (2013) conducted a free-living counterbalanced, randomized cross-over study ($n = 18$, mean age 21 ± 2 years) in healthy individuals that involved assigning participants to one of three physical activity treatment conditions: sitting for 14 h/day (sitting regime); sitting for 13 h/day plus 1 h of vigorous cycling (exercise regime); and sitting for 8 h/day plus 4 h walking and 2 h standing (minimal intensity physical activity regime). Participants underwent each condition for 4 days and were evaluated on the fifth day. The authors reported that the increased minimal physical activity protocol was effective in improving the lipid profile and insulin sensitivity when compared with the prolonged sitting condition. Importantly, in the exercise regime, despite the comparable energy expenditure to the minimal intensity physical activity protocol, no improvements were observed [82].

8.4.2 Breaking Prolonged Sitting with Standing

The majority of the sedentary behaviour experimental studies to date have investigated the metabolic benefits of breaking up prolonged sedentary time with light or moderate-intensity ambulation. The number of experimental studies examining the independent, acute effects of standing without ambulation, upon markers of cardiometabolic health, is limited. This is important as standing (and light intensity activity) are behaviourally more ubiquitous than moderate-to-vigorous physical activity and may therefore provide appealing intervention targets in the promotion of metabolic health. As such, national and international recommendations highlight the importance of chronic disease prevention strategies, whilst supporting interventions aimed at the identification and management of high risk individuals [16–18]. Furthermore, the focus on high risk individuals begins to address the issue of specificity as outlined previously in Sir Austin Bradford Hill's criteria [72].

In response, we recently investigated whether breaking up prolonged sitting with short bouts of standing or walking improved post-prandial markers of cardiometabolic health in women at high risk of type 2 diabetes [77]. 22 overweight/obese, dysglycaemic, postmenopausal women (mean age 66.6 ± 4.7 years) each participated in two of the following treatments; prolonged, unbroken sitting (7.5 h) or prolonged sitting broken up with either standing or walking at a self-perceived light-intensity.

Throughout the experimental day, participants were provided with two standardized mixed meals (breakfast and lunch) that each provided 0.66 g fat, 0.66 g carbohydrate, and 0.4 g protein per kg of body mass (58% fat, 26% carbohydrate, and 16% protein; 1717 ± 234 kcal/day). Blood sampling occurred at regular intervals, and 11 samples were taken across the course of the day. The following day, all participants underwent the 7.5 h sitting protocol [77].

The standing condition followed the same procedure as the sitting condition except that participants were instructed to break their sitting time by standing close to their chair for 5 min, every 30 min. The walking condition was similar to the standing condition, but sitting time was punctuated with 5 min bouts of walking at a self-perceived light intensity on a treadmill [3.0 km/h (range 1.5–4.0 km/h), average rate of perceived exertion = 10 (range 8–12)]. In total, individuals accumulated 12 bouts (60 min) of either standing or walking.

Compared to a prolonged bout of sitting, both standing and walking significantly reduced the glucose (34% and 28%, respectively) and insulin iAUC (20% and 37%, respectively)—see Fig. 8.1. Both standing and walking also attenuated the suppression of non-esterified fatty acids compared with prolonged sitting (33% and 47%, respectively). The effects on glucose (standing and walking) and insulin (walking only) persisted into the following day. These findings build upon previous work in overweight men and women by suggesting that metabolic benefits are also accrued when regularly breaking up prolonged sitting by moving from a sitting to a stationary upright position.

Thorp et al. (2014) also examined 23 overweight/obese adults (aged 35–65 years) in a simulated office environment to determine whether reductions in prolonged sitting time (8 h) through alternating 30 min bouts of sitting and standing

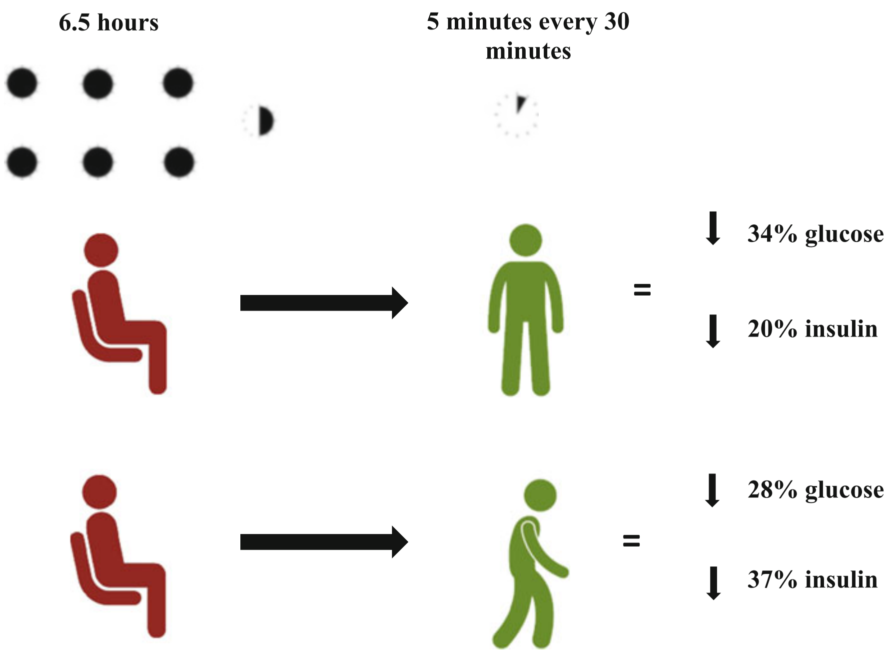

Fig. 8.1 The impact of breaking up prolonged sitting (6.5 h) with 5 min bouts of standing/walking on glucose and insulin incremental area under the curve (iAUC) [77]

could reduce postprandial glucose, insulin, and triglyceride responses. Participants in the intervention arm were provided with an electric, height-adjustable workstation. Following adjustments, the iAUC differed significantly between trial conditions for glucose (11% reduction), but no change was observed for insulin or triglycerides [74].

Although the evidence from these studies seems to corroborate most of the observational studies, there is still some controversy with respect to what would be the minimum type, intensity, and frequency of physical activity necessary to engineer such positive outcomes. Indeed, not all studies have found significant intervention effects.

For example, Miyashita et al. (2013) found that, compared to a prolonged bout of sitting (7.5 h), 30 min of exercise has a greater impact upon postprandial triaglycerol than regular standing breaks (6 $\times$ 45 min). The study included 15 healthy, young males (mean age 26.8 $\pm$ 2.0 years) who underwent a 2-day study protocol. The authors found no post-condition improvement in postprandial glucose, insulin, and triglyceride levels following 1 day of prolonged sitting punctuated with standing bouts (45 min every hour for 6 h) compared to prolonged sitting only [83].

Similarly, breaking 5 h of prolonged sitting with 2 min bouts of standing every 20 min did not elicit any positive effects upon postprandial glucose in 10 normal/overweight participants. However, undergoing 2 min bouts of light walking every 20 min was a sufficient stimulus to significantly reduce the glucose response when compared with the prolonged sitting condition [84].

The differences in results may be largely driven by the populations under investigation, as participants in the Miyashita et al. (2013) and Bailey and Locke (2015) studies were young, healthy individuals [83, 84] compared to overweight/obese sedentary individuals [74, 77]. More importantly, the metabolic profile (dysglycaemic vs. normal glucose tolerance) of participants appears to influence the size of the effect, with the results from experimental research mirroring those seen in the epidemiologic literature [32, 35, 41]. In addition, the duration and frequency of the standing protocols and blood samples were disparate [77, 83, 84]. Therefore, variations in standing and sampling frequency are of importance, particularly in those individuals who have been identified as being at high risk of chronic disease.

8.5 Recommendations for Health

The current research base examining the link between sedentary behaviour and health should encourage healthcare practitioners and policymakers to think about the whole spectrum of activity, from sedentary behaviour to moderate-to-vigorous physical activity. At present, no specific guidelines exist regarding the amount of time individuals should spend sedentary and as such, physicians rarely recommend limiting sedentary time to their patients (10% versus 53% for physical activity advice) [85]. That said, non-specific recommendations regarding the amount of time spent sitting are beginning to emerge alongside more traditional messages of moderate, vigorous, and resistance exercise [86–88]. For more information on sedentary behaviour recommendations, please refer to Sect. 1.4.

An expert statement has recently been published that promulgates specific sedentary behaviour guidelines for office workers. The guidance states that during working hours, office workers should initially aim to incorporate 2 h of standing (assuming a full working day), working up to 4 h over the longer term [89]. Assuming an average working day of 8 h, this equates to spending half our working lives standing. Unlike purposeful moderate-to-vigorous physical activity, which generally necessitates time away from the primary tool of productivity (i.e. computer), the provision of sit–stand desks can facilitate reduced sitting and increased standing without impacting productivity [90]; for example, standing does not affect typing speed [91]. Indeed, productivity over the longer term may actually be improved as regularly substituting sitting for standing has been shown to reduce feeling of fatigue and musculoskeletal complaints [92, 93], the latter of which is the primary source of lost productivity within the workplace.

As there are significant benefits to breaking sedentary time and given the positive metabolic effects observed in experimental studies, it seems prudent that public health messages for those at high risk of chronic disease should consider incorporating regular breaks in prolonged sitting along with traditional messages around accumulating 150 min per week of moderate-to-vigorous physical activity, in bouts of at least 10 min, which have formed the cornerstone of diabetes prevention programmes in the past. Given the epidemiologic and experimental work to date, it appears that reducing sitting time by approximately 60 min per day is likely to be around the minimum needed to gain clinical benefit for type 2 diabetes and metabolic syndrome outcomes, with greater reductions resulting in greater health gains [28, 39, 55, 75, 77].

As the sedentary behaviour research continues to mature, future translational work is likely to have a large public health impact and inform future policies on the prevention of type 2 diabetes. This will also subsequently develop our understanding of the importance of posture and the interplay between sedentary time, breaks in sedentary time, and metabolic markers in order to influence future interventions.

8.6 Summary

The subsequent recognition of sedentary behaviour as a unique health hazard, coupled with its ubiquitous nature, makes it possible that we have not yet reached our full sitting potential, thus fuelling the ever increasing epidemic of a cluster of inter-related chronic metabolic states, including type 2 diabetes and metabolic syndrome. Conversely, recent evidence suggests that repeated frequent bouts of low-intensity activity (including standing) may harness health benefits.

Therefore, findings from epidemiologic and experimental research should serve to influence future diabetes management and prevention programmes whilst reiterating that our penchant towards chair dependency is not without solutions. There are undoubtedly many solutions to improve one's overall health: genetic manipulation, pharmacological interventions, and invasive surgery. However, a lot could be gained by simply sitting less and moving more, regardless of the intensity level, particularly in the promotion of metabolic health.

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Chapter 9
Sedentary Behaviour and Cardiovascular Disease

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

Abstract Sedentary behaviour is ubiquitous in high income countries and increasingly so in low-to-middle income countries also. Despite substantial research progress achieved in the past decade, our understanding of the influence of sedentary behaviour on cardiovascular health and cardiovascular disease occurrence is still in its infancy. Multiple methodological issues such as poor measurement, unmeasured confounding, inconsistent definition, paucity of prospective study designs, incomplete understanding of key sedentary behaviour indicators such as television viewing, and large heterogeneity between studies hinder a confident translation of available research into quantitative sedentary behaviour public health and clinical guidelines for primary prevention of cardiovascular disease. 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 association. The best available epidemiologic evidence on sitting time in adults suggests that the risk for incident cardiovascular disease is elevated at 10 h/day and over. The association between sedentary time and cardiovascular disease appears to be modified by physical activity; equivalents of approximately 1 h of moderate intensity activity per day appear to largely offset cardiovascular events risk. But such an amount of daily physical activity may be beyond the reach of large parts of the population and therefore the public health relevance of sitting for cardiovascular health remains high. Although causality between sitting and cardiovascular disease is not established, there is scope for developing and testing sitting-reducing interventions targeting the most physically inactive population groups and those who are likely to be resistant or unable to increase physical activity of moderate-to-vigorous intensity. Existing sedentary behaviour-reducing interventions have reported modest effects and as such, the

E. Stamatakis (✉) • J.P. Rey-López
Charles Perkins Centre, University of Sydney, Sydney, Australia
e-mail: emmanuel.stamatakis@sydney.edu.au; juan.reylopez@sydney.edu.au

L.F.M. de Rezende
Department of Preventive Medicine, School of Medicine, University of Sao Paulo, Sao Paulo, Brazil
e-mail: leandrofmrezende@gmail.com

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assumption that decreasing sitting time in the population will be easier than effectively promoting physical activity may need further scrutiny. Further research efforts are warranted for optimizing the definition and measurement of sedentary behaviour, for understating better its independent cardiovascular effects and mechanisms of action, and for developing effective interventions with broad reach.

9.1 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. One of many mismatches, for example, 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 [1, 2]. In a similar way, sitting time today may be more prevalent in most regions around the world due to the wide use of motorized ways of transport (e.g. cars) and the nature of the predominant leisure time activities (e.g. screen-based activities) [3].

Cardiovascular disease is the leading cause of death worldwide, accounting for almost two-thirds of all deaths in 2013. Since 2013, cardiovascular disease has also become the main cause of death and disability-adjusted life years in developing countries, surpassing deaths due to infection and neonatal disorders [4]. In the coming decades, the burden of cardiovascular disease is expected to rise sharply in both developed and developing countries due to population ageing and the upward trajectory increase in the prevalence of several cardiovascular disease risk factors, such as ultra-processed food consumption [5] and obesity [6]. In the USA, for example, cardiovascular disease prevalence has been projected to rise by 10% between 2010 and 2030 [7]. 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 [8, 9], the Joint British Societies [10], and the Brazilian Society of Cardiology [11]. In contrast, sedentary behaviour is a new field of inquiry and relatively absent from such guidance. For more information on existing recommendations on sedentary behaviour, please refer to Sect 1.4. This is not surprising given that the question of whether sedentary behaviour is a promising target for preventing cardiovascular disease has been posed only recently and to some extent 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 U.S. Surgeon General's report on "Physical Activity and Health" which had incidental moderate intensity physical activity at its very

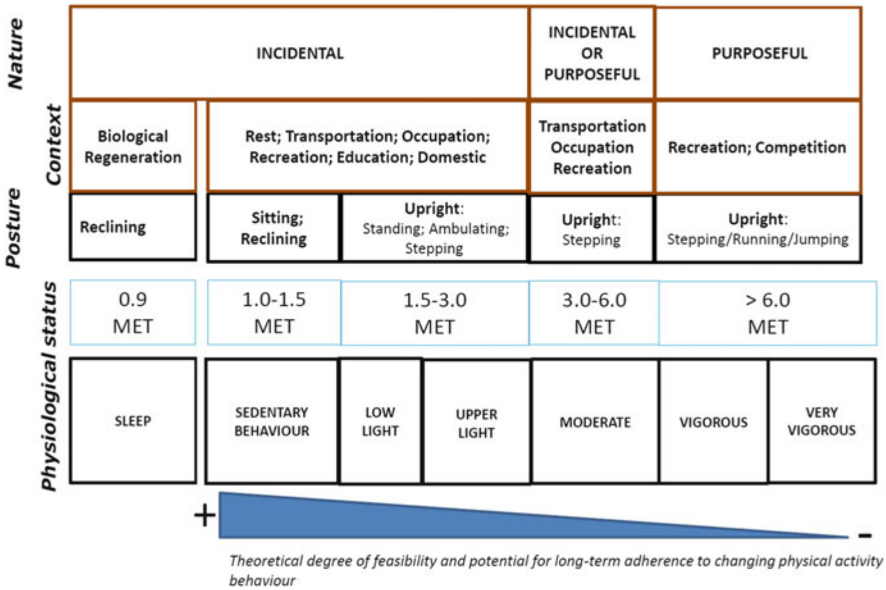

Fig. 9.1 Simplified representation of the *24-h physical activity and sleep continuum* according to (*from bottom to top*): physiological status, posture, context, and nature. The sedentary behaviour paradigm is primarily concerned with replacing time spent sitting (<1.5 METs) with an upright posture 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

core [12]. The main attraction for targeting solely sedentary behaviour as a health intervention (as opposed to promoting structured or incidental 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 minimize 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 (Fig. 9.1). This is an assumption worth revisiting when we discuss the evidence on the effectiveness of existing sedentary behaviour interventions at the end of the chapter.

9.1.1 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.

Although universal consensus has not yet been reached, two current definitions both denote engagement in activities that are characterized by complete or almost complete lack of physical movement. The first of these definitions is purely physiological and is synonymous with the lower end of the physical activity continuum <1.5 metabolic equivalents (METs) [13]. The second is an extension of this definition with a postural allocation and a context-related component, i.e. <1.5 METs in a sitting or reclining posture during waking times [14]. 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, socializing). As previously noted [15], the tabled MET values for common types of sitting range from 1 to 2 METs [16] and therefore do not strictly conform with these definitions. And neither of them readily defines the societal and operational context of sedentary behaviour (Fig. 9.1). 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 this context is necessary for designing targeted interventions.

9.1.2 Historical Context of Sedentary Behaviour as a Cardiovascular Risk Factor

The first indication that sedentary behaviour is linked to cardiovascular risk comes from Jerry Morris' (1953) seminal epidemiologic study among 31,000 employees of London Transport aged 35–64 years [17]. Although that 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. Interestingly, Morris' seminal work is also the very first example of a sedentary behaviour study where the context of bus drivers' sitting was not fully accounted for, i.e. the fact that, contrary to bus conductors, bus drivers had limited or no opportunity for potentially cardiovascular health promoting social interactions [18] during the workday. 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. It was not until the turn of the millennium when the first epidemiologic studies of TV viewing and obesity [19–21] or broader cardiometabolic risk [21, 22] contextualized sedentary behaviour as a distinct behavioural cardiovascular disease risk factor that may not simply be

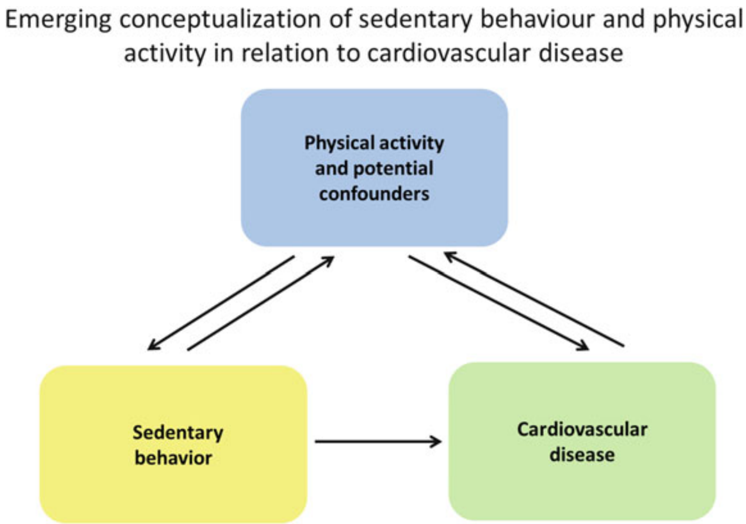

Fig. 9.2 The dominant conceptualization of the relationships between sedentary behaviour and physical activity and cardiovascular outcomes

the inverse of moderate-to-vigorous physical activity. The eloquent review of Hamilton et al. [23] gave further momentum to the field by proposing a widely cited physiological and mechanistic framework for the cardiometabolic effects of sedentary behaviour that was thought to be independent of the pathways through which physical activity exerted its beneficial effects. Hamilton's proposition was enthusiastically promoted by mass media at a large scale and also defined the currently dominant epidemiologic framework for examining the links between sedentary behaviour and physical activity and cardiovascular health (Fig. 9.2).

9.1.3 Prevalence of Sitting

Among other reasons, understanding the prevalence of sedentary behaviour in the population is important because of the likely "threshold effect" characterizing 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 [24]. There is a plethora of studies describing the distribution of sedentary time in a variety of settings and populations. A comparative study of over 49,000 adults in 20 countries [25] 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 [26] and self-reported US data [15]. On the other hand, it is not clear whether total sitting has changed in the recent decades. It has been estimated that mean occupational energy expenditure in US men has decreased by some 140 calories/day over the period from 1960 to 2006 [2]. 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 [27].

National surveillance studies that used waist-worn accelerometers to estimate the prevalence of sedentary behaviour reported higher daily averages than the self-reported studies cited above, e.g. 7.5–8 h/day for working age adults in the USA [28] and 9.5 h/day for working age adults in England in 2008 [29]. Waist-worn devices used in the above national US and UK accelerometry studies have an innate inability to differentiate between sitting and standing and are typically worn for approximately 85% of waking time around or an average of about 13.5 h/day [28, 29], with the remaining 15% (2–3 h/day) being unclassified. Interestingly, in a large population study of over 200,000 Australians aged 45 years and over [30], 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 sedentary time are roughly comparable with the accelerometry estimates of the English study above [29] but are well below the sitting times reported in studies that used inclinometers (devices that can specifically record time spent sitting/reclining, standing, and stepping) such as the Australian Diabetes, Obesity, and Lifestyle Study (AusDiab) of 700 participants aged 35 years and over that recorded nearly 9 h/day of sitting [31] and a Dutch study of nearly 2500 participants aged 40–75 which recorded over 9 h of sitting/day [32]. While the different populations employed make it difficult to make direct comparisons, the possibility that questionnaires largely underestimate sitting time is high. Such a likely underestimation may have consequences when interpreting studies on the dose–response of self-reported sitting and cardiovascular outcomes, as discussed in Sect. 9.2.2.

9.1.4 Television Viewing and Other Recreational Screen Time

Much of the sedentary behaviour literature, in particular in the early days [19–21], was consumed with the study of the associations of screen time, in particular television (TV) viewing and cardiovascular disease [33, 34]. While this literature is very valuable in that it brought scientific, policy, and public attention to an important issue and unarguably propelled the field of research, it offers relatively 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 per day watching TV. Although TV time has historically been the largest component of screen time, this is rapidly changing due to the advent and popularization of multiple screen devices that are owned by large parts of the population. But, overall, television viewing is a poor indicator of overall sedentary behaviour [35, 36] that is largely confounded by factors that are not fully accounted for in epidemiologic studies, such as socioeconomic status [37, 38], dietary intake [39], and mental health [40]. Other aspects of TV and screen media, such as programme content, excessive exposure to advertising (and development of potentially unfulfilled needs to consume), or exposure to excessive amounts of negative messages that may act as chronic psychological cardiovascular stressors [41] 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 objectively assessed sedentary behaviour and to a lesser extent on TV and other screen media.

9.2 Sedentary Behaviour and Cardiovascular Disease Across the Life Course

Age is unarguably the most important risk factor for cardiovascular disease, almost tripling the risk each decade of life [42]. For instance, in 2013, the Global Burden of Disease study estimated that cardiovascular disease death rates (per 100,000) at 35, 45, 55, 65, and 75 years of age were 39, 111, 313, 827, and 2209, respectively [43]. In high-income countries, the median age of cardiovascular disease events and deaths are much higher than in low-to-middle income countries [5]. 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) (Fig. 9.3) [44]. 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 [44–47]. Early-life unhealthy behaviours have been shown to be associated with increased risk of coronary heart disease in later life, perhaps independently of mid-life exposures, although the biological mechanisms are not clear [48]. For example, leisure-time physical

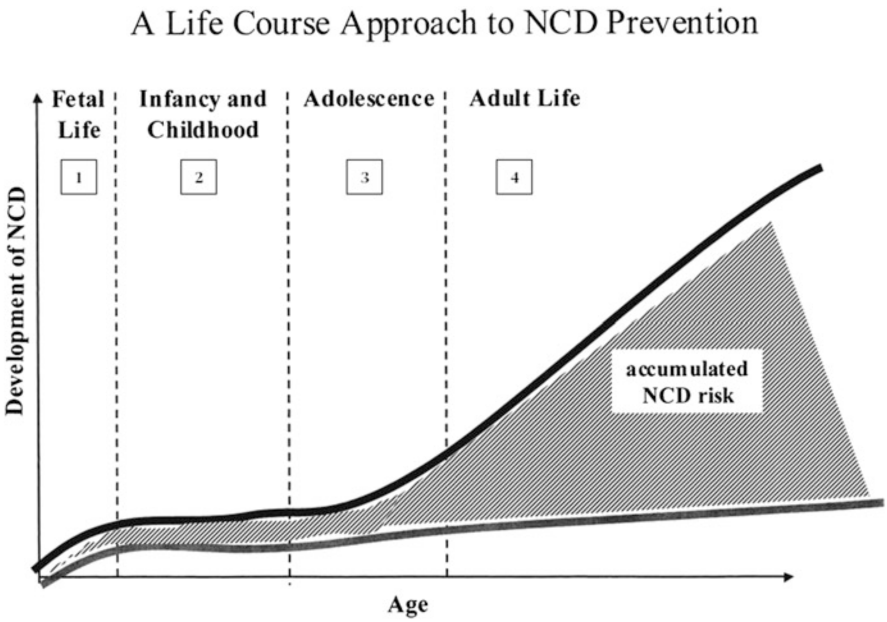

Fig. 9.3 Life-course approach to the development of non-communicable disease (NCD) including cardiovascular disease. Multiple risk factors (including physical activity and perhaps sedentary behaviour) act cumulatively or synergistically from early life and risk is rising steeply from early mid-life. *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* [44]

activity in boys and young adults has been shown to be associated with carotid artery elasticity 21 years later, independently of adult physical activity [49].

Despite the likely risk accumulated during early life, ongoing unhealthy behaviours during middle age and later in life have shown to increase the risk of cardiovascular disease, whereas changes during adulthood appear to be associated with lower premature morbidity, disability, and mortality. For instance, the seminal study by Paffenbarger and colleagues examined the association of changes in unhealthy behaviours and cardiovascular disease mortality in middle-aged and older men [50]. After more than a decade, men who increased their physical activity level had 41% lower risk of deaths from coronary heart disease (CHD) than those who remained physically inactive [50]. These results support the idea that changes in unhealthy behaviours in specific periods of life also have 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 age-specific studies, 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:

- 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 do socioeconomic and broader life circumstances across the life course influence the cardiovascular effects of sedentary behaviour?

It is worth noting that many of these questions could not be answered with confidence even if they referred to moderate and vigorous physical activity that is a much more mature area than sedentary behaviour. Nevertheless, the plethora of large cohorts around the world that are increasingly using sophisticated technologies to measure lifestyle behaviours offer much promise for understanding better the cardiovascular properties of sedentary behaviour.

9.2.1 Sedentary Behaviour in Youth in Relation to Cardiovascular Health

Youth in Western countries spend considerable time in sedentary behaviour; for example, the average daily accelerometry-estimated sedentary time of 5–15 year olds in England is 7–8 h [51]. Since no studies with mortality or cardiovascular "hard outcomes" 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 [52, 53]. 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 television viewing (but not all other kinds of screen time) is associated with adverse levels of a range of cardiovascular risk factors in youth [54–56]. 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 [57]. 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 subsample of almost 6500 participants but baseline waist circumference predicted sedentary time over an average follow up of 2.1 years [57]. This finding is in line with a cross-sectional accelerometry study of about 5400 twelve year olds that found no associations between sedentary time and dual-energy X-ray absorptiometry (DXA) assessed body fat mass or body mass index (BMI) [58]. 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 (CRP), a clustered standardized cardiometabolic risk score, and three adiposity markers including percentage body fat) over a follow-up of approximately 3.5 years [59]. Objectively 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. To date, there is only another one small ($n = 723$), very short-term (<7 months of follow-up) prospective study [60] 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) which also reported null associations.

Collectively, the literature summarized 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 [61]. 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 natural trajectory and timing of non-communicable disease (Fig. 9.3). 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—i.e. subclinical (raised biological risk factors with no symptoms)—clinical (diagnosed disease through an event)—fatal event trajectory. In children and adolescents, the pathogenesis associated with lifestyle-related exposures 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 objectively 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 [62], 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 physical inactivity are associated with cardiovascular risk endpoints [63], such endpoints may not be reactive to a relatively subtle exposure like sedentary behaviour. Of course, we cannot preclude the possibility that the lack of association in prospective epidemiological studies simply signals that sedentary behaviour does not cause deterioration of cardiovascular risk profiles in young age in its own right.

9.2.2 Sedentary Behaviour and Cardiovascular Disease in Adults and Older Adults

Cross-Sectional Studies

In a recent systematic review, Broklebank et al. [64] examined the cross-sectional associations of accelerometer-measured total sedentary time and breaks in sedentary time with individual cardiometabolic biomarkers in adults $\geq$18 years of age. The authors identified 25 cross-sectional studies (almost all in middle-aged adults) and concluded that in both middle-aged and older adults (>60 years old) there was consistent evidence of an unfavourable association between total sedentary time and triglycerides, even after adjusting for moderate-to-vigorous physical activity. However, the evidence for associations of total sedentary time with HDL-cholesterol was inconclusive, and there was no evidence of associations with total cholesterol or LDL-cholesterol. More recently, three studies also support independent associations of moderate-to-vigorous physical activity and sedentary time with other markers of vascular health (e.g. ankle brachial index). In elderly men, after adjusting for covariates, each 10 min block of moderate and vigorous physical activity per day was associated with an odds ratio (OR) of 0.81 (95% confidence interval (CI) = 0.72−0.91) for a low ankle brachial index, whereas each 30 min block of sedentary time was associated with an OR of 1.19 (95% CI = 1.07−1.33) for a low ankle brachial index [65]. Similar results were obtained in elderly (both sexes) using the National Health and Nutrition Examination Survey (NHANES). Sedentary time was positively associated with a low ankle brachial index (OR = 1.22 per 1 standard deviation, 95% CI = 1.03−1.43, $p = 0.02$) [66]. In Brazilian adults (mean 30 years of age), participants in the highest quartile of sedentary time had 0.39 m/s higher pulse wave velocity (a surrogate marker of increased vascular stiffness, 95% CI = 0.20−0.57) than those in the lowest quartile [67]. Importantly, associations persisted when adjusting for moderate-to-vigorous physical activity. In Spanish adults (mean 55 years of age), García-Hermoso et al. [68] also reported that total sedentary time was associated with worse arterial stiffness parameters but contrary to the previous studies, associations disappeared when adjusting for moderate-to-vigorous physical activity.

Sedentary Breaks

A widely discussed concept is that of “sedentary breaks”, i.e. 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 [69]. To date, no longitudinal study has shown associations between sedentary breaks and cardiovascular outcomes. The epidemiologic cross-sectional studies present an unclear picture that often also point towards no association. In a 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 surrogates markers and 2-h plasma glucose [69]. A larger investigation by the same group using accelerometry data among 4757 US adults aged 20 years and over [70] reported inverse associations of breaks only with 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 light intensity activity such as standing can produce favourable responses of cardiovascular markers [71, 72]. The cardio-protective effects of light intensity physical activity (that is often considered the opposite of sedentary time) is largely under-researched [73]. Beyond all these uncertainties and the limited evidence for narrow cardiovascular outcomes, the concept of sedentary breaks merits further attention as several well-designed laboratory controlled trials have shown beneficial effects of light intensity walking breaks on postprandial glucose metabolism among individuals who are habitually inactive [74, 75] and individuals with established metabolic dysfunction [76, 77]. Whether such acute beneficial glycaemic effects of sedentary interruptions translate into long-term reductions in cardiovascular events is currently unknown. This is an important question that merits attention by future studies because evidence from pharmacological trials suggests that even intensive glycaemic control does not always translate into better cardiovascular mortality and morbidity outcomes [78].

In summary, most published cross-sectional studies suggest that sitting is positively associated with surrogate markers of cardiovascular health, such as peripheral arterial disease or dyslipidaemia. But cross-sectional designs provide very little information to infer causal relationships, and it is very likely that they inflate the strength of the associations [79]. Both the epidemiologic and mechanistic evidence on the effect of sedentary breaks on classic cardiovascular outcomes is weak. An emerging body of mechanistic studies shows that frequent interruptions of sitting with light intensity activity induces favourable glycaemic responses, although it is unknown whether such acute responses translate into any long-term cardiovascular benefits.

Prospective Studies and Meta-Analyses of Total Sitting

There have been at least four major meta-analyses of (mostly prospective) epidemiologic studies reviewing the association between sedentary behaviour and incident cardiovascular disease [80–83]. Grontved and Hu reviewed studies of TV and screen time and reported a pooled relative risk of 1.15 (95% CI = 1.06−1.23) for fatal or non-fatal cardiovascular disease per 2 h of TV per day [80]. Biswas and colleagues considered a non-specific mixture of TV studies and sitting studies and reported pooled relative risks comparing high versus low 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 [81]. Wilmot and colleagues also considered a non-specific mixture of TV studies and sitting studies and reported relative risks 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 [83].

In the only meta-analytical review that considered specifically sitting (i.e. excluding TV studies) and incident cardiovascular disease or cardiovascular disease mortality to date, Pandey et al. [82] identified 9 prospective studies and reported a pooled relative risk of 1.14 (95% CI = 1.09−1.19) for the highest (median 12.5 h/day) versus the 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) [82]. The key studies included in this review are briefly summarized here. One of the first epidemiologic studies in the field was that of Katzmarzyk et al. [84], 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 was associated with higher cardiovascular disease risk versus sitting $\leq$10 h/day (HR = 1.45, 95% CI = 0.91−2.29) [85]. In the USA, 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) [86]. Conversely, in a sample of 6154 Australian women, no association was found in those who self-reported more than 8.4 h/day sitting vs. less than 2.7 h/day (HR = 0.90, 95% CI = 0.62−1.32) [87]. A similar finding was reported in Denmark [88], 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 [89], self-reported sitting of more than 12 h/day vs. 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. [90] 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. [36] 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 [91], sitting ≥10 h/day versus ≤5 h/day was associated with increased cardiovascular disease risk (HR = 1.15, 95% CI = 1.05−1.25).

Dose–Response Relationship Between Sitting Time and Cardiovascular Disease

The meta-analysis by Pandey et al. [82] was the only review to specifically examine the dose–response element of the examined associations with regard to cardiovascular disease risk. Similar to meta-analytical work on sitting and all-cause mortality risk [24], Pandey et al. found a nonlinear association between sitting time and risk for cardiovascular disease, with an increased risk only for sitting more than 10 h/day (Fig. 9.4). 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 [25, 26] or studies that examined cardiovascular effects of sitting [87]. Studies that measured sitting using inclinometers, on the other hand, consistently report daily sitting times in the region of 9–9.5 h [31, 32]. If this large discrepancy between objective and self-reported 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. 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.

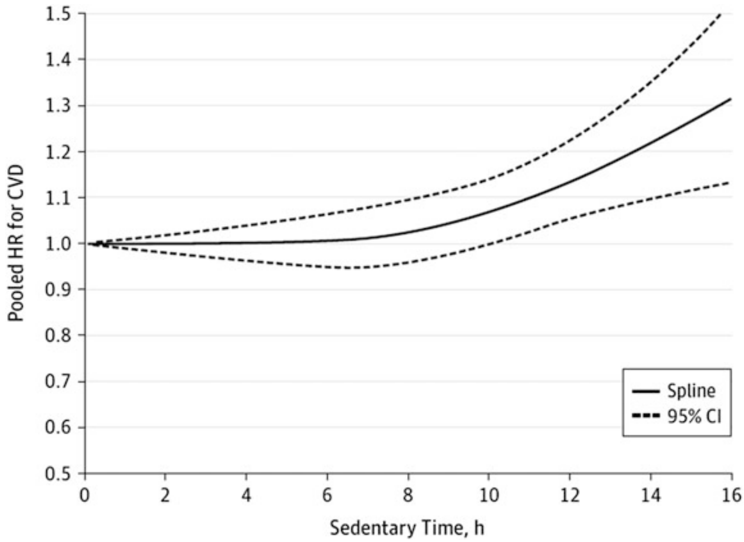

Fig. 9.4 Dose–response association between total sedentary duration and risk for incident cardiovascular disease. The *graph* here shows spline (smoothed fit) and 95% confidence interval of pooled hazard ratio of cardiovascular disease by hour. *Reproduced with permission from: Pandey A, Salahuddin U, 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* [82]

Occupational Sitting and Cardiovascular Disease

Sedentary time occurs in the domestic, transport, occupational, and leisure time domains (Fig. 9.1). 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. In a systematic review published in 2010 [92], no consistent associations between occupational sitting and cardiovascular disease were found. A possible explanation is that higher social status linked with sedentary occupations [37] might offset any adverse effects linked with the sedentary nature of these occupations. This has been suggested as a likely interpretation for the lack of association of occupational sitting and cardiovascular mortality in men, for example, in England and Scotland [93]. Also, the presence or absence of other cardiometabolic risk factors may influence the risk of cardiovascular mortality. In a median 12-year follow-up study conducted in Norway [94], the nature of occupation in terms of physical labour demands was not associated with cardiovascular mortality among those without metabolic syndrome. However, in individuals with metabolic syndrome, both physically demanding and sedentary jobs were associated with higher cardiovascular mortality risk.

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

9.3.1 Biologic Mechanisms

No established and broadly replicated biologic mechanism linking sedentary behaviour and cardiovascular disease currently exists. A rodent model-based hypothesis suggested that prolonged sitting causes dramatic reductions in lipoprotein lipase enzyme activity compared to standing up or ambulating regimens [95]. Although this hypothesis was put forward almost a decade and a half 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 [71, 96–98]. Please refer to Sect. 8.4 for more details on the experimental evidence linking sedentary behaviour with cardiometabolic markers and outcomes. Other proposed, but also unproven, biologic mechanisms include the lower expression of endothelial nitric oxide synthase (i.e. related to increased vascular oxidative stress and impaired endothelial function) and reduction of glucose transporter type 2 and glucose uptake [99, 100].

9.3.2 Appraisal of the Evidence: The Likely Causality of the Association of Sitting and Cardiovascular Disease

Associations found in epidemiologic studies could reflect either real (causal) or spurious relationships. Spurious findings are mainly due to non-comparability between groups—exposed and non-exposed—concerning disease risk. Non-comparability mainly arises by random chance, bias (systematic errors during the selection of study subjects or inaccurate measurement of variables of interest) and/or confounding (associated causes of disease unequally distributed between groups). On the other hand, whether associations found in studies reflect causality is more a philosophical endeavour based on the available information from a combination of theory, different methodological designs, and triangulation of research evidence [101]. To this aim, in 1965, Sir Bradford Hill devised [102] nine viewpoints 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; and that the relevance of these causality criteria to contemporary science has been questioned [103].

Herewith we present some basic reflections on whether sitting is linked causally with cardiovascular disease based on some of the core Hill's criteria that were used in a detailed appraisal of causality of the associations between sitting and all-cause mortality [104]. We based our appraisal mostly on the studies included in the recent Pandey et al.'s meta-analysis [82]. For a full list of the Bradford Hill criteria, please refer to Chap. 3.

Temporal Relationship Evidence from prospective cohort studies indicates that sedentary behaviour, especially TV viewing [80] but also total sitting [82], is associated with increased cardiovascular disease risk. In this study design, it is clear that exposure precedes the disease development. Some cohorts still present short average lengths of follow-up, which increases the probability of reverse causality. To minimize reverse causality, most of these studies performed sensitivity analysis excluding ill persons at enrolment and participants with less than 1 year of follow-up (where generally no major differences in associations were found).

Strength of Association The strength of association between sedentary behaviour and cardiovascular disease is generally small (e.g. the pooled relative risk for the highest versus lowest daily sitting categories was 1.14, 95% CI = 1.09−1.19 and even the continuous relative risk for >10 h of sitting per day was relatively low (1.08, 95% CI = 1.00−1.14) [82], leaving open the possibility that such increases in cardiovascular disease risk could be explained by a third incompletely measured or unmeasured variable (e.g. dietary intake).

Dose–Response Relationship In some cases, the dose of exposure increases the risk of diseases in a linear fashion, in others there may exist a threshold only above which there is an increment in the risk of disease. The Pandey et al. meta-analysis [82] found a nonlinear relationship between sedentary time and cardiovascular disease risk, with an increased risk only after high levels of exposure (>10 h/day) [82]. This is a higher threshold than the 7 h/day threshold reported in a meta-analysis of sitting with all-cause mortality [24].

Biologic Plausibility As highlighted in the previous section, the biologic plausibility of sedentary behaviour as an independent risk factor of cardiovascular disease remains elusive. There is a limited body of studies elucidating the likely biological mechanisms through which sedentary behaviour may influence cardiovascular health independently of moderate-to-vigorous physical activity but none has been confirmed or broadly replicated.

Consistency In the meta-analysis by Pandey et al. [82], five out of nine studies found a statistically significant association between sitting time and cardiovascular disease risk [82]. The other four studies with null findings presented, on average, shorter follow-up periods and smaller sample sizes, which might explain the results. Those studies were conducted in different populations, exclusively from high-income countries (e.g. the USA, Denmark, Australia, Canada, and Finland). There is still a need for studies investigating the association between sedentary time and cardiovascular disease risk using different methodological designs, including low-income countries and subgroups of the population.

Alternative Explanations Beyond the points discussed above, we cannot discount the possibility that confounding, bias, and chance are partially explaining the associations between sedentary behaviour and cardiovascular disease in epidemiologic studies. For instance, all nine studies included in a recent meta-analysis measured sedentary time using questionnaires, which increases the probability of information bias. Regarding residual confounding, despite all studies adjusting 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, which raises the probability of residual confounding explaining at least part of the magnitude of the association.

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 basic appraisal of causality against six of the Hill criteria suggests that there is some evidence for a causal relationship between sedentary time and cardiovascular disease risk based on temporal relationship, (nonlinear) dose–response relationship, and consistency. On the other hand, there is little evidence based on biologic plausibility and strength of association, and current evidence does not preclude alternative explanations. Future studies using different study designs, analyses (i.e. life-course exposure to sedentary time), and careful measurement of sedentary time and confounders would enhance our knowledge and support better judgment of a causal relationship between sedentary behaviour and cardiovascular disease. Whether the Hill criteria represent the ideal framework for assessing causation of an exposure in future sedentary behaviour research is debatable [103].

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

Although in Pandey et al.'s meta-analysis all studies were 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 physically active participants, such as the Danish adults' study [105] and the American women's [91] studies above. For example, Fig. 9.5 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 min of walking per day at 3.3 METs, 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 [106]. This was a pooled individual participant meta-analysis that involved 849,108 adults corresponding to 24,481 fatal cardiovascular events where sitting time was categorized as <4, 4 to <6, 6 to 8, and >8 h/day and the quartiles of physical activity had medians corresponding to roughly ≤ 5, 25 to 35, 50 to 65, and 60 to 75 min of moderate intensity per day. Compared to those in the

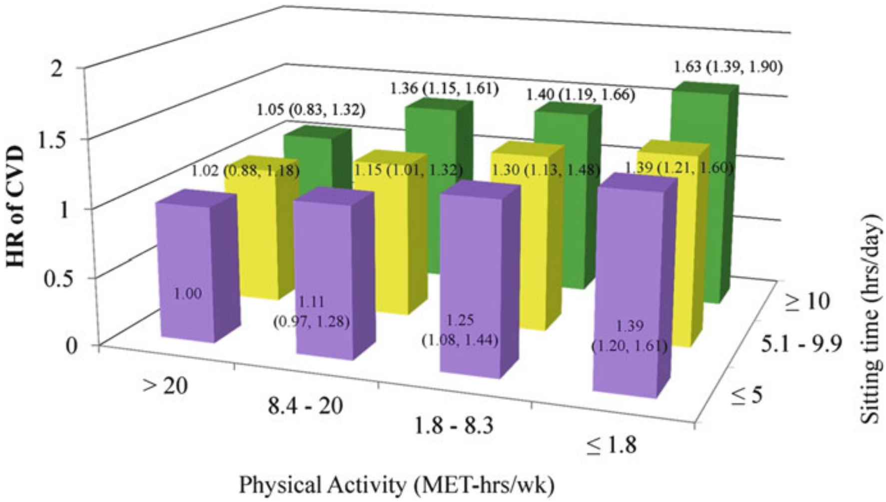

Fig. 9.5 Multivariable-adjusted hazard ratios (HR) for total cardiovascular disease (CVD) for a joint association between sedentary time and physical activity. For women with over 20 - MET-hours/week of physical activity, there was no association between sitting and CVD events. 20 MET-hours per week is roughly equivalent to 1 h 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* [91]

lowest sitting and highest physical activity group (referent), a dose–response association between sitting time and cardiovascular death was noted in the least physically active group, with HRs 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 to 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. Subject to the limitations of the literature noted above, these data provide good support to the idea that high levels of physical activity eliminate the cardiovascular disease death risk of sitting. However, translation of such evidence needs to also take into account the current population context of physical inactivity. The majority of the adult populations are inactive [107, 108], and the average daily amount of physical activity needed to offset cardiovascular risk (approximately 1 h per day) is unattainable for large parts of the population, in particular for middle-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 seminal report by Ekelund et al. [106] reminded us that physical activity should be the utmost public health priority, sedentary behaviour is still relevant.

9.3.3 Public Health Importance and Clinical Practice

How much certainty regarding the causal relationship between sedentary behaviour and cardiovascular disease do we need so that prevention efforts are justified? As Bradford Hill noted in 1965, we should have strong evidence before we make people start what they do not like and stop what they like. However, he continues arguing, "*All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us a freedom to ignore the knowledge we already have, or to postpone the action that it appears to demand at a given time*" [102].

Despite the ongoing uncertainties on issues such as biologic plausibility, independence of the associations from physical activity, and robustness of the relationship between sedentary behaviour and cardiovascular disease, reducing sedentary time has been flagged as having potentially high public health impact [109, 110]. The Australian Department of Health [111] and the U.K. Chief Medical Officers [112], among others [73], have already incorporated non-quantitative sedentary behaviour reductions in their public health guidance.

Despite the relatively small magnitude of the observed associations, sedentary behaviour has sharply increased since the industrial revolution and is highly pervasive in modern societies. For instance, in the USA and Australia, people spend around 8 and 9 h in sedentary activities, respectively, which represents around 60% of waking time [28, 31]. For additional information about the prevalence of sedentary behaviour, please refer to Chap. 4. 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*" [113]. Statistical modelling studies that assessed the effects of replacing sedentary behaviour studies with light physical activities are suggestive for a measureable impact of such replacements at the population level. For instance, some studies have found that replacing 1 h of sitting with light intensity movement [114] or even standing [30] is associated with lower surrogate cardiovascular disease risk markers (e.g. triglycerides) and lower all-cause mortality, respectively. As we alluded to at the start of this chapter, one of the main reasons for the 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 westernized societies where opportunities to be sedentary are many and environments are not conducive for physical activities [109]. Theoretically, these low intensity activities may motivate more people to start engaging in other activities along the physical activity intensity continuum, including those with moderate-to-vigorous intensity [109]. 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 modest effects (-42 min/day, 95% CI $= -79$ to -5 min for generic interventions and -77 min, 95% CI $= -120$ to -35 min for interventions involving sit-stand workstations) [115, 116]. 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 [117].

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 the 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 [118] and high levels of physical activity seem to offset or eliminate the negative cardiovascular effects of sitting time [91, 105, 106].

9.4 Directions for Future Research

Cross-sectional studies that compared accelerometry-based and self-reported measures of sedentary time against cardiovascular risk factors [29, 119] often report differential associations between the two measurement types. Such studies further highlight the importance of improving and, when possible, standardizing measurements of sedentary behaviour. Cross-sectional studies can be useful for hypothesis generation and as a guide for designing prospective studies but offer very little information on the existence and true magnitude [79] of the associations. Therefore, there is a need for well-designed prospective studies with objective measurements of posture and physical activity. Very few existing prospective studies had narrow cardiovascular disease outcomes such as myocardial infarction [105] 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 vs. standing as such a differentiation will have important implications for interventions. Prospective studies to date were conducted almost exclusively in the USA/UK/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.

9.5 Summary

Sedentary behaviour is ubiquitous across the life course in the developed as well as much of the developing world where cardiovascular disease is projected to remain the main cause of premature death and chronic disease. Despite the research progress achieved in the past decade, our understanding of the influence of sedentary behaviour on cardiovascular health and cardiovascular risk occurrence is still in its infancy. Multiple methodological issues hinder a confident translation of available research into quantitative sedentary behaviour public health and clinical guidelines for primary prevention of cardiovascular disease. Such issues include unstandardized or poor measurement, unmeasured confounding, 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 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. The risk for cardiovascular death seems to be offset by approximately one hour of moderate intensity physical activity per day, which is well above the average physical activity levels in most high income countries. In terms of sedentary behaviour as an intervention target for preventing cardiovascular disease and cardiovascular death, current evidence offers limited direction. It may be wise to promote *ambulatory* physical activity of any intensity that will naturally lead to sedentary time reductions. The modest effect sizes of existing sedentary behaviour interventions suggest that reducing sedentary behaviour is not necessarily easier than promoting physical activity of moderate intensity. Sedentary breaks as a stand-alone intervention has been researched less but overall there is very weak mechanistic or prospective epidemiologic evidence to suggest that breaking sedentary time with standing or ambulatory physical activity of light intensity has measurable effects on classic cardiovascular risk markers (e.g. lipidaemia, blood pressure) or incident cardiovascular disease.

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 provide 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 standardize the definition, measurement, research design, and analytical protocols and from a more unified multi-disciplinary approach involving scientists from diverse areas (such as media content experts, transportation experts, and psychologists) that will help us better understand and contextualize the constituent components of sitting, its relevance for cardiovascular health, and develop feasible and effective interventions for long-term behaviour change.

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Chapter 10
Sedentary Behaviour and Cancer

Brigid M. Lynch, Shahid Mahmood, and Terry Boyle

Abstract How sedentary behaviour affects cancer risk is still largely unknown. This chapter summarizes the modest, but growing, body of evidence accrued to date. Based on the findings of 25 different studies that have examined 17 different cancer sites, all-cancer mortality, and site-specific mortality (colorectal and liver cancer), we conclude that sedentary behaviour is associated with increased risks of endometrial (36%) and ovarian cancers (32%). We cannot rule out an increased risk for breast, colorectal, and lung cancers, but there is a lack of consistency across findings. Sedentary behaviour increases risk for all-cancer mortality (13%) and colorectal cancer-specific mortality (38% for pre-diagnosis sitting time; 61% for post-diagnosis sitting time). The association between sedentary behaviour and cancer risk is biologically plausible. Postulated mechanisms underlying the association include: body composition (most evidence relates to adiposity), sex hormones, metabolic function, chronic inflammation, and immune function. Better mechanistic understanding will help strengthen causal inference from epidemiologic data. The adoption of contemporary epidemiologic methods and analytic techniques may also facilitate improved causal inference.

B.M. Lynch (✉) • S. Mahmood
Cancer Epidemiology and Intelligence Division, Cancer Council Victoria, Melbourne, VIC 3004, Australia

Centre for Epidemiology and Biostatistics, Melbourne School of Population and Global Health, The University of Melbourne, Melbourne, Australia
e-mail: brigid.lynch@cancervic.org.au; shahidsethi@hotmail.com

T. Boyle
School of Public Health, Curtin University, Perth, Australia
e-mail: terry.boyle@curtin.edu.au

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10.1 Introduction

A modest body of knowledge now suggests that sedentary behaviour contributes to an increased risk of cancer across a number of sites [1, 2]. Sedentary behaviour is highly prevalent (see Chap. 4), 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 incidence and mortality. We will also summarize the emerging literature examining the biologic mechanisms whereby sedentary behaviour influences cancer risk and provides 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.

10.1.1 Prevalence and Trends of Cancer

Cancer is a generic term representing a group of diseases that are characterized 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 (17% of all worldwide incident cancers in males in 2012), prostate (15%), colorectum (10%), stomach (9%), and liver (8%) are the five most common malignancies [3]. Among females, the five most common cancers are breast (25% of all worldwide incident cancers in females in 2012), colorectal (9%), lung (9%), cervical (8%), and stomach (5%) [3].

Globally, it has been estimated that in 2012 there were 14.1 million new cases of cancer diagnosed, 8.2 million deaths due to cancer, and 32.6 million people living with cancer (within five years of diagnosis) [3]. Cancer (all types combined) was the second leading cause of death worldwide behind only cardiovascular disease (17.5 million deaths) [4]. 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 2020 the number of worldwide incident cancer cases and cancer deaths will rise to approximately 17 million and 10 million, respectively [3]. 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 (57%) of all incident cancer cases, approximately two-thirds (65%) of all cancer deaths, and nearly half (48%) of all prevalent cases in 2012 occurred in less developed regions [3]. Cancer incidence rates vary greatly across different regions and countries, with four-fold differences in rates seen among males and three-fold variations seen in females [3]. For most cancer types, trends over time also differ across regions [5], providing clues about the aetiology of the disease.

10.1.2 Cancer Risk Factors

Age is by far the major determinant of cancer risk. Worldwide, the incidence rates rise sharply with age, increasing from 38 per 100,000 people in those aged 15 to 39 years to 489 per 100,000 people in those aged 55 to 59 years and to 1544 per 100,000 years in those aged 75 years and older [3]. 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 14 different types of cancer, with the greatest risk increase observed for lung and laryngeal cancers. Approximately, 31% of all cancer deaths in males, and 6% in females, can be attributed to tobacco smoking [6, 7]. Epidemiologic research indicates that alcohol consumption increases the risk of at least seven cancers, notably colorectal, female breast, and liver [8], and around 10% of all cancer cases in males and 3% of all cancer cases in females can be attributed to alcohol consumption [9]. Being overweight or obese is a risk factor for at least ten types of cancer, including colon and postmenopausal breast cancers, and it is estimated that around 4% of all incident cancers are attributable to high body mass index (BMI) [10]. 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 [11], while there is convincing or probable evidence that physical inactivity is associated with increased risks of colon, postmenopausal breast, and endometrial cancers [12]. It is estimated that around 20% of all incident cancers could be prevented through improvements in nutrition, alcohol, physical activity, and body fatness [13].

More than 50 occupational agents have been classified by the International Agency for Research on Cancer (IARC) as carcinogenic or probably carcinogenic to humans, and it is estimated that between 4% and 8% of cancers in developed countries are attributable to occupational carcinogens [14]. Many of these carcinogens, such as asbestos, diesel engine exhaust, ionizing 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 [15].

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 16% of all incident cancers attributable to infections [16]. This percentage is much higher in certain regions (e.g. 33% in sub-Saharan Africa and 26% in China) and much lower in other regions (e.g. less than 4% in North America, Australia, and New Zealand) [16]. Finally, around 5% to 10% of all cancers are thought to be caused by highly penetrant genetic mutations [17].

10.2 Methods

This chapter updates the sedentary behaviour and cancer risk meta-analyses conducted by Schmid and Leitzmann [1]. Here, we have incorporated relevant studies published in December 2015. Table 10.1 summarizes studies investigating the associations of sedentary behaviour and risk of incident bladder cancer (one), breast cancer (11 studies), colorectal/colon cancer (seven), endometrial cancer (five), oesophageal cancer (one), gallbladder cancer (one), head and neck cancer (one), kidney cancer (two), liver cancer (one), lung cancer (five), melanoma (one), multiple myeloma (one), non-Hodgkin lymphoma (one), ovarian cancer (three), pancreatic cancer (one), prostate cancer (three), and stomach cancer (one). This chapter also summarizes the literature relating to sedentary behaviour and cancer mortality, including eight studies examining all-cancer mortality, three focused on colorectal cancer-specific mortality, one on liver cancer-specific mortality, and one on prostate cancer-specific mortality (Table 10.2).

Where multiple publications from the same study were found, the most recent publication was included. We prioritized 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 (TV) time) or occupational sitting. The risk estimates 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 is considered an important mediating variable in the sedentary behaviour-cancer association [1]. 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 recommended by Lynch and Boyle [18]. 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) [18].

Random-effects meta-analysis was used to estimate the summary relative risks (RRs) for cancer incidence (by site) and mortality, if at least three studies had been published. To compute summary risk estimates, we generated natural logarithms of extracted estimates with their corresponding standard errors on a log scale and calculated the weighted average of these log RRs, while allowing for between-study variability using DerSimonian–Laird random-effects models [19, 20]. Forest plots were generated to depict study-specific and pooled estimates. Statistical

Table 10.1 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)	Multivariate adjustment
Bladder cancer						
Patel et al., 2015 [24] USA	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.) categorized as 0– < 3, 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
Breast cancer						
Patel et al., 2015 [24] USA After Hildebrand	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	Leisure-time sitting (TV, reading, etc.) categorized as <3, 3–5, or ≥6 h/day.	All women RR = 1.10 (1.00–1.21)	Age, physical activity (exercise, daily-life, housekeeping), race, smoking status, duration and frequency of

(continued)

Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
et al., 2013 [107]			registry, or National Death Index.			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
Ekenga et al., 2015 [31] USA 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.	All women 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
Rosenberg et al., 2014 [30]. USA	Prospective cohort study	44,708 African American women, aged 30 or older at enrolment in	1364 invasive breast cancers identified by self-report followed by	Predefined categories for time spent sitting watching TV (<1, 1–2,	All women TV: RR = 1.13 (0.91–1.40)	Age, questionnaire cycle, BMI, education, parity, fruit/vegetable

		the Black Women's Health Study. Mean follow-up 16 years.	confirmation via hospital or cancer registry.	3–4, ≥5 h/day) or sitting at work (<1, 1–2, 3–4, ≥5 h/day).	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- TV: RR = 1.39 (0.94–2.07) Occupation: RR = 1.19 (0.90–1.57)	intake, meat/fried foods intake, vigorous PA, mutual adjustment for TV/occupational sitting
Catsburg et al., 2014 [33] Canada	Case-cohort study	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) categorized as <12.5, 12.5–24, 24–39, 39–54, >54 h/week. TV time categorized as ≤1, 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) Postmenopausal women Total sitting: HR = 0.98 (0.69–1.39) TV: HR = 1.20 (0.81–1.80) Premenopausal women Total sitting: HR = 0.99 (0.68–1.43) TV: HR = 1.08 (0.65–1.79)	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

(continued)

Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Cohen et al., 2013 [25] USA	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 distribution (<5.5, 5.5–8.1, 8.2–11.9, ≥12 h/day).	All women Top vs. bottom quartile of sitting OR = 1.41 (1.01–1.95) Black women OR = 1.23 (0.82–1.83) White women OR = 1.94 (1.01–3.70)	Age, race, menopausal status, enrolment source, education, household income, BMI at age 21, smoking, ever use HRT, parity, age at menopause, family history, health insurance
Lynch et al., 2013 [28] 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, 0.1–2.1, 2.1–7.2, ≥7.3 h/week/year).	Postmenopausal women OR = 0.71 (0.52, 0.97) Premenopausal women OR = 0.85 (0.58–1.24)	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 breastfed
George et al., 2010 [26] USA	Prospective cohort study	97,039 women from the NIH-AARP Diet and Health Study, aged 51-72 years at risk factor assessment.	2866 invasive and 570 in situ 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, 3–4, 5–6, 7–8, ≥9 h/day); time spent sitting during a typical 24 h period in the past 12 months (<3, 3–4, 5–6, 7–8, ≥9 h/day).	Invasive cancer 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 [29] 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, 60–119, 120–179, ≥180 m/day) and weekends (<60, 60–179, ≥180 m/day). Cases asked to report TV from the year preceding diagnosis.	Postmenopausal women Weekday TV viewing: OR = 0.82 (0.51–1.35), p trend = 0.33 Weekend TV viewing: OR = 1.01 (0.64–1.59), p trend = 0.313 Premenopausal women Weekday TV viewing: OR = 0.94 (0.62–1.45), p trend = 0.035 Weekend TV viewing: OR = 0.91 (0.61–1.34), p trend = 0.10	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 [32] 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, 11.3–29.7, >29.7–47.8, >47.8 MET h/week across lifetime).	All women 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 recreational, household activity physical activity

(continued)

Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Lahmann et al., 2007 [27] Nine European countries	Prospective cohort study	218,169 women from EPIC, aged 20–80 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.	Postmenopausal women HR = 1.08 (0.95–1.23) Premenopausal women HR = 0.98 (0.82–1.16)	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 [23] 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.	All women 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 cancer						
Patel et al., 2015 [24] USA	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.) categorized as 0- < 3, 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 [35] USA	Prospective cohort study	300,673 participants from the NIH-AARP Diet and Health Study, aged 51–72 at questionnaire administration.	4722 incident colorectal cancers identified through linkage to 11 state cancer registries.	Predefined categories for (i) time spent watching TV or videos (<3, 3–4, 5–6, 7–8, ≥9 h/day) and (ii) sitting during a typical 24 h period in past 12 months (<3, 3–4, 5–6, 7–8, ≥9 h/day).	Women TV: RR = 1.45 (0.99–2.12), p trend = 0.174 Total sitting: RR = 1.24 (0.90–1.70), p trend = 0.361 Men TV: RR = 1.61 (1.14–2.27), p trend <0.001 Total sitting: 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

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Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Johnsen et al., 2006 [37] 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 [34] Nine European countries	Prospective cohort study	413,044 EPIC participants, mainly aged 35–70 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
Steindorf et al., 2000 [36] Poland	Case-control study	180 cases treated at a Polish hospital, and 180 age- and sex-matched controls selected from patients without cancer or digestive tract disorders.	Histologically confirmed incident cases of colon and rectal cancer.	Time spent watching TV in leisure time, categorized as tertiles (<1.14, 1.14–2, ≥2 h/day).	All participants OR = 2.22 (1.19–4.17)	Education, total energy intake

Levi et al., 1999 [38] 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.	<u>All participants</u> 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 [39] 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.	<u>Women</u> 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) <u>Men</u> 15–19 years: OR = 1.12 (0.81–1.56) 30–39 years: OR = 0.99 (0.94–1.69) 50–59 years: OR = 0.94 (0.70–1.28)	Study centre, age, total alcohol intake, total energy intake, education

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Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Endometrial cancer						
Patel et al., 2015 [24] USA After Patel et al., 2008 [108]	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.) categorized as 0- <3, 3–5, or ≥ 6 h/day.	All women 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 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 [40] USA	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, 4- <6, 6- <8, ≥ 8 h/day).	All women 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 [42] 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 ($\leq$3.59, 3.60–9.26, 9.27–16.94, $\geq$16.95 h/week/year).	All women 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 $\geq$20 weeks gestation
Moore et al., 2010 [43] USA After Gierach et al., 2009 [109]	Prospective cohort study	69,648 women from the NIH-AARP Diet and Health Study, aged 51–72 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, 3–4, 5–6, 7–8, $\geq$9 h/day).	All women 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 [41] Sweden	Prospective cohort study	33,723 women from the Swedish Mammography Cohort, aged 50–83 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, $\geq$ 5 h/day).	All women 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

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Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Esophageal cancer						
Patel et al., 2015 [24] USA	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.) categorized as 0- < 3, 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 [24] USA	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.) categorized as 0- $<$ 3, 3–5, or $\geq$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						
Patel et al., 2015 [24] USA	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.) categorized as 0- $<$ 3, 3–5, or $\geq$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,

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Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
						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
Kidney cancer						
Patel et al., 2015 [24] USA	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.) categorized as 0- <3, 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 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 [53] USA	Prospective cohort study	289,512 participants from the NIH-AARP Diet and Health Study, aged 51–72 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, 3–4, 5–6, 7–8, ≥9 h/day), and (ii) sitting during a typical 24 h period in past 12 months (<3, 3–4, 5–6, 7–8, ≥9 h/day).	All participants 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						
Patel et al., 2015 [24] USA	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.) categorized as 0- < 3, 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), endoscopy screening, BMI

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Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Lung cancer						
Patel et al., 2015 [24] USA	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.) categorized as 0- <3, 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
Ukawa et al., 2013 [47] Japan.	Prospective cohort study	54,258 participants from the Japan Collaborative Cohort Study for Evaluation of Cancer Risk, aged 40–79 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 = 0.0	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

Lam et al., 2013 [45] USA	Prospective cohort study	158,415 never-smokers from the NIH-AARP Diet and Health Study, aged 50–71 at baseline. Mean follow-up 11 years.	532 incident lung cancers identified through linkage to 11 state cancer registries.	Predefined categories for (i) time spent watching TV or videos (<3, 3–4, ≥5 h/day), and (ii) sitting during a typical 24 h period in past 12 months (<3, 3–4, ≥5 h/day).	All participants TV: HR = 1.06 (0.77–1.46), p trend = 0.53 Total sitting: HR = 1.28 (0.96–1.72), p trend = 0.23	Age, BMI, education, ethnicity, vigorous physical activity, alcohol intake, total caloric intake
Steindorf et al., 2006 [46] Nine European countries	Prospective cohort study	416,227 participants from EPIC, mostly aged 35–70 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 [44] Denmark	Prospective cohort study	54,422 participants from the Danish Diet, Cancer and Health cohort, aged 50–64 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

(continued)

Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Melanoma						
Patel et al., 2015 [24] USA	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.) categorized as 0- <3, 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), postmenopausal hormone use (women), endoscopy screening, BMI

Multiple myeloma						
Patel et al., 2015 [24] USA	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.) categorized as 0- $<$ 3, 3–5, or $\geq$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

(continued)

Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Non-Hodgkin lymphoma						
Patel et al., 2015 [24] USA After Teras et al., 2012 [110]	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.) categorized as 0- < 3, 3–5, or ≥ 6 h/day.	Females RR = 1.07 (0.86–1.35) Males 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, diabetes, menopausal status (women), postmenopausal hormone use (women), BMI
Ovarian cancer						
Hildebrand et al., 2015 [50] USA After Patel et al., 2015 [24]	Prospective cohort study	63, 972 women from the CPS-II Nutrition Cohort, aged 50–74 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.) categorized as 0- < 3, 3–5, or ≥ 6 h/day.	Total ovarian cancer RR = 1.44 (1.12–1.85), *p* trend = 0.006 Serous ovarian cancer	Age, education, BMI, smoking status, number of live births, use of OC pill, postmenopausal hormone use (time dependent)

Patel et al., 2006 [111]					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	
Xiao et al., 2013 [48] USA	Prospective cohort study	95,768 women from the NIH-AARP Diet and Health Study, aged 50–71 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, 3–4, 5–6, ≥7 h/day), and (ii) sitting during a typical 24 h period in past 12 months (<3, 3–4, 5–6, ≥7 h/day).	All women 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 for MVPA and BMI (data not shown)
Zhang et al., 2004 [49] 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 categorized (<4, 4–10, >10 h/day).	All women 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

(continued)

Table 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Pancreatic cancer						
Patel et al., 2015 [24] USA	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.) categorized as 0- <3, 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						
Patel et al., 2015 [24] USA	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.) categorized as 0- <3, 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 [51] USA	Prospective cohort study	170,481 men from the NIH-AARP Diet and Health Study, aged 51–72 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 and (ii) sitting during a typical 24 h period in past 12 months.	Total prostate cancer Watching TV ≥ 7 vs. <1 h/day HR = 1.03 (0.92–1.15) Total sitting duration ≥ 9 vs. <3 h/day HR = 0.98 (0.91–1.05) Advanced prostate cancer Watching TV ≥ 5 vs. <3 h/day	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 10.1 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
					HR = 0.93 (0.79–1.09) Total sitting duration ≥7 vs. < 3 h/day HR = 0.91 (0.77–1.08) Fatal prostate cancer Watching TV ≥ 5 vs. < 3 h/day HR = 1.07 (0.85–1.33) Total sitting duration ≥7 vs. < 3 h/day HR = 1.07 (0.84–1.35)	
Orsini et al., 2009 [52] Sweden	Prospective cohort study	Population-based sample of 45,887 Swedish men, aged 45–79 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) Localized 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

Stomach cancer						
Patel et al., 2015 [24] USA	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.) categorized as 0- <3, 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); relative risk (RR); incidence rate ratio (IRR); body mass index (BMI); oestrogen receptor positive (ER+); Oestrogen receptor negative (ER-); American Cancer Society (ACS); Cancer Prevention Study (CPS); physical activity (PA); moderate-to-vigorous physical activity (MVPA); waist-to-hip ratio (WHR); HRT (hormone replacement therapy); non-steroidal anti-inflammatory drug (NSAID)

Table 10.2 Studies investigating the associations of sedentary behaviour and cancer-related mortality

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
All-cancer mortality						
Keadle et al., 2015 [61] 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, 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 [57] USA	Prospective cohort study	63,308 participants from the Southern Community Cohort Study, aged 40–79 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, 5.76–8.50, 8.51–12.00, >12 h/d) 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 [59] USA	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 ($\leq$4, >4–8, >8–11, $\geq$11 h/d) 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, 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 [56] USA	Prospective cohort study	134,596 participants from the Multiethnic Cohort Study, aged 45–75 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, 5- < 10, $\geq$10 h/d) 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

(continued)

Table 10.2 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Wijndaele et al., 2011 [60] UK	Prospective cohort study	13,197 English adults from the EPIC-Norfolk cohort, aged 45–79. Mean follow-up 9.5 years.	570 cancer deaths identified through the Office of National Statistics (UK)	Hours per week spent watching TV and videos over past year.	For each 1 h/day increase in TV: HR = 1.04 (0.98–1.10)	Age, sex, education level, smoking status, alcohol consumption, hypertension medication, dyslipidaemia medication, baseline history of diabetes, family history of cardiovascular disease, family history of cancer, physical activity energy expenditure
Patel et al., 2010 [58] USA	Prospective cohort study	123,216 participants from the CPS-II Nutrition cohort. Mean follow-up 14 years.	6989 cancer deaths identified through the National Death Index.	Predefined categories for time spent sitting outside of work, on an average day (<3, 3–5, ≥ 6 h/day)	Women RR = 1.30 (1.16–1.46), p for trend <0.0001 Men RR = 1.04 (0.94–1.15), p for trend <0.29	Age, race, marital status, education, smoking status, BMI, alcohol consumption, total caloric intake, comorbidities score, total physical activity

Dunstan et al., 2010 [54] Australia	Prospective cohort study	8800 Australian adults (≥ 25 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, 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 [55] Canada	Prospective cohort study	17,013 Canadians aged 18–90 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", "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
Colorectal cancer-specific mortality						
Cao et al., 2015 [64] USA	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, 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, pre-diagnostic smoking status, regular aspirin use, alcohol intake, folate, calcium, read meat intake, and energy intake, leisure-time physical activity

(continued)

Table 10.2 (continued)

Authors, country	Design	Sample	Outcome	Measure of sedentary behaviour	Results (highest vs. lowest exposure categories)	Multivariate adjustment
Arem et al., 2015 [62] USA	Prospective cohort study	Participants from the NIH-AARP Diet and Health Study, diagnosed with invasive, non-metastatic CRC. For pre-diagnosis analyses: n = 3784, mean follow-up 12.8 years. Post-diagnosis analyses: n = 1630, mean follow-up 7.1 years.	745 CRC-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 h period in past 12 months. Categories collapsed to 0–2, 3–4, ≥5 h/day for pre-diagnosis TV and 0–2, >2–4, >4 h/day for post-diagnosis TV.	Pre-diagnosis ≥ 5 vs. 0–2 h/day HR = 1.21 (0.99–1.49), p trend = 0.068 Post-diagnosis HR = 1.73 (1.11–2.72), p trend = 0.079	Age (as underlying metric), sex, tumour site, tumour grade, tumour stage, surgery, radiation, chemotherapy, leisure-time physical activity, smoking status
Campbell et al., 2013 [63] USA	Prospective cohort study	Participants of the CPS-II Nutrition Cohort diagnosed with invasive, non-metastatic 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.) categorized as <3, 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

Liver cancer						
Ukawa et al., 2014 [65] 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 categorized into three groups (<, 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 gallbladder disease, previous blood transfusion

Abbreviations: hazard ratio (HR); odds ratio (OR); relative risk (RR); body mass index (BMI); Cancer Prevention Study (CPS); National Institutes of Health (NIH); American Association of Retired Persons (AARP); Womens' Health Initiative (WHI); moderate-vigorous physical activity (MVPA); high density lipoprotein-cholesterol (HDL-C); coronary heart disease (CHD); congestive heart failure (CHF); prostate-specific antigen (PSA); colorectal cancer (CRC); chronic obstructive pulmonary disease (COPD) heterogeneity among studies was examined using Cochrane's Q test and the I^2 statistic [21]. There was no evidence of publication bias suggested by funnel plot asymmetry or by statistical test (Egger's regression test) [22] for any of the cancer sites included in the meta-analyses.

We conducted sensitivity analyses, firstly excluding studies where ordinal scales were used to assess occupational sedentary behaviour (i.e. "sitting" versus "standing"), as these measures can introduce substantial misclassification bias [18]. We also performed the meta-analyses after excluding case-control studies, as this design may be subject to recall bias and reverse causality [2].

10.3 Sedentary Behaviour and Cancer Risk

10.3.1 Sedentary Behaviour and Breast Cancer Risk

To date, there have been 11 studies that have examined the association of sedentary behaviour with breast cancer risk (Table 10.1) [23–33]. Five of these studies involved prospective cohorts [24, 26, 27, 30, 31], four were case-control studies [23, 28, 29, 32], one was a nested case-control study [25], and one used a case-cohort design [33]. Three studies generated an estimate of total sitting time [25, 26, 33], Patel et al. assessed leisure-time sitting [24], two studies examined television viewing time [29, 30], two studies examined occupational sitting [28, 32], and the remaining studies used an ordinal scale of occupational exposure (we compared the "sitting" to the "standing" category) [23, 27, 31].

Our main meta-analysis found that sedentary behaviour was not associated with risk of breast cancer (RR = 1.06, 95% confidence interval (CI) = 0.98–1.14) (Fig. 10.1). Heterogeneity across the studies was not statistically significant ($I^2 = 41\%$, $p = 0.076$). The exclusion of studies using an ordinal scale for occupational sedentary behaviour did not change the risk estimate (RR = 1.05, 95% CI = 0.95–1.15), nor did the test of heterogeneity ($I^2 = 79\%$, $p = 0.010$). When we also excluded the case-control studies, the risk increased slightly (RR = 1.10, 95% CI = 1.02–1.18), and no heterogeneity was noted ($I^2 = 0\%$, $p = 0.818$). Based on this final model, we conclude that sedentary behaviour is significantly associated with a 10% increased risk of breast cancer in cohort studies.

10.3.2 Sedentary Behaviour and Colorectal Cancer Risk

Seven studies have examined the association of sedentary behaviour with colon or colorectal cancer risk [24, 34–39]. The main design features and results of these studies are summarized in Table 10.1. Five of these studies examined colon and rectal cancers together [24, 34–36, 38], whereas two studies only included colon cancers [37, 39]. Four studies were prospective cohort studies [24, 34, 35, 37] and

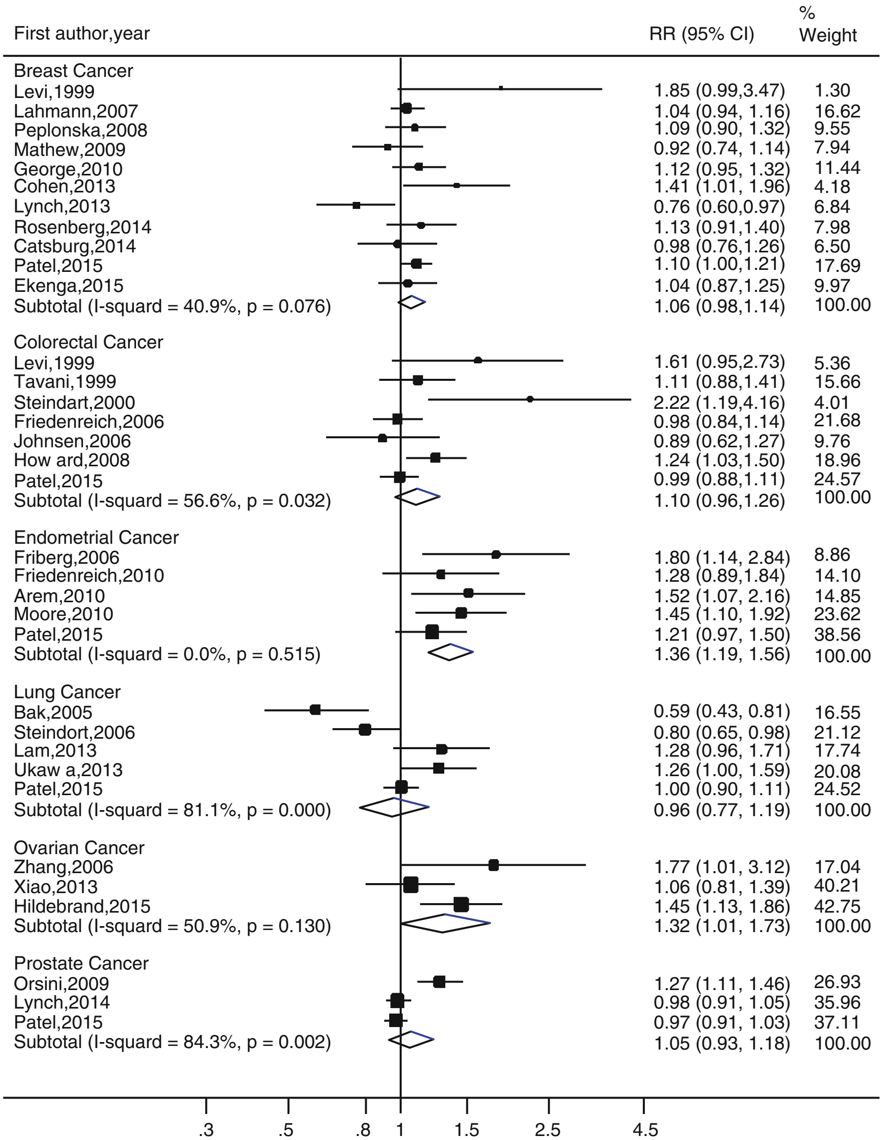

Fig. 10.1 Forest plot for main random-effects meta-analysis synthesizing the associations between sedentary behaviour and site-specific incident cancer. *RR* relative risk; *CI* confidence interval

three were case-control studies [36, 38, 39]. Howard et al. assessed total sitting time [35], Patel et al. reported on risks associated with sitting in leisure time [24], Steindorf et al. examined TV viewing time [36], and the remaining studies used an ordinal scale of occupational exposure (we compared the "sitting" to the "standing" category) [34, 37–39].

Comparing the highest category of sedentary behaviour to the lowest category (reference), we observed a non-significant 10% risk increase for colorectal cancer (RR = 1.10, 95% CI = 0.96–1.26). We observed significant heterogeneity across the colorectal cancer studies ($I^2 = 57\%$, $p = 0.032$) (Fig. 10.1). The exclusion of studies using an ordinal scale for occupational sedentary behaviour increased the pooled risk estimate to 1.22 (95% CI = 0.92–1.61), again with significant heterogeneity ($I^2 = 79\%$, $p = 0.010$). When we further restricted our inclusion to prospective cohort studies only, the risk increase was similar to our main meta-analysis (RR = 1.09, 95% CI = 0.88–1.36), and heterogeneity remained ($I^2 = 75\%$, $p = 0.046$).

10.3.3 Sedentary Behaviour and Endometrial Cancer Risk

Five studies have examined the association of sedentary behaviour with endometrial cancer risk (Table 10.1) [24, 40–43]. Three were prospective cohort studies [24, 41, 43], whereas two used a case-control design [40, 42]. Two studies assessed total sitting time [40, 43], Patel et al. reported on risks associated with sitting in leisure time [24], Friberg et al. examined TV viewing time [41], and Friedenreich et al. estimated lifetime occupational sitting [42].

Across the five studies, sedentary behaviour was associated with a 36% risk increase (RR = 1.36, 95% CI = 1.19–1.56). We observed no heterogeneity across the studies ($I^2 = 0\%$, $p = 0.515$) (Fig. 10.1). As none of the endometrial cancer studies had used an ordinal scale for occupational sedentary behaviour, the only sensitivity analysis we performed excluded the two case-control studies on this topic. No meaningful change in risk was noted (RR = 1.38, 95% CI = 1.13–1.68), and there was no heterogeneity between studies ($I^2 = 28\%$, $p = 0.252$).

10.3.4 Sedentary Behaviour and Lung Cancer Risk

Five prospective cohort studies have examined the association of sedentary behaviour with lung cancer to date (Table 10.1) [24, 44–47]. One study examined risk associated with leisure-time sitting [24], two studies examined TV viewing time [45, 47], and two studies used an ordinal scale of occupational exposure [44, 46].

Overall, sedentary behaviour was not associated with lung cancer risk (RR = 0.96, 95% CI = 0.77–1.19). Heterogeneity across the studies was statistically significant ($I^2 = 81\%$, $p < 0.001$) (Fig. 10.1). The exclusion of studies using an ordinal scale for occupational sedentary behaviour changed the risk estimate considerably, suggesting an increase in risk of 13% (RR = 1.13, 95% CI = 0.94–1.36). After excluding the studies using the ordinal scale of exposure, there was no significant heterogeneity ($I^2 = 59\%$, $p = 0.085$).

10.3.5 Sedentary Behaviour and Ovarian Cancer Risk

Sedentary behaviour and ovarian cancer risk has been investigated by three studies (Table 10.1) [48–50]. The reports by Hildebrand et al. [50] and Xiao et al. [48] were prospective cohort studies, whereas Zhang et al. used a case-control design [49]. Each of these studies assessed a different type of sedentary behaviour: total sitting time [49], sitting during leisure time [50], and TV viewing time [48].

Our meta-analysis showed sedentary behaviour to be associated with a 32% risk increase (RR = 1.32, 95% CI = 1.01–1.73). We observed no significant heterogeneity across the studies ($I^2 = 51\%, p = 0.130$) (Fig. 10.1). After excluding the case-control study from the meta-analysis, the result was attenuated (RR = 1.25, 95% CI = 0.92–1.69; $I^2 = 64\%, p = 0.095$).

10.3.6 Sedentary Behaviour and Prostate Cancer Risk

Three prospective cohort studies have examined the association of sedentary behaviour with prostate cancer risk (Table 10.1) [24, 51, 52]. One study assessed total sitting time [51], one reported on risks associated with sitting in leisure time [24], and one used an ordinal scale of occupational exposure [52].

Across these three studies, sedentary behaviour was associated with no risk increase (RR = 1.05, 95% CI = 0.93–1.18), although we did observe significant heterogeneity ($I^2 = 84\%, p = 0.002$) (Fig. 10.1). Excluding the study that used an ordinal scale for occupational sedentary behaviour removed the heterogeneity from the pooled risk ($I^2 = 0\%, p = 0.832$), which was null (RR = 0.97, 95% CI = 0.93–1.02).

10.3.7 Sedentary Behaviour and Risk of Other Cancers

Two prospective cohort studies have examined the association of sedentary behaviour with kidney cancer risk [24, 53]. Patel et al. found that leisure-time sitting was not associated with risk amongst women (RR = 0.97, 95% CI = 0.62–1.51), but that there was a small, suggested risk increase amongst men (RR = 1.10, 95% CI = 0.80–1.48) [24]. George et al. examined the risk associated with total sitting time in both women and men and similarly found little suggestion of an increased risk (RR = 1.08, 0.92–1.27) [53].

The association between sedentary behaviour and a number of less-common cancers (bladder, oesophageal, gallbladder, head and neck, liver and pancreatic cancer, melanoma, multiple myeloma, and non-Hodgkin lymphoma) was examined within the American Cancer Society's Cancer Prevention Study II Nutrition Cohort [24]. Patel et al. found that, amongst women, leisure-time sitting was associated with: a significant risk increase for multiple myeloma (RR = 1.65, 95% CI = 1.07–2.54); a non-significant risk increase for bladder cancer (RR = 1.17, 95% CI = 0.80–1.70), oesophageal cancer (RR = 1.13, 95% CI = 0.47–2.72), gallbladder cancer (RR = 1.43, 95% CI = 0.65–3.14), and head and neck cancer (RR = 1.49, 95% CI = 0.86–2.61); a non-significant risk decrease for liver cancer (RR = 0.73, 95% CI = 0.35–1.53); and no association with melanoma (RR = 0.99, 95% CI = 0.79–1.25), non-Hodgkin lymphoma (RR = 1.07, 95% CI = 0.86–1.35), pancreatic cancer (RR = 1.02, 95% CI = 0.73–1.41), or stomach cancer (RR = 1.06, 95% CI = 0.55–2.03) [24]. For men, non-significant risk increases were noted for gallbladder (RR = 2.11, 95% CI = 0.87–5.09), head and neck (RR = 1.22, 95% CI = 0.88–1.69), and pancreatic cancers (RR = 1.14, 95% CI = 0.87–1.49); a non-significant risk decrease was observed for liver cancer (RR = 0.83, 95% CI = 0.54–1.28); and there was no association between leisure-time sitting and bladder cancer (RR = 1.01, 95% CI = 0.86–1.19), oesophageal cancer (RR = 1.04, 95% CI = 0.74–1.46), melanoma (RR = 1.05, 95% CI = 0.88–1.24), multiple myeloma (RR = 1.00, 95% CI = 0.68–1.45), non-Hodgkin lymphoma (RR = 1.04, 95% CI = 0.86–1.25), or stomach cancer (RR = 1.05, 95% CI = 0.71–1.55). However, the findings presented for these cancer sites are likely underpowered, particularly oesophageal, gallbladder, head and neck, liver, and stomach cancers, which had less than ten cases within some or all categories of sitting time.

10.4 Sedentary Behaviour and Cancer Mortality

10.4.1 Sedentary Behaviour and All-Cancer Mortality

Eight prospective cohort studies have examined the association of sedentary behaviour with all-cancer mortality [54–61]. The main design features and results of these studies are summarized in Table 10.2. Four studies examined risk associated with total sitting time [55–57, 59], one assessed sitting in leisure time [58], and three examined TV viewing time [54, 60, 61].

Comparing the highest category of sedentary behaviour to the lowest category (reference), we observed a 12% risk increase for all-cancer mortality (RR = 1.12, 95% CI = 1.03–1.22). We observed significant heterogeneity across these studies (I^2 = 64%, p = 0.011) (Fig. 10.2). There was no evidence of publication bias suggested by funnel plot asymmetry (data not shown) or by statistical test (Egger's regression asymmetry test, p = 0.61).

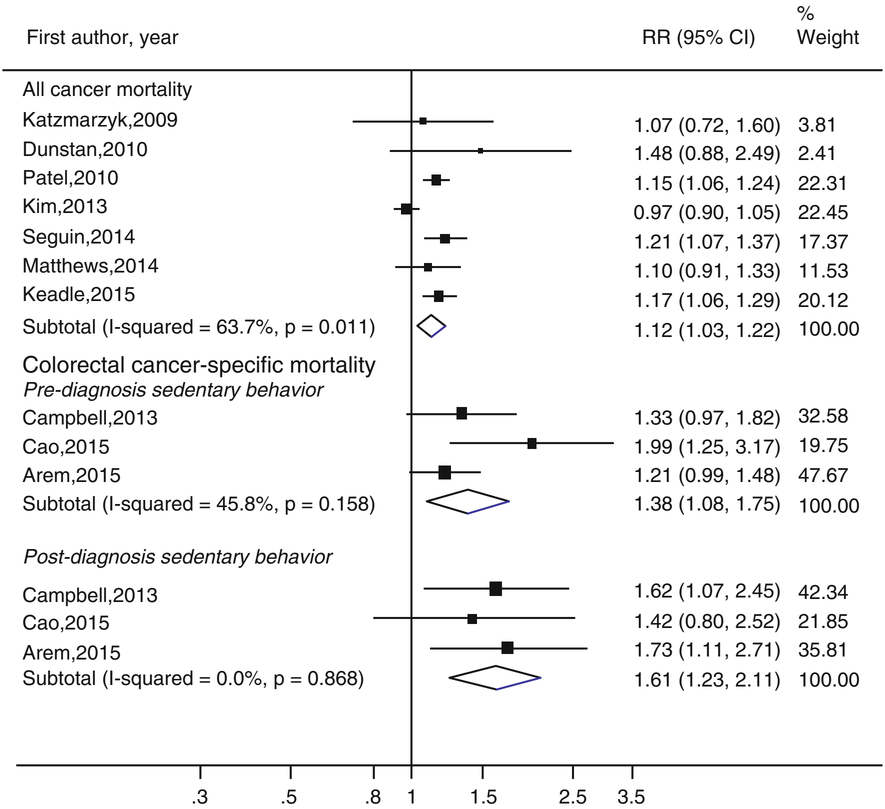

Fig. 10.2 Forest plot for main random-effects meta-analysis synthesizing the associations between sedentary behaviour and cancer-related mortality. *RR* relative risk; *CI* confidence interval

10.4.2 Sedentary Behaviour and Colorectal Cancer-Specific Mortality

Three prospective cohort studies have examined the associations of sedentary behaviour (exposure assessed pre- and post-diagnosis) with colorectal cancer-specific mortality [62–64]. The studies by Cao et al. [64] and Arem et al. [62] examined risk associated with TV viewing time, whereas Campbell et al. assessed sitting during leisure time [63]. Within these cohort studies, multiple exposure assessments were taken, so that baseline questionnaires (risk-factor questionnaire for the NIH-AARP Diet and Health Study that was administered approximately six months following the baseline questionnaire) 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.

In pooled analyses, sedentary behaviour performed prior to a colorectal cancer diagnosis was associated with a 38% risk increase for colorectal cancer-specific mortality (RR = 1.38, 95% CI = 1.08–1.76). We did not observe significant heterogeneity across these studies ($I^2 = 46\%$, $p = 0.158$). The association of post-diagnosis sedentary behaviour with colorectal cancer-specific mortality was even stronger (RR = 1.61, 95% CI = 1.23–2.11; $I^2 = 0\%$, $p = 0.867$) (Fig. 10.2). Minimal funnel plot asymmetry was observed on visual inspection, and there was some evidence of small study effects suggested by Egger's regression asymmetry test ($p = 0.04$).

10.4.3 Sedentary Behaviour and Liver Cancer-Specific Mortality

One study has considered the association of pre-diagnosis TV viewing time with liver cancer-specific mortality. Ukawa et al. identified 267 deaths from liver cancer within the Japanese Collaborative Cohort Study. Participants watching four or more hours of TV a day had a modest, non-significant risk increase for liver cancer death than participants who watched less than 2 h per day (HR = 1.20, 95% CI = 0.82–1.77, p trend = 0.27) [65].

10.5 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 [66]. In this section, for each proposed biologic pathway, we first outline how it is related to carcinogenesis, then summarize what is known about its association with sedentary behaviour. Many of these proposed mechanisms are interrelated, and it is hypothesized that their relative contributions vary 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.

10.5.1 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 [67, 68]. Contemporary evidence suggests that adiposity increases the risk of cancers of the colon and rectum, breast (postmenopausal women only), ovaries, endometrium, kidneys, oesophagus, pancreas, and gallbladder (women only) [10].

Sedentary behaviour displaces time spent in physical activities that expend higher amounts of energy [69]. There are significant differences in the metabolic/energy cost of sitting and standing: Júdice et al. recently demonstrated that both $\dot{V}O_2$ and energy expenditure were significantly higher when standing than when sitting, independent of sex and body mass [70]. Postural transitions and unstructured movement throughout the day differ sufficiently between obese and lean individuals to explain differences in body mass [71, 72]. Despite this context, there is limited epidemiologic evidence that an association exists between sedentary behaviour and weight gain or risk of obesity among adults [69–71]. For further details, please refer to Chap. 6.

A number of studies included in this chapter presented risk estimates for the association between sedentary behaviour and cancer without and with adjustment for BMI. As noted by Schmid and Leitzmann, the associations across these studies were not consistently attenuated by additional adjustment for body mass index (BMI) [1]. 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 [73, 74]. 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 [1]. 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 [75, 76].

10.5.2 Molecular Pathways

Sex Hormones

Exposure to circulating endogenous sex hormones may increase the risk of some cancers, particularly breast, endometrial, ovarian, and prostate cancers [76, 77]. Animal and in vivo studies have demonstrated that oestrogens have mitogenic and mutagenic effects [76]. Higher circulating levels of oestrogen-related hormones are linked most strongly to breast and endometrial cancer risk [76]. Sex hormone binding globulin (SHBG) may also affect cancer risk by binding to oestrogens and androgens, rendering them biologically inactive [67].

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 aromatization (the conversion of adrenal androgens to oestrone, which occurs within peripheral adipose tissue) [78, 79] and through the production of adipokines (which influence oestrogen biosynthesis) [80]. If sedentary behaviour increases blood insulin (see next section), this would decrease hepatic synthesis of SHBG, in turn increasing bioavailability of endogenous sex hormones [12].

Dallal et al. recently 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 oestrone and oestradiol. 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 (oestrone, oestradiol) 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 [81]. An earlier, cross-sectional study of 565 postmenopausal women found no associations between self-reported sedentary behaviour and various oestrogens, androgens, or SHBG [82].

Metabolic Dysfunction

Elevated blood insulin levels increase growth promoting signalling [76] and enhance activation of the insulin-like growth factor 1 (IGF-1) system, which is involved in cell differentiation, proliferation, and apoptosis [83]. High levels of insulin levels also suppress hepatic synthesis of SHBG [12]. Hyperglycaemia may promote carcinogenesis by providing an amiable environment for tumour growth [84]. Associations between insulin and glucose levels with colorectal, postmenopausal breast, pancreatic, and endometrial cancers have been demonstrated in epidemiologic studies [66].

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 standardized glucose infusion [83]. 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 [85]. The muscular inactivity that characterizes sedentary behaviour may reduce glucose uptake through blunted translocation of glucose transporter type 4 (GLUT-4) to the skeletal muscle surface [86, 87]. The acute metabolic response to sedentary behaviour suggested by these experimental studies supports the epidemiologic findings that link sitting time with type

2 diabetes [86], 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 [87].

Inflammation, Including Adipokines and Myokines

Inflammation is a risk factor for most types of cancer [67, 77]. Inflammation can stimulate cell proliferation, micro-environmental changes, and oxidative stress, which can deregulate normal cell growth and promote progression and malignant conversion [88]. Adipose tissue secretes multiple biologically active polypeptides (adipokines) [89, 90]. Adiponectin is the only known anti-inflammatory adipokine; others, including leptin, adipsin, tumour necrosis factor-α (TNF-α), and interleukin-6 (IL-6), are pro-inflammatory. Adipokines may play a role in the development of insulin resistance. Leptin suppresses insulin signalling (resulting in insulin resistance), whereas adiponectin enhances insulin sensitivity through activation of adenosine monophosphate (AMP) protein kinase [89]. Adipokines might also increase cancer risk by affecting oestrogen biosynthesis and activity [80].

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 positively associated with IL-6, leptin, and leptin: adiponectin ratio in multivariate models, but after additionally adjusting for moderate-to-vigorous physical activity only the association with IL-6 remained statistically significant [91]. 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 (NHANES) have shown significant positive associations between accelerometer-assessed sedentary time and CRP in postmenopausal women [92] and in the broader adult population [93]. However, prospective studies examining television viewing time and CRP have found no association between the two [94, 95].

Skeletal muscle is an active endocrine organ that expresses and releases cytokines or other peptides known collectively as myokines [75]. 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 pro-inflammatory adipokines [75]. When seated, the large, postural muscles used to keep the body upright are not fully activated [69, 90]. Thus, an altered myokine response may underlie the association between sedentary behaviour and cancer.

10.5.3 Immune Function

The immune system plays numerous roles to counteract the development of cancer, including eliminating carcinogens and tumour cells, and repairing DNA damage [77]. A diminished immune response is a recognized predictor of cancer risk [96], and immunocompromised individuals have long been known to be more susceptible to oncogenic viruses. Engel et al. examined the rates of cancer amongst 175,732 organ transplant recipients and concluded that these individuals (taking immunosuppressive drugs to prevent organ rejection) had a two-fold increased risk for diverse infection-related and unrelated cancers [97].

The only study to date to examine associations between sedentary behaviour and markers of immune function has shown no link [98]. Loprinzi et al. demonstrated that there was no association between accelerometer-assessed sedentary time with white blood cell or neutrophil counts amongst adults with a mobility disability [98].

10.6 Interpretation of the Evidence and Causality

10.6.1 Interpretation of the Evidence

Sedentary behaviour and cancer is 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 December 2015) differ somewhat from the findings presented by Schmid and Leitzmann [1] and by Shen et al. [2] Our meta-analysis suggests that sedentary behaviour increases the risk of endometrial cancer by 36% and ovarian cancer by 32%. We cannot rule out an association between sedentary behaviour and breast, colorectal, or lung cancer risk, based on the results of our sensitivity analyses. Schmid and Leitzmann drew somewhat different conclusions, acknowledging a significant risk increase for colorectal [1], endometrial, and lung cancer, while Shen et al. reported that sedentary behaviour increased the risks of breast, colorectal, endometrial, and lung cancer [2]. The primary reason for the different conclusions drawn by our meta-analysis is the inclusion of new publications, whose findings differed from previously published studies. In particular, the updated analysis from the American Cancer Society's Cancer Prevention Study II Nutrition Cohort presented null findings for colorectal and lung cancer, which changed the conclusions drawn from previous meta-analyses due to the high proportion of weight contributed by this study [24]. The variation in findings between the meta-analyses conducted to date may also be due, in part, to differences in inclusion criteria or prioritization of exposure type.

Across the cancer sites we identified as being associated with (or possibly associated with) sedentary behaviour, a modest 10% to 35% risk increase was observed for the highest versus lowest categories of sitting time. We recognize, 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. 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. The cost of accelerometers, complexity of data processing and analysis, problems with compliance, and burden on participants limit the application of objective monitoring across large-scale cohort studies. It is, however, 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 [99, 100]. Cohort studies that incorporate such validation sub-studies may provide improved estimates of the association between sedentary behaviour and cancer risk.

We have presented the first comprehensive meta-analysis of studies examining the association between sedentary behaviour and cancer-related mortality. Our results suggest that there is a modest, but statistically significant, 12% 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- (38%) and post-diagnosis sitting time (61%). However, these estimates (particularly for post-diagnosis sedentary behaviour) may be biased by only healthy colorectal cancer survivors remaining in the cohort studies. Further studies of site-specific mortality are warranted.

10.6.2 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 randomized, controlled trial (RCT). In practice, RCTs are limited by a number of methodologic 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 [101]. 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 [102]. 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 [102, 103]. 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. For example, consider the effect of sedentary behaviour on colon cancer risk. Sedentary behaviour might be high because an individual is obese (BMI > 30 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 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 [104, 105]. 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.

There is also a need within sedentary behaviour and cancer research for clearer conceptual approaches to analysis. An important element of this is to formalize assumptions made in modelling. Directed acyclic graphs (DAGs) are useful tools for helping researchers clarify their research questions and examine potential confounding pathways [106]. 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 conceptualize 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.

10.7 Summary

Based on the evidence available, we suggest that sedentary behaviour is associated with increased risks of endometrial (36%) and ovarian cancers (32%). Breast, colorectal, and lung cancer risk may also be increased by sitting time, but further evidence is needed to clarify these associations. There is evidence of a small risk increase for all-cancer mortality (13%) and a significant risk increase for colorectal cancer-specific mortality (38% for pre-diagnosis sitting time; 61% 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 epidemiologic data, provide insights into gene–environment interactions, and potentially inform precision public health initiatives.

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Chapter 11
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 suggests 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 effects of sedentary behaviours on mental health. Sedentary leisure pursuits, such as viewing television, films, playing video games, etc., are generally perceived to be enjoyable and relaxing. It is, therefore, somewhat of a paradox that emerging data suggest sedentary behaviour may be a risk factor for depression independently from physical activity. In this overview, we examine epidemiologic 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, and data should be interpreted in light of several limitations including the use of poor exposure measures, potential for residual confounding, and lack of gold standard experimental data.

11.1 Introduction

Mental illness is now recognized 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

M. Hamer (✉)
School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, UK
e-mail: m.hamer@lboro.ac.uk

L. Smith
The Cambridge Centre for Sport and Exercise Sciences, Department of Life Sciences, Anglia Ruskin University, Cambridge, UK
e-mail: lee.smith@anglia.ac.uk

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and will rank first in high-income countries by 2030 [1]. Prospective studies have demonstrated that clinical and subclinical 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 limited understanding about 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 effects of sedentary behaviours on mental health. Sedentary leisure pursuits, such as viewing television, 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. In this chapter, we will present an overview of the evidence linking sedentary behaviour with depressive symptoms and discuss the plausibility of the findings.

11.2 Epidemiologic Evidence on Sedentary Behaviour and Depression

11.2.1 Evidence in Adults

The epidemiologic 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 ($n = 13$ cross-sectional studies and $n = 11$ longitudinal 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 by 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 have demonstrated an association of self-reported TV (television)/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 (self-reported) 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. 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 [17, 18]. Thus, associations between sedentary time and depression are likely to be bidirectional.

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. Very few studies have examined associations between objectively assessed sedentary time and mental health and those that have revealed inconsistent findings. Data from the National Health and Nutrition Examinations (NHANES) in 2862 participants showed null associations between objectively assessed sedentary time and depressive symptoms in the main sample, although in sensitivity analyses a relationship between sedentary time and higher risk of depressive symptoms was found in a subsample of overweight/obese adults [19]. In our study of 1947 English adults from the Health Survey for England, we demonstrated an association between higher sedentary time and depressive symptoms whether using objective or self-reported measures of sedentary time [20]. 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 [21, 22]. Evidence from randomized controlled trials also suggests more favourable effects of undertaking lighter to moderate intensity exercise on positive mood/fatigue symptoms as opposed to vigorous exercise [23, 24]. 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 are 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. For further details regarding methods of sedentary behaviour measurement, please refer to Chap. 2.

11.2.2 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 [25], 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 [26]. 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 degree of heterogeneity possibly reflects reporting biases in addition to the significant limitations discussed earlier. There are little longitudinal data with extended follow-up to explore how childhood sedentary behaviours relate to mental health in adulthood. In a recently published study using data from the 1970 British Cohort study, higher screen time at age 16 was associated with depressive symptoms at age 42 although the association was attenuated after adjustment for covariates [27]. 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. 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 bidirectional 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 [28].

Taken together, the epidemiologic evidence largely suggests sedentary behaviour is an emerging risk factor for depressive symptoms. These data should be interpreted in light of several limitations including the use of poor exposure measures, potential for residual confounding, and lack of gold standard experimental data.

11.3 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 hypothesized mechanisms largely drawn from the literature in exercise and psychobiology.

11.3.1 The Immune System

There has been much interest in the association between depressive symptoms and inflammatory risk markers [29]. Several studies have reported elevated concentrations of various inflammatory markers in differing populations reporting depressive symptoms, including the medically healthy [30, 31], elderly [32–34], and patients with acute coronary symptoms or existing cardiovascular disease risk factors [35, 36]. 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 [37]. 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 are 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) [38]. 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 [39]. Unlike IL-6 release during acute mental stress, which appears to be dependent on activation of the NFκB[1] signalling pathway [40], intramuscular IL-6 expression is

[1]NFκB: nuclear factor kappa B

regulated by a network of signalling cascades that are likely to involve the CA^{2+}/NFAT[2] and glycogen/p38 MAPK[3] 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 [41]. In addition, we recently 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 [42]. 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 hypothesize 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 [43].

11.3.2 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 [44]. Further research has focused on the hippocampus, where exercise-induced neurogenesis and growth factor expression have been proposed as potential mediators [45]. 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 [46], suggesting that other compensatory mechanisms might be at play. The BDNF

[2]NFAT: nuclear factor of activated T-cells

[3]MAPK: mitogen-activated protein kinase

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 [47]; thus, pro-inflammatory actions of excess sedentary behaviour may again be important.

11.3.3 Hypothalamic Pituitary Adrenal (HPA) Axis

The interaction of the immune system with the HPA axis and 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 manifest by a reduction in this hormone's capacity to suppress the production of inflammatory cytokines [48]. 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 [49]. HPA axis dysregulation and cortisol hyper-secretion have been implicated in mental health, and some studies have shown lower stress-induced cortisol responses in physically trained individuals compared to the untrained [50, 51], 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 [52]. The effects of sedentary behaviour on HPA function have not yet been investigated and further work is required in this area.

11.3.4 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 [53].

In summary, there is mounting evidence to suggest 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 [42, 54], thus the underlying mechanisms might partly act through these pathways.

11.4 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 [55]. There are, however, limited experimental data on 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 hypothesized 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 [56, 57]. 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 [58]. Healthy men that 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 [59]. However, another study reported that reduced parasympathetic nervous activity as measured by heart rate variability was predictive of negative mood following exercise withdrawal [60].

In a further study, we investigated the impact of exercise withdrawal on psychophysiological responses to mental stress. Although 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 sensitization so that the response to a later cytokine or stressor stimulus is enhanced, resulting in an increased vulnerability to depressed mood [61]. We experimentally manipulated sedentary time by asking a group of habitual exercisers to replace their regular exercise training with sedentary activities for two weeks [62]. The adherence to the intervention was mixed, as indicated by objective accelerometry, 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 (Fig. 11.1). 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 mental stress were higher in the intervention phase compared to 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.

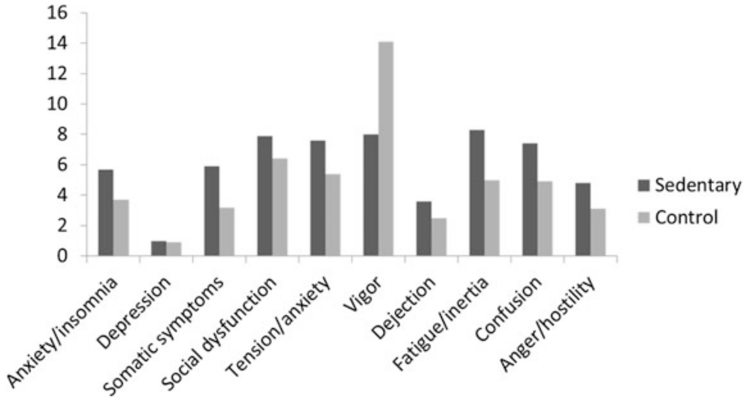

Fig. 11.1 The effect of a two-week sedentary intervention on mood symptoms and psychological distress measured using Profile of Mood States and General Health Questionnaire, respectively [62]

11.5 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 television, 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 largely come from observational population studies and experimental work is lacking. Thus, the current evidence should be interpreted in light of several limitations including the use of poor exposure measures, 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 plausible mechanisms underlying the links between sedentary behaviour and adverse mental health.

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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 summarize and explain the literature on sedentary behaviour and psychosocial health across the life course, with a focus on the psychosocial domains: bullying/victimization, 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.

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

L. Smith (✉)
The Cambridge Centre for Sport and Exercise Sciences, Department of Life Sciences, Anglia Ruskin University, Cambridge, UK
e-mail: lee.smith@anglia.ac.uk

M. Hamer
School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, UK
e-mail: m.hamer@lboro.ac.uk

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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 new born 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 summarized 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 victimization 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.

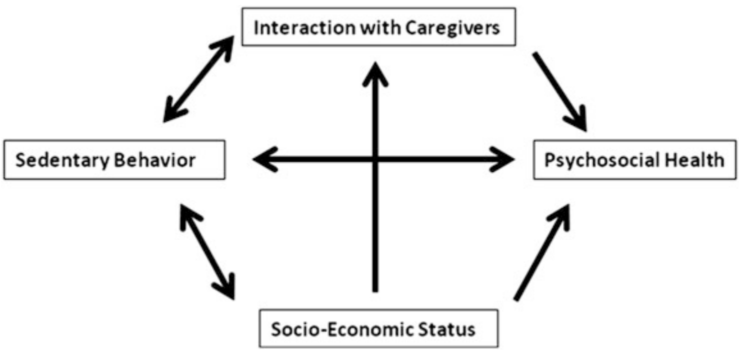

Fig. 12.1 The association between young children's and young people's sedentary behaviour and psychosocial health via socioeconomic status and interaction with caregivers

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 judgment 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 to 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 ($r = -0.38, p = 0.05$) and global self-esteem ($r = 0.36$, $p = 0.05$) [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, victimization, 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 ($\geq$17 years) [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 well-being [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/victimization, 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.

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Chapter 13
Sedentary Behaviour and Ageing

Dawn A. Skelton, Juliet A. Harvey, and Calum F. Leask

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 reduced function, mental health, and longevity. Only a small number of interventions to reduce sedentary behaviour in older adults have been published, but the short-term benefits of such interventions appear to have positive outcomes to function. Clearly more work in this vulnerable population, especially in those transitioning to frailty, is warranted.

13.1 Prevalence of Sedentary Behaviour in Older Adults

Globally, almost 60% of older adults report sitting for more than 4 h of their waking day [1]. Both screen time and television (TV) time are used as proxy measurements of sedentary behaviour. When screen time is reported, 53% sit in front of a screen for over 4 h daily. As with younger adults, self-report underestimates the prevalence of sedentary behaviour. When objectively measured, 67% of the older population are sedentary for more than 8.5 h of their waking day [2]. When objective data from a number of studies are weighted and pooled, a mean of 9.4 h (ranging from 8.5 to 10.7 h) per day is measured [3]. From the available studies, the UK and USA record the highest levels of sedentary behaviour at approximately 11 h per day [4–7]. For more information on the prevalence and correlates of sedentary behaviour in older adults, please refer to Sects. 4.2.5 and 4.3.2.

In older adults, there is little difference in sedentary behaviour trends between genders [8], although a recent study suggests women are more likely to accumulate

D.A. Skelton (✉) • J.A. Harvey • C.F. Leask
School of Health and Life Sciences, Glasgow Caledonian University, Glasgow G4 0BA, UK
e-mail: dawn.skelton@gcu.ac.uk; juliet.harvey@gcu.ac.uk; calum.leask@gcu.ac.uk

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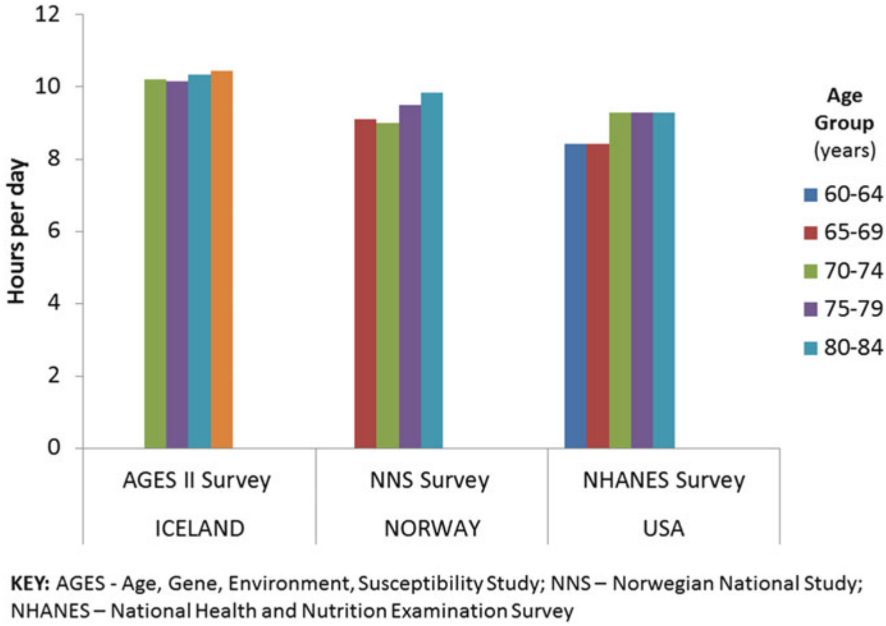

Fig. 13.1 Sedentary behaviour measured by accelerometry (>60 year by age group), adapted from Harvey et al. 2015 [3]

their sedentary time in shorter bouts and therefore more likely to break up prolonged periods of sitting than men [9]. In twin studies, there is a suggestion, however, that environment is more important in the gender aetiology of sitting [10]. In a Finnish cohort of older individuals, women sat less than men and older age was associated with less sitting time [10]. There is a trend of increased sedentary behaviour with increasing age, with both objectively measured (Fig. 13.1) and via self-reported (Fig. 13.2) sedentary time [11–19]. 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 [11, 12, 14]. When compared to younger adults (populations >20 years), older adults have, and report to have, higher levels of sedentary time across all domains, with the exception of computer time and screen time [11, 13, 14, 16, 18, 20–25].

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 [26]. Adverse socioeconomic circumstance and lower education have been related to increased screen-based activities [14].

TV viewing is also associated with other unhealthy habits such as poor nutrition or the influence of advertising to encourage these behaviours, therefore may also be a confounding factor with negative health effects of sitting [2].

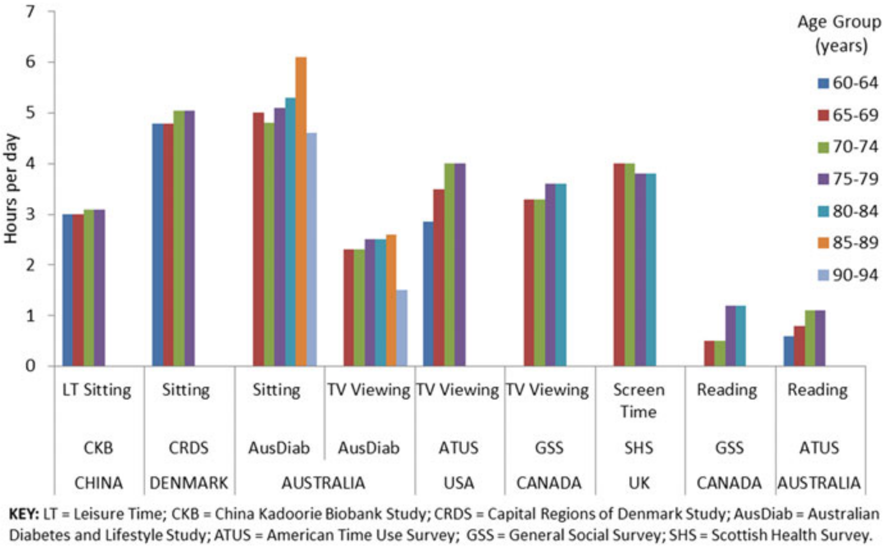

Fig. 13.2 Sedentary behaviour by various methods of self-report (>60 years by age group), adapted from Harvey et al. 2015 [3]

13.1.1 Sedentary Behaviour in Residential Settings

Sedentary behaviour is particularly prevalent in those older adults living in residential care settings. Some of this inactivity 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 [27]. 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 [28]. Residents spend a median of 12.4 h sitting/lying (with 73% of this accumulated in unbroken bouts of $\geq$30 min), only 1.9 h standing, and 214 min stepping in their waking day [29]. Potential barriers for implementing interventions to increase physical activity or reduce sedentary behaviour in these settings have been reviewed [30] and include resident health status, lack of space for physical activity, and staffing and funding constraints.

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 [31, 32]. 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) [33] (see also Sects. 2.1.2 and 26.2). 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 [34]. Leask et al. [35] 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.

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 [35]. The main non-screen-based sedentary activities include reading (22.9%), eating (7.4%), and driving (7.4%) (Fig. 13.3). Although a lot of time is spent reading, this has been shown to be a cognitively stimulating activity in ageing [2] (see also Chap. 12) and therefore may not be a sedentary context which future research may wish to target. Of screen-based periods, television viewing, computer/laptop usage, and using small devices comprise of 84%, 9.6%, and 5.9% of time, respectively.

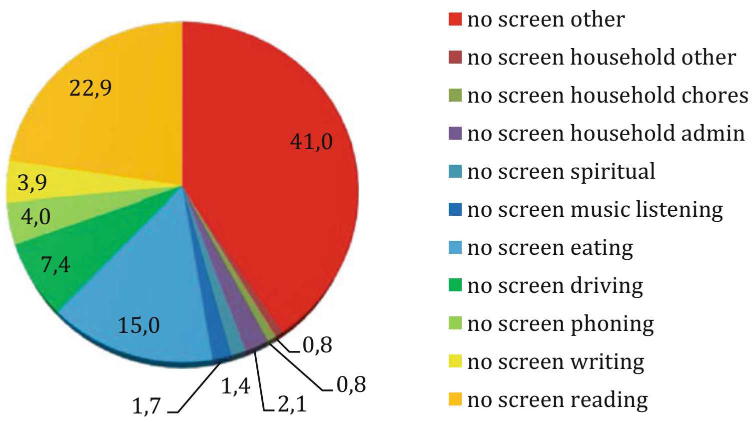

Fig. 13.3 Distribution of non-screen-based sedentary time (% of day) in older adults (≥65 years), adapted from Leask et al. 2015 [35]

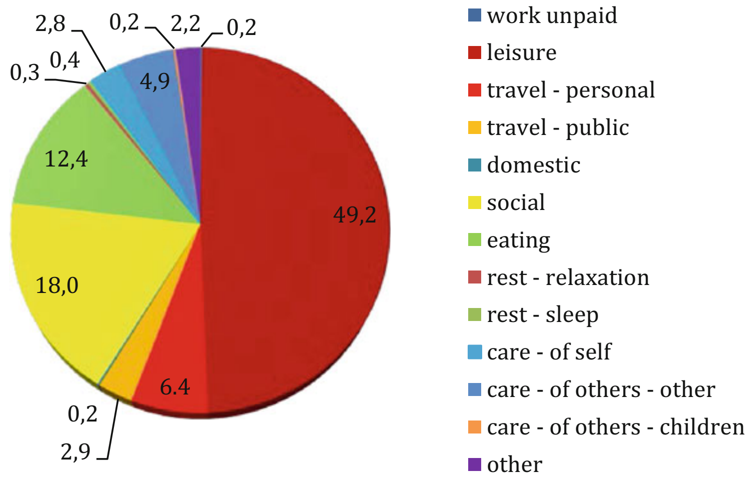

Fig. 13.4 Distribution of the purpose of sedentary time (% of day) in older adults (≥65 years), adapted from Leask et al. 2015 [35]

13.2.2 Why Older Adults Are Sedentary?

The purpose for older adults' sedentary time, as viewed on the time-lapse camera, were predominantly leisure (49.2%), social (18%), and eating (12.4%) (Fig. 13.4) [35]. 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) [35].

Although social sedentary periods account for a large percentage of time, being socially isolated, especially in older age, may influence depression [36], suggesting that social interactions may enhance mental health and as such should not be the target for interventions to reduce sedentary time.

13.2.3 With Whom Are Older Adults Sedentary?

Data show 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%). There is an association between loneliness and sedentary time [37], whilst loneliness in older adults is also predictive of reduced cognition [38] and all-cause mortality [39]. Therefore, these periods where older adults are alone may be important for future interventions to target.

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]. They were presented with a personal storyboard with objective records (1 day activity monitor and time-lapse camera images) of their daily behaviour. 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 socializing (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.

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 [42, 43] (see also Chap. 14). Katzmarzyk and Lee [44] 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 h daily and a gain of 1.38 years by reducing TV viewing to less than 2 h. Indeed, long periods of sitting are associated with a larger waist-to-hip ratio and therefore an increased risk of metabolic syndrome and stroke [45]. 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 h sedentary bout increment [46]. Longitudinal 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) [2, 42, 43, 45, 47, 48]. 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 [49].

Finally, frailty is strongly associated with sedentary behaviour [50, 51], and sedentary behaviour (>7 h per day measured on self-report) can be a potential marker in the screening of frailty in community dwelling older adults [52].

13.3.2 Quality of Life and Function

Older adults who report sitting less tend to age more successfully, report better quality of life, have less dizziness, and have better balance [26, 53, 54]. Intriguingly, one study has shown no relationship between sedentary behaviour and postural stability (measured in a composite equilibrium score) or lower body strength [55]. But another more recent study has shown that 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 [56]. 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 [51]. Even in young old age (60–64 years), time spent sedentary is associated with lower grip strength and lower timed up and go speed [57]. Self-reported TV time was positively related to 400 m walk time [56], and prolonged TV viewing has been related to reduced grip strength, in contrast to use of the internet, which showed a positive relationship [58]. Fallers spend more time sedentary than non-fallers (22 min per day extra in men) and if they also experience fear of falling this increases to an additional 45 min of sedentary time per day [59]. Sedentary behaviour has also been associated with diminished physical function over time [60, 61]. 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 [62]. 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 [62].

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 [63]. 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 min over a 10-week intervention period [64, 65].

13.3.3 Mental Health and Cognition

Sitting, TV time, and screen time have all been associated with negative mental health outcomes and reduced levels of cognition [26, 58, 66]. Sedentary pastimes have also been associated with executive dysfunction [67]. Interestingly, fallers are known to have executive dysfunction, and fear of falling is associated with high sedentary time in older adults [56]. High TV viewing has been related to lower psychological well-being and depression [8], mood disorder, and sense of belonging to community [68], and long periods of sitting are associated with depression and social isolation [45]. In order to see if the link between sedentary behaviour and depression was related to underlying inflammatory processes, Hamer et al. [69] looked at C-reactive protein (CRP) and self-reported TV viewing time. Those older adults who watched more TV had higher CRP and higher levels of depression, but the authors concluded that smoking and alcohol had more of an effect than CRP or body mass index (BMI). 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 h compared with sitting under 4 h [70].

Not all sitting is bad, with certain sedentary tasks such as computer use, playing games, and completing craft projects being positively associated with cognition [45, 58, 66]. Although Kesse-Guyot et al. (2012) did not find an association with reading and cognition, this is likely due to reading time generally being a short duration in the day, making it difficult to affect outcomes. In a 15-year prospective study, the risk of dementia was examined against sedentary behaviour and no relationship was observed [71]. 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 [72].

A large study, looking at accelerometer data and cognitive function, found that declining cognition over a 12-month period was not associated with total sedentary time but was associated with moderate-to-vigorous physical activity [73].

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 [74]. 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 [74]. For further details on the association between sedentary behaviour and psychosocial health in older adults, please refer to Sect. 12.6.

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 [75]. When temperatures are above or below normal, the effects of even short periods of sitting can be marked. One study showed that in women aged 70 years and older, sitting in a cold room (15 °C) for just 45 min 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 [76]. The same research group also looked at older women sitting in a hot (30 °C) room for 45 min and saw a marked increase in postural hypotension, increased blood pressure, and reduced stamina [77].

13.4.1 Sedentary Behaviour in Hospital

Bed rest or sedentary behaviour in hospital is ubiquitous, with older patients spending the majority of time during their hospitalization 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 [78]. The median amount of time spent standing or walking was 3%, or 43 min per day [78]. Activity patterns of older people (>65 years) measured in an urban inpatient rehabilitation ward showed that, on average, patients were in an upright position for only 70 (± 50) min per day, with 70% of this time spent in standing or walking epochs of less than 5 min [79]. Stroke patients in a rehabilitation ward spent only 8.3% of their day in an upright position [80].

This lack of mobilization and encouraged sedentary behaviour is one of the main reasons for the dramatic functional decline seen in older people following hospital admission. One study in Spain showed that there was a fourfold (OR = 3.92) increased chance of dramatic functional decline in people over the age of 75 having had a hospital admission [81]. A hospital admission in the past 12 months was more predictive of severe functional loss than cognitive decline (OR = 2.60) or previous lower limb functional impairment (OR = 2.01). Indeed, the rates of functional decline after hospital discharge range from 10% to 50% [82, 83]. Approximately, 30% of adults aged 70 and above who are hospitalized for medical illness are discharged with an activity of daily living disability that they did not have before the onset of the acute illness [84].

Staffing issues and risk aversion surrounding the cost of falls in hospital have led to patients being mobilized less and sitting more. Resnick et al. [27] found that patients spent most of the time in bed, and optimizing 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 hospitalization, this concern is well founded [85], yet activity restriction may instead result in increased fall risk by contributing to deconditioning and functional loss [86]. 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 [87].

Yet for older adults, the effects of bed rest are profound. One study found a significant decrease in muscle protein synthesis, strength, and lower extremity and whole-body mass in a group of healthy older adults placed on bed rest for 10 days [88]. 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 [88].

13.5 Sedentary Behaviour Interventions in 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 future 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 [89]. 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 [33], abnormal BMI, smoking, and polypharmacy [90]. 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 [91], 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 [89].

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 [92]. Indeed, sit-to-stand transitions could be seen as small bouts of functional

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 conceptualizing 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
Programme 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	Programme barriers	• No accountability for self-logs • Difficulty with goal setting feedback hard to interpret • Health coach calls too long • Intervention too short • Reminders agitating or hard to use

Adapted from qualitative studies: Greenwood-Hickman et al. 2016 [89]; Chastin et al. 2014 [33]; Harvey et al. 2016b, c [64, 65]; Nicholson, 2012 [93], and quantitative studies: Gardner et al. 2014 [102]; Hamer and Stamatakis, 2014 [103]; Heseltine et al. 2015 [90] training that are achievable for older adults who are not able to engage in exercise programmes requiring a greater energy cost. This alongside the known association of chair rise ability and mortality [62], and improvements in sit-to-stand ability with repeated sit-to-stand practice [64, 65] could be a good motivator for older people to break prolonged periods of sitting. The notion that minimizing 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 [93]. However, the notion of balancing active and nonactive periods in order to provide sufficient rest, which contributed to better quality of functionality during the active times, resonated 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 [93].

There are still limited published interventions to reduce sedentary behaviour in older adults, although the emerging evidence shows positive effects (Table 13.2). Unfortunately, none of the studies published so far have had follow-up periods beyond the intervention so the longer term effect is not known.

Gardiner et al. [94] used a combination of face-to-face goal setting consultations in addition to individually tailored mailing to deliver feedback to participants on their objectively measured sedentary time. Participants significantly reduced their

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 socialization
Greater telomere length		Self-efficacy for physical activity
		Increased walking

Adapted from qualitative studies: Greenwood-Hickman et al. 2016 [89]; Harvey et al. 2016b, c [64, 65] and quantitative studies: Gardiner et al. 2011 [94]; King et al. 2011 [95]; Fitzsimons et al. 2013 [97]; Chang et al. 2013 [98]; Matei et al. 2015 [99]; Rosenberg et al. 2015 [100]; Sjögren et al. 2014 [49] total sedentary time (3.2%) over the 2-week intervention, increased breaks in sedentary periods, and also reported high satisfaction from participation in the study [94].

King et al. [95] used mobile phone applications over an 8-week period to successfully promote reducing sedentary behaviour in ageing 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 TV viewing, with average TV viewing time being reduced by 29.1 min [95].

Utilizing a tailored approach to intervention implementation has previously been shown to improve effectiveness of interventions [96], and Fitzsimons et al. (2013) used an individualized method in their study. Following an intervention consisting of individualized consultations, individualized goal setting, and activPAL feedback, the authors demonstrated a reduction of 24 min per day in sitting/lying time after the 2-week intervention [97].

Chang et al. [98] combined lifestyle modification education, exercise training, and group discussions in their 8-week empowerment intervention, specifically targeting older adults with hypertension. Post-intervention, older adults had significantly reduced their self-reported sedentary time by 534 min per week, in addition to increasing their physical activity, self-efficacy for physical activity, and their perceived health.

More recently, 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 h per day self-reported sitting) showed an effect on reported sitting time only in the community-dwelling older adults [99]. Adherence to the booklet self-monitoring tick-sheets was lower in the assisted living residents (40% compared to 58% of the community-dwelling older adults), and attrition (not completing intervention period) was also much higher (25% compared to 15%) [99]. Both groups gave positive feedback in terms of acceptability of the intervention, but the authors concluded that seasonal influences may have affected the adherence.

Reducing sitting time in overweight and obese older adults may be potentially more tricky, but an intervention with over 60 year olds with a BMI greater than 27 kg/m^2 over an 8-week period showed reduced sitting time of 27 min/day, greater sit-to-stand transitions (2 per day), and increased standing time of 25 min/day [100]. The older adults had improved gait speed and reduced depressive symptoms in this small study.

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 [64, 65]. 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 personalized time periods) had better outcomes than those who just received feedback each month from the activity monitors [64, 65]. For more information on approaches to decrease sedentary behaviour among older adults, please refer to Chap. 19.

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 personalization based on individual preferences, understanding personal behavioural assets to break up prolonged sitting, action planning, and reviewing their perceptions of change over time [101]. It will be interesting to see if this co-created intervention has effective outcomes once it is trialled.

It certainly seems as if targeting those with a low socioeconomic status, those not using the internet, those with a higher 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 [102, 103]. 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 [93].

13.6 Summary

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. The poor long-term health outcomes of those with prolonged sitting periods in the day are clear and independent of physical activity [104]. Yet interventions to reduce sedentary behaviour appear more acceptable to older people than interventions aimed at increasing moderate-to-vigorous activity and, at least in the short term, appear to have clinically important improvements that may lead to an improved functional profile. More work in the older population, particularly those transitioning into frailty, is needed [105].

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Chapter 14
Sedentary Behaviour and Mortality

Megan S. Grace and David W. Dunstan

Abstract Throughout the past century, non-communicable diseases have formed the leading cause of death worldwide, accounting for 68% of all deaths globally in 2012. 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 settings) 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 risk of mortality. 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. However, more needs to be done to inform specific public recommendations on how often sitting should be interrupted and whether these interruptions need to include some form of activity to provide maximum benefits. Within an overarching view, these recommendations could be used as a catalyst towards more active living in the general population, where the deleterious effects of prolonged sedentary behaviour are viewed separately to, not as the opposite in a continuum of 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 midlife by an exponential acceleration in association with an increase in disease and dysfunction [1]. The history of disease and mortality across the centuries offers

M.S. Grace (✉)
Baker Heart and Diabetes Institute, Melbourne, VIC, Australia
e-mail: megan.grace@bakeridi.edu.au

D.W. Dunstan
Baker Heart and Diabetes Institute, Melbourne, VIC, Australia

Mary MacKillop Institute for Health Research, Australian Catholic University, Melbourne, Australia

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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 [1, 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, small pox, typhoid, and plague), injuries and accidents [1, 2]. 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 [1]. Intriguingly, Egyptian mummies have also been found to have atherosclerotic calcification [1].

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, immunization, 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 [3–5]. 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 disease, 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, 7]. 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 [7]. Projections for 2030 estimate that ischemic heart disease and stroke will remain at the top of the list for cause of death, with chronic obstructive pulmonary disease rising to third and diabetes rising to fifth [8].

Globally, life expectancy is continuing to rise. In 2013, life expectancy at birth for both sexes was estimated at 71 years. However, there is wide socioeconomic disparity, with life expectancy only 62 years in low-income countries versus 79 years in high-income countries [9]. In 2012, non-communicable diseases were responsible for 68% of all deaths globally, with three in every ten 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]. As a consequence, 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, HIV/AIDS and diarrhoeal diseases the fourth, sixth and seventh leading causes of death in 2012, respectively [7]. Tuberculosis, though no longer in the top 10, was still in the top 15 causes of death [7]. Significantly, with the ever-increasing threat of antimicrobial resistance, there is a growing concern that infectious disease may re-emerge as a major challenge in the future (Fig. 14.1) [4, 10].

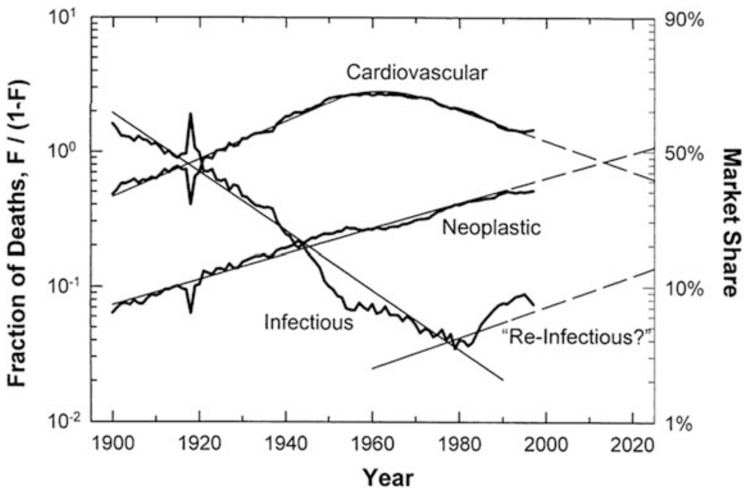

Fig. 14.1 Major causes of death analysed with a multispecies model of logistic competition. The fractional shares are plotted on a logarithmic scale which makes linear the S-shaped rise and fall of market shares. Reproduced with consent from Ausubel et al. (2001) [4]

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 [11, 12] (see also Sect. 1.3). The extent of the problem was highlighted in a recent study by Ng and Popkin [12] 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, the UK, Brazil, China, and India, with forecasts given through to 2030 [12]. 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 across the globe (Fig. 14.2). In 2009, the average American adult spent nearly 38 h/week being sedentary. Based on current trends, by 2030, this will increase to nearly 42 h/week (Fig. 14.2) [12]. Time spent in sedentary behaviours was even higher in

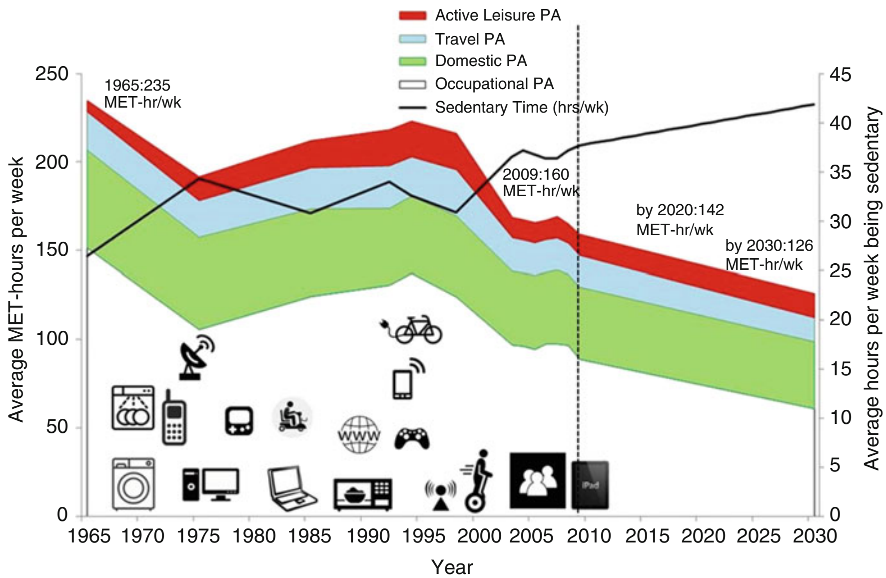

Fig. 14.2 US adults' metabolic equivalent (MET) hours/week (based on time-use surveys) of all physical activity and hours/week of time in sedentary behaviour: measured for 1965–2009 and forecasted for 2010–2030. Icons indicate time- and labour-saving devices or popular products that promote sedentary 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—World Wide 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 and Popkin (2012) [12]

the UK, estimated at around 42 h/week in 2005 and projected to increase to 51.5 h/week by 2030 [12].

A growing body of epidemiologic studies support an adverse association between excessive sitting with poor health outcomes (including cardiometabolic risk biomarkers and type 2 diabetes; see also Chaps. 8 and 9) and premature mortality [13]. 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 [13]. Here, we review the current literature investigating the association between sedentary behaviour and risk of premature mortality. We also briefly cover the potential biological mechanisms that have been proposed to link increased sedentary time with cardiometabolic outcomes.

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 [14], which summarized four decades of epidemiologic research on various health and disease outcomes, and has led to a raft of public health messages recommending regular participation in moderate-to-vigorous physical activity. These recommendations have been widely promulgated with the aim of reducing the burden of non-communicable diseases [15, 16] and have been consistently supported by research showing beneficial associations of physical activity with reduced risk of type 2 diabetes [17, 18], cardiovascular disease [19], and premature mortality [20–22].

The majority of epidemiologic studies investigating the beneficial effects of moderate-to-vigorous physical activity have regarded time spent in sedentary behaviours as simply the opposite end of a physical activity spectrum (Fig. 14.3). However, an emerging paradigm views sedentary behaviour as distinct from physical activity, and it has recently been demonstrated that participation in leisure time physical activity does not fully mitigate the health risks associated with high levels of sedentary behaviour, except for those participating in very high levels of physical activity (>35 MET h/week, equivalent to 60–75 min/day) [23, 24]. This suggests that moderate levels of physical activity may not be protective for those who spend large amounts of time in sedentary behaviours and 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

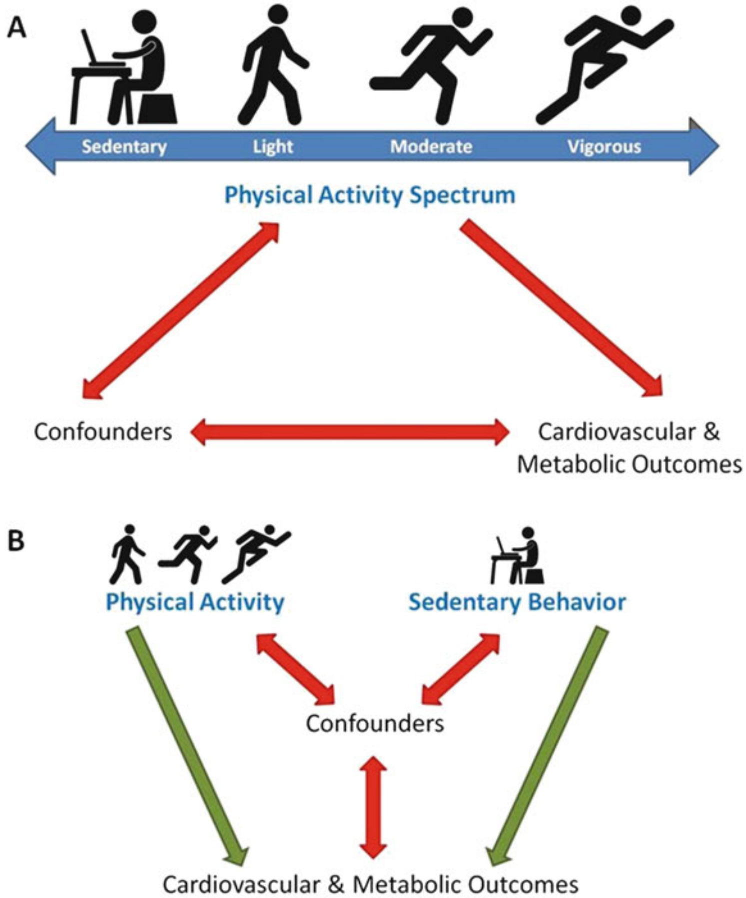

Fig. 14.3 Traditional (**a**) and emerging (**b**) conceptualizations of the relationships between sedentary behaviour and physical activity and their impact on cardiovascular and metabolic outcomes. (**a**) Time spent in sedentary behaviours was traditionally regarded as part of one end of a physical 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 coexist with high levels of total physical activity and that they may have independent effects on health outcomes. Adapted from Ford and Caspersen (2012) [54]

(Fig. 14.2) [13]. The emergence of this new "physical activity paradigm" has highlighted the potential role that all aspects of human movement may play in impacting health [16, 25].

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. A review of the current meta-analyses focusing on sedentary behaviours and mortality is presented in Sect. 14.2.3. The main findings of these prospective and meta-analysis studies are summarized in Table 14.1.

14.2.1 Specific Sedentary Behaviours

Data from the US 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%) [26]. Many epidemiologic studies have attempted to capture overall sedentary behaviour through the examination of common domain-specific sedentary behaviours, as this is easier for an individual to accurately recall compared to total sitting throughout the day, which is generally underestimated by the population [27]. Below, we summarize the epidemiologic literature investigating domain-specific sedentary behaviours and mortality risk.

Occupational Sitting

The modern field of physical activity epidemiology arguably dates back to the early 1950s with the seminal studies of Morris and colleagues [28], 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 [25]. Unfortunately, the independent contributions to mortality risk of sitting versus lack of physical activity cannot be determined from these studies [16].

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 [29, 30]. 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” [29, 30]. 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-year follow-

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. [44] Japan Public Health Center (JPHC) Study	*Men*				
	Overall sitting	All-cause	<3 h/day	≥8 h/day	HR 1.18 (1.04–1.35)
	Women				
	Overall sitting	All-cause	<3 h/day	≥8 h/day	HR 1.10 (0.82–1.25)
Katzmarzyk et al. [45] Canada Fitness Survey	*Combined*				
	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. [37] Australian Diabetes, Obesity and Lifestyle Study (AusDiab)	Television viewing	All-cause	<2 h/day	≥4 h/day	HR 1.46 (1.04–2.05)
		CVD	<2 h/day	≥4 h/day	HR 1.80 (1.00–3.25)
		Cancer	<2 h/day	≥4 h/day	HR 1.48 (0.88–2.49)
		Other causes	<2 h/day	≥4 h/day	HR 1.03 (0.49–2.15)

Warren et al. [38] Aerobics Center Longitudinal Study (ACLS)	Television viewing	CVD	<4 h/week	>12 h/week	HR 0.96 (0.68–1.36)
	Travel	CVD	<4 h/week	>10 h/week	HR 1.50 (1.08–2.09)
	Combined TV and travel	CVD	<11 h/week	>23 h/week	HR 1.37 (1.01–1.87)
Patel et al. [42] Cancer Prevention Study II	*Men*				
	Leisure time sitting	All-cause	<3 h/day	≥6 h/day	RR 1.17 (1.11–1.24)
		CVD	<3 h/day	≥6 h/day	RR 1.18 (1.08–1.30)
		Cancer	<3 h/day	≥6 h/day	RR 1.04 (0.94–1.15)
		Other causes	<3 h/day	≥6 h/day	RR 1.33 (1.20–1.47)
	Leisure time sitting (h/day) and total physical activity (MET h/week)	All-cause	<3 h/day + ≥52.5 MET h/week	≥6 h/day + <24.5 MET h/week	RR 1.48 (1.33–1.65)
			<3 h/day + ≥52.5 MET h/week	≥6 h/day + ≥52.5 MET h/week	RR 1.07 (0.97–1.18)
	Women				
	Leisure time sitting	All-cause	<3 h/day	≥6 h/day	RR 1.34 (1.25–1.44)
		CVD	<3 h/day	≥6 h/day	RR 1.33 (1.17–1.52)
		Cancer	<3 h/day	≥6 h/day	RR 1.30 (1.16–1.46)
		Other causes	<3 h/day	≥6 h/day	RR 1.41 (1.25–1.60)
	Leisure time sitting (h/day) and total physical activity (MET h/week)	All-cause	<3 h/day + ≥52.5 MET h/week	≥6 h/day + <24.5 MET h/week	RR 1.94 (1.70–2.20)
			<3 h/day + ≥52.5 MET h/week	≥6 h/day + ≥52.5 MET h/week	RR 1.25 (1.07–1.45)
Stamatakis et al. [40] Scottish Health Survey	Recreational screen time	All-cause	<2 h/day	≥4 h/day	HR 1.54 (1.06–2.24)
		Fatal and nonfatal CVD	<2 h/day	≥4 h/day	HR 2.10 (1.14–3.88)
Wijndaele et al. [36] European Prospective Investigation Into Cancer and Nutrition (EPIC)-Norfolk Study	Television viewing	All-cause	Every 1 h/day increase		HR 1.05 (1.01–1.09)
		CVD	Every 1 h/day increase		HR 1.08 (1.01–1.16)
		Cancer	Every 1 h/day increase		HR 1.04 (0.98–1.10)

(continued)

Table 14.1 (continued)

Reference	Sedentary domain	Cause of death	Reference category	Comparison category	Summary estimate (95% CI)
Matthews et al. [23]	Television viewing	All-cause	<1 h/day	≥7 h/day	HR 1.61 (1.47–1.76)
		CVD	<1 h/day	≥7 h/day	HR 1.85 (1.56–2.20)
		Cancer	<1 h/day	≥7 h/day	HR 1.22 (1.06–1.40)
		Other causes	<1 h/day	≥7 h/day	HR 2.11 (1.77–2.50)
	Overall sitting	All-cause	<3 h/day	≥9 h/day	HR 1.19 (1.12–1.27)
		CVD	<3 h/day	≥9 h/day	HR 1.16 (1.02–1.30)
		Cancer	<3 h/day	≥9 h/day	HR 1.12 (1.02–1.24)
		Other causes	<3 h/day	≥9 h/day	HR 1.34 (1.20–1.51)
Ford et al. [41] US National Health and Nutrition Examination Survey (NHANES)	Recreational screen time	All-cause	<1 h/day	≥5 h/day	HR 1.34 (0.81–2.21)
		Circulatory system diseases	<1 h/day	≥5 h/day	HR 1.12 (0.47–2.65)
van der Ploeg et al. [46] 45 and Up Study	*Combined*				
	Overall sitting	All-cause	<4 h/day	≥11 h/day	HR 1.40 (1.27–1.55)
	Overall sitting (h/day) and physical activity (min/week)	All-cause	<4 h/day + 0 min/week	≥11 h/day + 0 min/week	HR 1.56 (1.26–1.92)
	Overall sitting (h/day) and physical activity (min/week)	All-cause	<4 h/day + ≥300 min/week	≥11 h/day + ≥300 min/week	HR 1.57 (1.28–1.93)
	Men				
	Overall sitting	All-cause	<4 h/day	≥11 h/day	HR 1.32 (1.16–1.50)
	Women				
	Overall sitting	All-cause	<4 h/day	≥11 h/day	HR 1.62 (1.37–1.92)

Koster et al. [49] US National Health and Nutrition Examination Survey (NHANES)	Overall sitting	All-cause	Lowest quartile	Highest quartile	HR 3.26 (1.59–6.69)
Leon-Munoz et al. [50]	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. [30] Nord-Trøndelag Health Study 3 (HUNT3)	Occupational sitting	All-cause	"Mostly sitting"	"Heavy labour"	HR 0.95 (0.64–1.40)
			"Mostly sitting"	"Much walk and lift"	HR 0.65 (0.44–0.97)
		Cardiometabolic disease	"Mostly sitting"	"Heavy labour"	HR 1.55 (0.83–2.90)
	Television viewing	All-cause	<1 h/day	≥4 h/day	HR 1.11 (0.83–1.48)
		Cardiometabolic disease	<1 h/day	≥4 h/day	HR 1.08 (0.68–1.72)
	Overall sitting	All-cause	<4 h/day	≥10 h/day	HR 1.65 (1.24–2.21)
		Cardiometabolic disease	<4 h/day	≥10 h/day	HR 2.15 (1.34–3.44)
Kim et al. [31] Multiethnic Cohort Study	*Men*				
	Overall sitting	All-cause	<5 h/day	≥10 h/day	HR 1.04 (0.98–1.11)
		CVD	<5 h/day	≥10 h/day	HR 1.06 (0.96–1.18)
		Cancer	<5 h/day	≥10 h/day	HR 0.97 (0.87–1.07)
		Other causes	<5 h/day	≥10 h/day	HR 1.11 (1.00–1.23)
	Television viewing	All-cause	<1 h/day	≥5 h/day	HR 1.19 (1.10–1.29)
		CVD	<1 h/day	≥5 h/day	HR 1.20 (1.05–1.37)
		Cancer	<1 h/day	≥5 h/day	HR 1.16 (1.00–1.33)
		Other causes	<1 h/day	≥5 h/day	HR 1.21 (1.05–1.40)

(continued)

Table 14.1 (continued)

Reference	Sedentary domain	Cause of death	Reference category	Comparison category	Summary estimate (95% CI)
	Leisure time sitting (excl. television)	All-cause	<1 h/day	≥3 h/day	HR 1.06 (1.00–1.12)
		CVD	<1 h/day	≥3 h/day	HR 1.09 (0.99–1.20)
		Cancer	<1 h/day	≥3 h/day	HR 1.04 (0.94–1.14)
		Other causes	<1 h/day	≥3 h/day	HR 1.05 (0.95–1.17)
	Travel	All-cause	<1 h/day	≥3 h/day	HR 1.00 (0.94–1.08)
		CVD	<1 h/day	≥3 h/day	HR 1.08 (0.96–1.21)
		Cancer	<1 h/day	≥3 h/day	HR 1.03 (0.91–1.16)
		Other causes	<1 h/day	≥3 h/day	HR 0.90 (0.79–1.02)
	Occupational sitting	All-cause	<1 h/day	≥5 h/day	HR 0.94 (0.88–1.02)
		CVD	<1 h/day	≥5 h/day	HR 0.93 (0.82–1.05)
		Cancer	<1 h/day	≥5 h/day	HR 0.92 (0.81–1.05)
		Other causes	<1 h/day	≥5 h/day	HR 1.00 (0.87–1.15)
	Women				
	Total sitting	All-cause	<5 h/day	≥10 h/day	HR 1.11 (1.04–1.19)
		CVD	<5 h/day	≥10 h/day	HR 1.19 (1.06–1.34)
		Cancer	<5 h/day	≥10 h/day	HR 0.97 (0.87–1.09)
		Other causes	<5 h/day	≥10 h/day	HR 1.20 (1.07–1.35)
	Television viewing	All-cause	<1 h/day	≥5 h/day	HR 1.32 (1.21–1.44)
		CVD	<1 h/day	≥5 h/day	HR 1.33 (1.14–1.55)
		Cancer	<1 h/day	≥5 h/day	HR 1.07 (0.92–1.25)
		Other causes	<1 h/day	≥5 h/day	HR 1.62 (1.39–1.89)
	Other leisure activities	All-cause	<1 h/day	≥3 h/day	HR 1.07 (1.01–1.14)
		CVD	<1 h/day	≥3 h/day	HR 1.10 (0.99–1.22)
		Cancer	<1 h/day	≥3 h/day	HR 1.05 (0.95–1.17)
		Other causes	<1 h/day	≥3 h/day	HR 1.07 (0.96–1.19)

	Travel	All-cause	<1 h/day	≥ 3 h/day	HR 1.04 (0.95–1.13)
		CVD	<1 h/day	≥ 3 h/day	HR 1.16 (1.01–1.34)
		Cancer	<1 h/day	≥ 3 h/day	HR 1.03 (0.88–1.19)
		Other causes	<1 h/day	≥ 3 h/day	HR 0.92 (0.78–1.09)
	Occupational sitting	All-cause	<1 h/day	≥ 5 h/day	HR 0.98 (0.90–1.08)
		CVD	<1 h/day	≥ 5 h/day	HR 1.12 (0.95–1.31)
		Cancer	<1 h/day	≥ 5 h/day	HR 0.87 (0.76–1.00)
		Other causes	<1 h/day	≥ 5 h/day	HR 1.01 (0.85–1.21)
Campbell et al. [43] Cancer Prevention Study II	Pre-diagnosis overall sitting	All-cause	<3 h/day	≥ 6 h/day	RR 1.36 (1.10–1.68)
		Colorectal cancer	<3 h/day	≥ 6 h/day	RR 1.33 (0.96–1.84
		CVD	<3 h/day	≥ 6 h/day	RR 1.22 (0.73–2.03)
		Other causes	<3 h/day	≥ 6 h/day	RR 1.48 (1.05–2.08)
	Post-diagnosis overall sitting	All-cause	<3 h/day	≥ 6 h/day	RR 1.27 (0.99–1.64)
		Colorectal cancer	<3 h/day	≥ 6 h/day	RR 1.62 (1.07–2.44)
		CVD	<3 h/day	≥ 6 h/day	RR 1.27 (0.73–2.21)
		Other causes	<3 h/day	≥ 6 h/day	RR 1.02 (0.68–1.54)
Seguin et al. [47] Women's Health Initiative Observational Study	Overall sitting	All-cause	≤ 4 h/day	≥ 11 h/day	HR 1.12 (1.05–1.21)
		CVD	≤ 4 h/day	≥ 11 h/day	HR 1.13 (0.99–1.29)
		CHD	≤ 4 h/day	≥ 11 h/day	HR 1.27 (1.04–1.55)
		Cancer	≤ 4 h/day	≥ 11 h/day	HR 1.21 (1.07–1.37)
Pavey et al. [48] Australian Longitudinal Study on Women's Health	Overall sitting	All-cause	<4 h/day	8 to <11 h/day	HR 1.21 (1.01–1.44)
			<4 h/day	≥ 11 h/day	HR 1.24 (0.98–1.56)
	Overall sitting (h/day) and physical activity guidelines (PAG)	All-cause	<4 h/day + not meeting PAG	≥ 11 h/day + not meeting PAG	HR 1.52 (1.17–1.98)
		All-cause	<4 h/day + meeting PAG	≥ 11 h/day + meeting PAG	HR 0.48 (0.24–0.96)

(continued)

Table 14.1 (continued)

Reference	Sedentary domain	Cause of death	Reference category	Comparison category	Summary estimate (95% CI)
Keadle et al. [39] NIH-AARP Diet and Health Study	Television viewing	All-cause	<1 h/day	>7 h/day	HR 1.33 (1.25–1.41)
		Cancer	<1 h/day	>7 h/day	HR 1.12 (1.02–1.24)
		CHD	<1 h/day	>7 h/day	HR 1.64 (1.42–1.90)
		Stroke	<1 h/day	>7 h/day	HR 0.97 (0.72–1.30)
		COPD	<1 h/day	>7 h/day	HR 1.54 (1.10–2.16)
		Accidents	<1 h/day	>7 h/day	HR 1.01 (0.62–1.64)
		Alzheimer disease	<1 h/day	>7 h/day	HR 1.46 (0.91–2.34)
		Diabetes	<1 h/day	>7 h/day	HR 1.93 (1.24–2.98)
		Influenza/ pneumonia	<1 h/day	>7 h/day	HR 2.18 (1.29–3.69)
		Parkinson disease	<1 h/day	>7 h/day	HR 1.77 (1.04–3.02)
		Kidney disease	<1 h/day	>7 h/day	HR 1.22 (0.70–2.11)
		Sepsis	<1 h/day	>7 h/day	HR 1.85 (0.95–3.59)
		Liver disease	<1 h/day	>7 h/day	HR 1.65 (0.91–2.99)
		Suicide	<1 h/day	>7 h/day	HR 1.55 (0.72–3.36)
		Hypertension	<1 h/day	>7 h/day	HR 1.22 (0.56–2.65)
Meta-analyses					
Grontved and Hu [32]	Television viewing	All-cause	Risk per 2 h/day increase		RR 1.13 (1.07–1.18)
Ford and Caspersen [54]	Screen time	Fatal and nonfatal CVD	Risk per 2 h/day increase		HR 1.17 (1.13–1.20)
	Overall sitting	Fatal and nonfatal CVD	Risk per 2 h/day increase		HR 1.05 (1.01–1.09)

Wilmot et al. [52]	Various (television viewing, screen time, overall sitting)	All-cause	Low sitting	High sitting	HR 1.49 (1.14–2.03)
		CVD	Low sitting	High sitting	HR 1.90 (1.36–2.66)
Chau et al. [30]	Total daily sitting	All-cause	Risk per 1 h/day increase		HR 1.02 (1.01–1.03)
Biswas et al. [53]	Various (television viewing, screen time, overall sitting)	All-cause	Low sitting	High sitting	HR 1.22 (1.08–1.38)
		CVD	Low sitting	High sitting	HR 1.15 (1.07–1.24)
		Cancer	Low sitting	High sitting	HR 1.13 (1.06–1.21)

CHD coronary heart disease, *CI* confidence interval, *COPD* chronic obstructive pulmonary disease, *CVD* cardiovascular disease up [31]. 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 sedentary behaviour in industrialized countries [32]. 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/day of television viewing in European countries, 4 h/day in Australia, and 5 h/day in the USA based on self-reported measures [32–35]. 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 [36].

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 cardiovascular disease, but not from cancer [37]. For each 1 h/day increase in television viewing time, the risk of all-cause mortality increased by 11% and risk of cardiovascular disease mortality increased by 18%. After adjustment for exercise time, those who watched television for $\geq$4 h/day were at 46% increased risk of all-cause mortality and 80% increased risk of cardiovascular disease mortality and showed a trend towards an increased risk of cancer mortality, compared to those who watched $<$2 h/day [37].

Similarly, an analysis of the European Prospective Investigation into Cancer and Nutrition (EPIC)-Norfolk Study over 9.5-year follow-up showed 5% increased risk of all-cause mortality and 8% increased risk of cardiovascular disease mortality for each 1 h/day increase in television viewing time. Again, there was a non-significant trend for an association between television viewing time and cancer mortality [36].

In the NIH-AARP Diet and Health Study, television viewing time ($>$7 h/day compared with $<$1 h/day) was associated with greater risk of all-cause, CVD, and cancer mortality [23]. Participation in high levels of moderate-to-vigorous physical activity ($>$7 h/week) did not fully mitigate this effect in participants with high television viewing time [23].

For both men and women, television viewing in the Multiethnic Cohort Study was deleteriously associated with all-cause, cardiovascular disease, and other-cause mortality, but not cancer mortality [31]. Compared to $<$1 h/day, $\geq$5 h/day of television viewing was associated with a 19% and 32% increased risk of all-cause mortality, 20% and 33% increased risk of cardiovascular disease mortality and 21% and 62% increased risk of other (non-cardiovascular disease, 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 [31].

However, not all studies have shown significant associations between television viewing and mortality. A 21-year follow-up of the Aerobics Center Longitudinal Study (ACLS) showed a non-significant trend for increased cardiovascular disease mortality risk across incremental quartiles of television viewing [38]. There was also no significant difference in cardiovascular disease mortality risk observed between the highest (>12 h/week) and lowest (<4 h/week) 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/week) of combined sedentary behaviour showed 37% higher risk of cardiovascular disease mortality compared to those in the lowest quartile (<11 h/week) [38].

Similar to the findings observed for occupational sitting, television viewing in the HUNT3 study [29, 30] 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/day) and the lowest category (<1 h/day). 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/day 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 [29, 30].

A recent study expanded on the known causes of mortality that have been associated with prolonged television viewing time [39]. After 14.1 years of follow-up from the NIH-AARP Diet and Health Study, each 2 h/day 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. This study substantially increases the breadth of mortality outcomes that have been associated with high levels of television viewing and suggests that sedentary behaviour, particularly television viewing, may be a more important target for public health intervention than previously thought [39].

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 cardiovascular disease mortality risk. For every 1 min/day increase in screen time, the risk of all-cause mortality and cardiovascular disease events (both fatal and nonfatal) increased by 0.1% [40].

Conversely, Ford [41] 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).

Leisure Time Sitting

In a 14-year follow-up of the Cancer Prevention Study II, men and women who reported sitting ≥6 h/day had 17% and 34% increased risk of all-cause mortality, respectively, compared to those who reported sitting ≤3 h/day [42]. In a stratified analysis, men and women who had high levels of sitting (≥6 h/day) and low levels of physical activity (<24.5 metabolic equivalent (MET)-h/week) were at higher risk of all-cause mortality than those who reported both sitting the least (<3 h/day) and being the most physically active (≥52.5 MET h/week). 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 cardiovascular disease for both men and women, whereas it was associated with increased cancer mortality risk only among women [42].

A study specifically investigating a cohort of participants diagnosed with colorectal cancer found that spending ≥6 h/day 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/day of leisure time sitting, whereas leisure time spent sitting post-diagnosis was significantly correlated with mortality specifically related to colorectal cancer [43].

Analysis of the Multiethnic Cohort Study revealed that ≥3 h/day compared to <1 h/day 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 [31]. 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 cardiovascular disease mortality risk across quartiles of time spent riding in a car [38]. Men in the highest quartile (>10 h/week) were at 50% greater risk of cardiovascular disease mortality compared to those in the lowest quartile (<4 h/week) [38].

No association between any cause of mortality and sitting in a car or bus was observed for men in the Multiethnic Cohort Study [31]. However, women in the highest transport sitting category (≥3 h/day) showed a 16% higher risk of cardiovascular disease mortality compared to those in the lowest category (<1 h/day).

14.2.2 Overall Sedentary Behaviour/Sitting

An analysis of the Japan Public Health Center (JPHC) Study reported that Japanese men who spent ≥8 h/day in sedentary behaviours had a significantly elevated risk of all-cause mortality compared with men who spent <3 h/day sedentary [44]. However, there was no corresponding association observed in Japanese women [44]. 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 cardiovascular disease mortality in both men and women. Similar results were obtained after stratification by smoking status, body mass index, and leisure time physical activity level (greater or less than 7.5 MET h/week) [45]. The relationship between sitting and cancer mortality was not significant [45]. 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 moderate-to-vigorous physical activity, overall sitting was found to be positively associated with all-cause but not cardiovascular disease or cancer mortality [23]. Compared to those who sat for <3 h/day, individuals sitting ≥9 h/day showed a 19%, 16% and 12% increased risk of all-cause, cardiovascular disease, and cancer mortality, respectively [23].

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/day, 4–8 h/day, 8–11 h/day, ≥11 h/day) [46]. 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 [46].

Similarly, Chau and colleagues [29, 30] observed a significant positive association between total sitting and all-cause and cardiometabolic-related mortality in the HUNT3 Study after 3.3-year 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/day), 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/day) [29, 30].

In the Multiethnic Cohort Study, total daily sitting was not significantly associated with all-cause, cardiovascular disease, or cancer-related mortality in men [31]. 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/day, those who sat ≥10 h/day had 11% greater risk of all-cause, 19% greater risk of cardiovascular disease, and 20% greater risk of other causes of mortality [31].

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 [47]. Significant deleterious linear trends between sedentary behaviour and risk of all-cause, cardiovascular disease, coronary heart disease, and cancer mortality were observed. Compared with women who reported the least time in sedentary behaviours (≤4 h/day), women reporting the highest time in sedentary behaviours (>11 h/day) had 12% increased risk of all-cause mortality, 27% increased risk of coronary heart disease mortality, and 21% increased risk of cancer mortality, but no significant effect on risk of cardiovascular disease 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 multiracial women) compared to those in the White and Hispanic categories [47].

Similarly, an analysis of the Australian Longitudinal Study on Women's Health [48] 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 h of sitting per day. This is consistent with the thresholds suggested by previous studies. Women sitting for 8 to <11 h/day and ≥11 h/day 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/day 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 [48].

In the only 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 [49]. Participants in the two highest quartiles of sedentary time (h/day) were at 174% and 226% greater risk of all-cause mortality than those in the lowest quartile, independent of moderate-to-vigorous physical activity. Importantly, this study is in agreement with the majority of epidemiologic studies using subjective measurements of sedentary time. However, the estimated risk is much higher than previously reported, and more studies using objective monitoring, 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 old), the risk of continued sedentariness or changes in sedentary behaviour on mortality were assessed [50]. 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 [50].

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 cardiovascular disease-related mortality in both men and women; however, an association with cancer is less clear. Importantly, associations with mortality risk do not appear to be fully moderated by leisure time physical activity nor mediated by body mass. 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. Importantly, the only study thus far to use objective monitoring confirmed an association between sitting time and mortality [49]. Although there are also limitations with this type of data collection, more studies using objective data will help 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 have 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 underestimate 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 and meta-analyses 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 [32] 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/day 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/day 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 [51]. However, pooling of the estimates with additional adjustment for dietary variables did not attenuate the effect estimate for all-cause mortality in that study [32].

Wilmot and colleagues [52] 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 standardized 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.

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 [30] reported a 34% higher risk among adults sitting for 10 h/day compared with 1 h/day. 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 [32], the association between sitting time and all-cause mortality was non-linear, with a significant effect above 7 h/day.

Biswas and colleagues [53] 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 is limited by the lack of definition of high versus 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.

Indeed, Ekelund and colleagues recently performed a systematic review of 16 studies, focusing on the associations of sedentary behaviour and physical activity with all-cause mortality [24]. The authors found that participation in moderate levels of physical activity (16–30 MET h/week) attenuated but did not abolish the mortality risk associated with high levels of overall sitting time or television viewing time. It was only in the highest activity group (>35.5 MET h/week, equivalent of 60–75 min of moderate-to-vigorous activity per day) that the association of overall sitting time with mortality was eliminated. However, an association with television viewing time was still evident irrespective of physical activity level [24].

Cardiovascular Disease Mortality

In an analysis of six studies that have reported on screen time, and two studies on sitting time, Ford and colleagues [54] found 17% and 5% increase in fatal and nonfatal cardiovascular disease risk, respectively, for each additional 2 h/day 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 [52] found a 90% increase in risk of cardiovascular disease 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 [53] analysed seven studies reporting on sedentary behaviour and cardiovascular disease mortality. After adjustment for physical activity, greater time spent sedentary was independently associated with 15% higher risk of cardiovascular disease mortality.

Cancer Mortality

In contrast to all-cause and cardiovascular disease 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 [53] found that greater time spent sedentary was independently associated with 13% higher risk of cancer mortality, after adjustment for physical activity. For further detail on all-cancer and cancer-specific mortality, please refer to Sect. 10.4.

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. Measurement of sitting time for the majority of studies analysed have been based on self-report which can be subject to measurement error and recall bias. 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 [55].

14.2.4 Remaining Questions

What Can Objective Activity Monitoring Tell Us?

Self-report of overall sedentary behaviour can be subject to high levels of bias, as many individuals underestimate the amount of time they spend sitting throughout the day. This effect may be somewhat mitigated by asking respondents to recall specific domains of sedentary behaviour, such as television viewing which tends to occur in regular blocks that occupy long and distinct periods of time [27]. However, the reliability and validity of overall and domain-specific measures used to estimate sedentary behaviour are variable [27, 56]. The use of objective activity monitors that provide valid and reliable data on the duration, amount, frequency and time of day with respect to sedentary and activity time is relatively new in epidemiologic research. Their use in population-based studies has provided valuable insight into how the majority of adults spend their waking hours. In one study, analysis of accelerometer data from over 6000 participants in the NHANES study found that mean accelerometer-derived sedentary time ranged between 7.3 and 9.3 h/day, with older adults generally the most sedentary [57]. As a proportion, sedentary time has been reported to occupy approximately 51–68% of an adult's total waking hours [57, 58]. As an interesting comparison, only around 4–5% of waking hours is spent in moderate-to-vigorous physical activity, with the remaining 27–44% being spent in light-intensity or "baseline" physical activity [58, 59].

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 nearly all of the variation in sedentary time can be attributed to displacement of light physical activities, whereas the correlations between sedentary activity and moderate-to-vigorous physical activity, or light activity and moderate-to-vigorous physical activity, are generally weak [58]. That is, the more time participants spend in light-intensity activity, the less time they spend sedentary. This further highlights the importance of investigating sedentary behaviour as a risk factor for premature mortality distinct to lack of moderate-to-vigorous physical activity and the viability of promoting light-intensity physical activity as a means to reduce sedentary time. However, presently only one epidemiologic study has investigated the association between sedentary behaviour and mortality using objective activity monitoring [49]. In addition to overall sedentary behaviour, these types of studies could shed light on the patterns of sedentary behaviour that are most detrimental and dose-response relationships that may help scientists to answer the often-asked question "how much sitting is too much?"

Is the Association Between Sedentary Behaviour and Mortality Independent of Physical Activity Level?

Three strategies have been used in an attempt to answer this question: (1) inclusion of physical activity in multivariate-adjusted regression models, (2) inclusion of interaction terms for sedentary behaviour and physical activity and (3) stratification by physical activity level. Using multivariate adjustment or the inclusion of interaction terms has generally not significantly modified the observed relationships between sedentary time and mortality. However, stratification by physical activity level has revealed some interesting observations within the population data, with several studies demonstrating that physically inactive individuals with high sitting time are at substantially greater risk of mortality than physically active individuals with high sitting time, although it is also worth noting that those in the high sitting and high activity groups could still be at greater risk than those in the low sitting and high activity groups [23, 24, 42, 45, 46, 49].

Are Health Risks Equivalent Across All Types of Sedentary Behaviours?

There is a growing body of epidemiologic evidence indicating that certain sedentary behaviours may be more detrimental for health than others [55]. As such, future epidemiologic studies should employ more sophisticated analyses, rather than selecting just one or few behaviours as an overall marker of sedentary behaviour [55]. Adoption of emerging technologies, such as geolocation data, acceleration signals in mobile phones and inclinometers, will help to obtain more accurate measurements and contextual information of sedentary behaviour [55].

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 $\geq$60 years [23, 57]. This could be due to chronic conditions that reduce the ability to participate in physical activity and conversely promote 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 recent 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 [60]. However, the causal relationships in this context are unclear, and other domains of sedentary behaviour also need to be 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 [37]. This stems from evidence showing that increased snacking is associated with high levels of television viewing time and increased adiposity [51, 61]. However, the association between sedentary behaviour and mortality has been shown to be independent of diet quality and energy intake [36, 37]. 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 [37, 40, 42, 46–49].

In a recent review, Bouchard and colleagues [62] summarized 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 effects, and additional research is needed to help clarify how each of these variables contributes to health and mortality risk.

An understanding of the underlying biological mechanisms is therefore necessary to help researchers untangle the complicated interplay between sedentary behaviour, physical activity, and their cardiometabolic outcomes on mortality risk. In the next section, we review the current approaches being used to understand the biological basis of sedentary behaviour and health outcomes and the proposed mechanisms linking sedentariness with increased risk of morbidity and mortality.

14.3 Underlying Biologic Mechanisms

Moderate-to-vigorous physical activity is well-known to provide a strong and largely beneficial physiological stimulus, encompassing biological, structural and systemic effects on glucose homeostasis and other metabolic pathways of cardiovascular disease risk [63]. However, despite the growing evidence from epidemiologic studies indicating that sedentary behaviour is a risk factor for disease and mortality outcomes, relatively little is known about the deleterious physiological responses caused by prolonged sitting [11]. The distribution of activity time, and the strong relationship between sedentary and light-intensity physical activity time, raises novel and significant health implications. As discussed, up to two-thirds of an adults' waking hours are spent sedentary, which may impart a unique biological stimulus that has negative health consequences. An understanding of the biological mechanisms that underlie associations of prolonged sitting with adverse health outcomes is required in order to identify the potential causal nature of these relationships. That is, if sitting is implicated in the disease process, then specific cells within the body must respond to stimuli triggered by prolonged sitting, leading to a cascade of events that eventually disrupts physiological homeostasis within certain tissues and thus increases the risk of developing chronic disease (Fig. 14.4).

14.3.1 Sedentary Behaviour and Chronic Disease Risk Factors

Numerous cross-sectional studies have investigated the association between sedentary behaviours and chronic disease risk factors. Sedentary time, independent of physical activity, has been shown to be associated with specific biomarkers of obesity [64–68]; thrombosis [69]; cardiovascular disease risk factors such as blood pressure, triglycerides, and high-density lipoprotein (HDL) cholesterol [64, 70–72]; fasting and 2 h plasma glucose [71, 73, 74]; markers of insulin resistance [71, 74, 75]; leptin [70]; inflammation [40, 75]; and clustering of cardiometabolic risk factors or metabolic syndrome [74, 76–79]. Sedentary behaviour in older adults with knee-joint osteoarthritis has also been associated with reduced mitochondrial biogenesis and increased electron leak from the mitochondrial electron transport chain. This exposes the skeletal muscle intracellular milieu to increased toxicity, altered mitochondrial DNA deletions, and mutations caused by exposure to reactive oxygen species [80]. Ultimately, this chain of events could lead to accelerated cellular senescence and cell death. Moreover, a recent analysis of NHANES study data revealed that higher screen-based sedentary behaviour levels are associated with shorter leukocyte telomere length, which is thought to be an indicator of oxidative stress and inflammation and is predictive of cardiovascular disease [81].

These epidemiologic studies indicate that time spent in prolonged sitting holds important metabolic consequences that are associated with adverse alterations in metabolic risk and may explain the higher mortality risk associated with high sedentary time. However, more highly controlled experimental evidence is needed to determine the biological mechanisms that occur over the short and long term which lead to physiological dysfunction. Below we summarize the evidence from bed rest, detraining and reduced activity and prolonged sitting studies attempting to elucidate the biological mechanisms leading to the deleterious effects of prolonged sedentary behaviour.

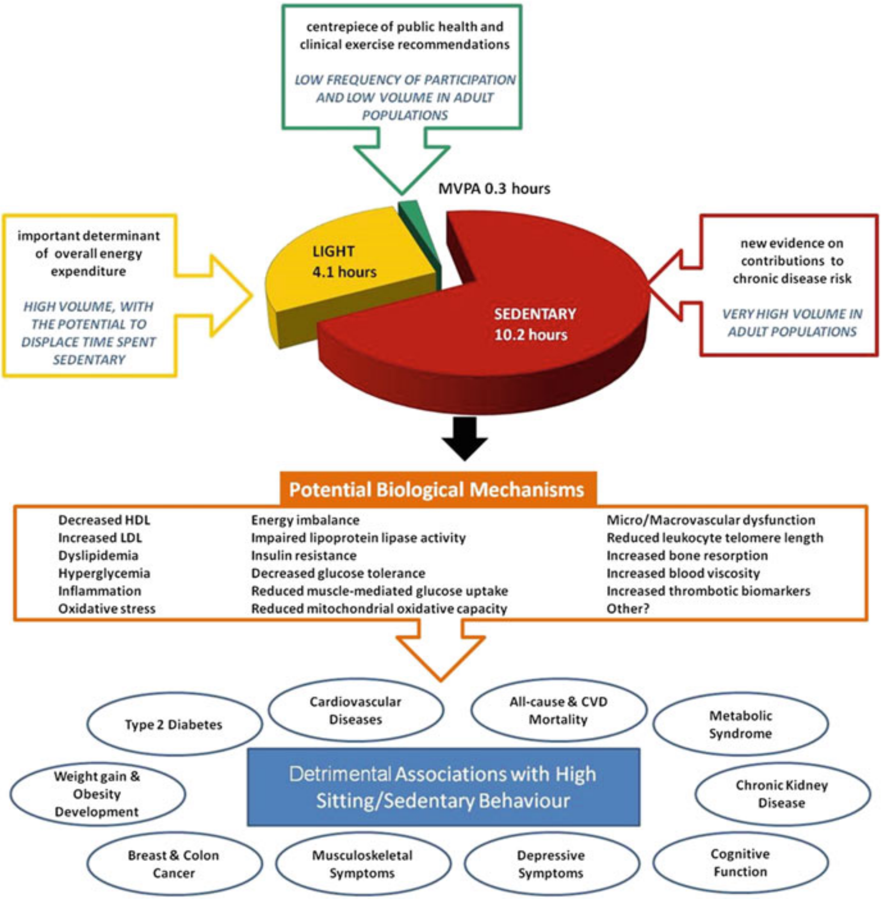

Fig. 14.4 Illustration of how the most sedentary individuals in the population allocate their waking hours and potential biological mechanisms linking sedentary behaviour to health outcomes. Data from the pie chart was populated using objective activity monitoring from accelerometer measurements in a 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 (100–1951 cut-point) and moderate-to-vigorous intensity activity (>1952 cut-point). Adapted with permission from Owen et al. (2012) [127]

14.3.2 Bed Rest Studies

Although bed rest provides a unique and useful model to study the underlying mechanisms that lead to physiological defects induced by physical activity in healthy participants, it is important to note that this type and level of inactivity is extreme and likely to be quantitatively and qualitatively different from that observed in the general population [82]. The postural changes associated with lying in bed also cause haemodynamic shifts that mimic reduced gravity and do not reflect many typical sedentary behaviours such as sitting [16]. Despite this, bed rest provides a helpful short-term model to investigate the effects of sedentary living and has revealed that routine non-exercise physical activity in everyday life is important in human physiology. For example, bed rest studies show an increase in insulin resistance, reduced glucose tolerance, hyperlipidaemia, increased total and very-low-density lipoprotein (VLDL) cholesterol, decreased HDL cholesterol, microvascular dysfunction, deconditioning and muscle atrophy associated with bed rest from as short as 3–10 days [83–89]. The negative impact of bed rest can be partially, but not fully, mitigated with the use of exercise, which can help maintain glucose tolerance and work capacity and prevent physiological decline during prolonged periods of bed rest [83, 88]. Tissue-specific effects are also being explored, for example, 10 days of bed rest has been shown to result in marked changes in adipose metabolism including decreases in lipolysis and increases in glucose uptake [90].

The deleterious effects of sedentary behaviour on metabolic health may be partly mediated by changes in lipoprotein lipase (LPL) activity. LPL is an enzyme that facilitates the uptake of free fatty acids into skeletal muscle and adipose tissue. Low levels of LPL are associated with increased circulating triglyceride levels, decreased HDL cholesterol, and an increased risk of cardiovascular disease [25]. It may also have effects on hypertension, diabetes-induced dyslipidaemia, and metabolic syndrome [91–94]. In a 20-day bed rest study, Yanagibori and colleagues [89] showed a significant decrease in LPL activity within the first 10 days, which was sustained but not enhanced over the 20-day period. This was accompanied by significant increases in plasma triglycerides and decreases in HDL [89].

Bone health is mediated by the balance between bone resorption and deposition. It has been demonstrated that urinary calcium excretion and markers of bone resorption can increase within 1–2 days of bed rest, whereas markers of bone formation are largely unaffected [31, 95, 96]. This would eventually result in reduced bone mineral content and increased risk of osteoporosis. Moreover, bouts of daily exercise fail to completely prevent the deleterious changes in bone metabolism resulting from prolonged bed rest, suggesting that physical activity alongside reduced sedentary behaviour may be necessary to mitigate these effects [97].

Vascular health is also affected by bed rest, with studies showing a reduction in reactive hyperaemia, increase in blood pressure, and increased endothelial damage [98]. However, most of these studies have used protocols that simulate microgravity, which is also known to influence blood volume and blood flow distribution. Therefore, it is unclear whether the reported changes in vascular function following bed rest are due to sedentary behaviour per se [98].

14.3.3 Detraining/Reduced Activity Studies

The detraining model requires generally healthy and active individuals to transiently reduce their daily activity (subsequently leading to increased sedentary time). These studies have reported deleterious physiological and metabolic consequences, including muscle atrophy, accumulation of visceral adipose tissue (irrespective of overall weight change), reduced insulin sensitivity, increased plasma triglycerides, reduced dietary fat oxidation, and reduced mitochondrial oxidative capacity [99–102]. Biopsies also revealed a decrease in phosphorylated/total Akt ratio following 2 weeks of reduced ambulatory activity, supporting a reduction in insulin sensitivity at the level of the muscle [100].

Similar to bed rest studies, 2 weeks of detraining in endurance athletes was associated with significant decreases in muscle LPL activity, with no change in mRNA level [103]. By contrast, adipose tissue LPL activity increased, but there was still no change in mRNA. This suggests that shifts in LPL activity during detraining are due to posttranslational changes [103].

These studies have been highly insightful and demonstrate that reduced physical activity triggers the development of metabolic features akin to those observed in obesity, diabetes and metabolic syndrome. However, although these studies are informative for understanding the acute alterations that occur in metabolic parameters following reduced activity, the model essentially evaluates the effect of transitioning from a habitually active to a less active state. This is not likely to be highly applicable for the general population in which the default is excessive sitting and little or no activity.

14.3.4 Prolonged Sitting Studies

For modern societies, it is likely to be more applicable to examine a population who habitually sit for prolonged periods and the metabolic effects of transitioning to a more active state. From the available evidence, it appears that prolonged sitting, compared to the incorporation of regular activity or standing breaks, has a rapid and deleterious impact on insulin resistance and glycaemia, potentially providing a mechanistic explanation for the strong and consistent associations between sedentary time, cardiometabolic disorders and mortality seen in large epidemiologic studies and meta-analyses.

Reductions in whole-body insulin sensitivity have been observed after just 1 day of prolonged sitting compared to a day where sitting was minimized and substituted with more standing (9.8 h/day vs. 0.2 h/day) and stepping (2.2 h/day vs. 0.1 h/day) [104]. To investigate the impact of energy surplus, a reduced-calorie intake condition was incorporated to approximate the lower energy expenditure of the prolonged sitting condition. The decline in insulin action observed following prolonged sitting was attenuated, but not completely prevented by reducing caloric intake, indicating that factors other than energy surplus are involved in the detrimental impact of sitting on insulin action [104]. Similarly, insulin area under the curve, triglyceride levels and non-HDL levels were significantly improved when participants were asked to substitute 6 h of sitting for 4 h of walking and 2 h of standing, compared to 14 h of sitting [105]. In contrast, replacing 1 h of sitting with vigorous intensity exercise, compared to 14 h of sitting, did not significantly improve these same outcomes [105].

Other studies have focused on tightly controlling the amount and pattern of sitting and activity breaks in a laboratory setting. Compared to uninterrupted sitting, standing for 30 min every hour or regular light or moderate activity breaks were shown to significantly lower postprandial glucose and insulin area under the curve in young and healthy participants, middle-age overweight participants, and patients with type 2 diabetes [106–110]. When considering whole-of-day glucose and insulin profiles, regular activity breaks appear to be more effective than both standing only and an acute morning exercise bout [106–108]. Interestingly, no statistical differences were observed between light and moderate activity break conditions for either glucose or insulin area under the curve, suggesting that brief active interruptions to sitting are equally beneficial for these outcomes, irrespective of intensity [106]. Unexpectedly, 3 days of interrupting prolonged sitting with regular light-intensity activity breaks was shown to have no further benefit for postprandial glucose and insulin responses, compared to just 1 day [111]. However, whereas 1 day of interrupting prolonged sitting was associated with upregulation of the muscle contraction stimulated, AMPK[1]-mediated glucose uptake pathway; 3 days of interrupting sitting showed a transition to upregulation of the Akt-mediated insulin-sensitive glucose uptake pathway [112]. Importantly, this data establishes a mechanistic basis to explain the improved postprandial glucose metabolism observed with regular interruptions to sitting time and suggests that sustaining this type of behaviour over the long term could benefit skeletal muscle insulin sensitivity.

Complex regulatory systems control skeletal muscle function at multiple levels. Changes in skeletal muscle gene expression associated with small-molecule biochemistry, cellular development, growth and proliferation, and carbohydrate metabolism have been observed with regular light or moderate activity breaks, compared to prolonged sitting [113]. This type of analysis provides valuable insight and may help scientists in beginning to unravel the muscle-mediated regulatory systems and molecular processes underlying the physiological benefits of regularly interrupting prolonged sitting.

Nitric oxide is synthesized by endothelial cells and plays a key role in the control of vascular tone. Endothelial dysfunction, leading to reduced production of nitric oxide and an inability of the blood vessels to dilate appropriately, is an important predictor of cardiovascular risk [114, 115]. Two recent studies have directly assessed the effects of prolonged sitting on endothelial function using flow-mediated dilation (FMD), which assesses the extent of blood vessel dilation in response to reactive hyperaemia. As little as 3 h of uninterrupted sitting was associated with a significant decline in femoral artery FMD, which was prevented by three 5 min walking breaks throughout the 3 h period [116]. Moreover, sitting uninterrupted for 6 h was associated with a marked reduction in popliteal and

[1]AMPK: adenosine monophosphate-activated protein kinase

brachial artery microvascular hyperaemic blood flow and a significant reduction in popliteal but not brachial artery FMD [117]. Intriguingly, a short (10 min) bout of walking following the sitting period fully reversed the lower limb impairments induced by prolonged sitting but had no effect on impaired microvascular reactivity in the upper arm [117]. This study highlights the diverse (local and systemic) effects that sedentary time can have on various tissues throughout the body and the capacity for physical activity to mitigate only some of these deleterious outcomes. Importantly, these studies also shed light on some of the possible mechanisms associated with the improvement in blood pressure observed for light and moderate activity breaks compared to prolonged sitting [110, 118].

Prolonged uninterrupted sitting has long been known to be associated with elevated risk of thrombosis, and frequent ambulatory breaks or even simple foot movements are sufficient to reduce the associated loss of plasma volume and avoid venous stasis. However, most of these studies have focused on the elevated risk of thrombosis during air travel in young, healthy populations [119]. More recently, a study in middle-age overweight participants demonstrated a significant increase in plasma fibrinogen, haematocrit, haemoglobin, and red blood cell count and decrease in plasma volume, with 5 h of prolonged sitting [119]. These responses were significantly attenuated when participants interrupted their sitting with regular light or moderate intensity breaks, indicative of an ameliorating influence on the procoagulant effects of prolonged sitting [119].

14.3.5 Animal Studies

Research from animal studies [120] has suggested that hindlimb unloading in rodents (simulating prolonged sitting by removing intermittent standing and ambulation) suppresses LPL activity due to reduced muscle contractile activity. LPL began to decrease within 4 h of hindlimb unloading, reaching a minimum of around 6% of control LPL activity at 18 h [120]. Importantly, though LPL protein and activity was markedly reduced, hindlimb unloading did not change LPL mRNA concentration, even with 11 days of 10 h/day unloading [120]. This suggests that the changes in LPL activity and protein level are likely due to transcriptional changes. It is also interesting to note that the decrease in LPL activity following 12 h of hindlimb unloading could be reversed with just 4 h of light-intensity walking and normal cage activity [120].

These animal studies expand on the studies investigating changes in LPL activity with bed rest and detraining [89, 103]. It appears that LPL regulation is extremely sensitive to changes in low-intensity muscle contractile activity, with changes in LPL activity occurring within hours of muscle inactivity. It is intriguing that the regulation of LPL activity is qualitatively different between exercise and sedentary behaviour [25]. That is, the increase in LPL activity associated with exercise has been linked to increased LPL mRNA levels, whereas short- and long-term sedentary behaviour is linked to a transcription-mediated decrease in LPL activity, without an effect on mRNA levels [25]. These results, albeit within the animal model, suggest that different mechanisms are governing the metabolic process during common sedentary behaviours, which could be distinct from the effects observed in exercise studies.

A global gene expression profiling study identified 38 genes that were upregulated by just 12 h of hindlimb unloading in rats, 27 of which remained above control levels after returning to normal standing and ambulation for 4 h [121]. This suggests that some of the gross metabolic disturbances observed with sedentary behaviour result from metabolic alterations at the level of the muscle and that some of the effects of sedentary behaviour persist for long periods after the behaviour is changed. Thus, a certain amount of baseline activity is required to prevent these adaptations from occurring. In a separate study, downregulation of lipid phosphate phosphatase-1 (LPP1) was observed in both humans and rats within hours after sitting. LPP1 is a key gene for degrading pro-thrombotic and pro-inflammatory lysophospholipids and indicates that muscle inactivity may contribute to haemostatic disorders via changes in the epigenome [122].

14.3.6 Summary of Experimental Models

These short-term studies, though interesting, cannot be extrapolated to long-term exposures of either prolonged sitting or frequent interruptions to sedentary behaviour. However, the dramatic attenuation in postprandial glucose and insulin observed in the activity break conditions of prolonged sitting studies suggests the importance of briefly breaking up prolonged periods of sitting with activity of at least light intensity. The findings from studies that have specifically addressed the cardiometabolic consequences of prolonged sitting are promising and point to the need for further, more long-term trials; studies focusing on other at-risk populations such as the aged; and studies investigating other risk factors, for example, dementia and vascular health. In addition, direct physiologic measurements, rather than surrogate markers, would provide more reliable information on the underlying biological mechanisms associated with prolonged sitting and risk of disease and mortality.

14.4 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 moderate-to-vigorous physical activity. 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 [123]. Notably, Australia [124], New Zealand [125] and the UK [126] have included public health guidelines around reducing sitting where possible and breaking up prolonged sitting often (for further detail, please refer to Sects. 1.4 and 25.3.7). However, these guidelines are broad and non-prescriptive, and no definitive recommendations on how long people should sit for or how often people should break up their sitting time exist. There is much more that needs to be done in this area to inform specific guidelines and 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. This could be used as a catalyst towards more active living in many patients, in a paradigm where the deleterious health consequences of too much sitting should be seen as an addition to, and not an alternative to the well-recognized benefits of participation in health enhancing moderate-to-vigorous physical activity.

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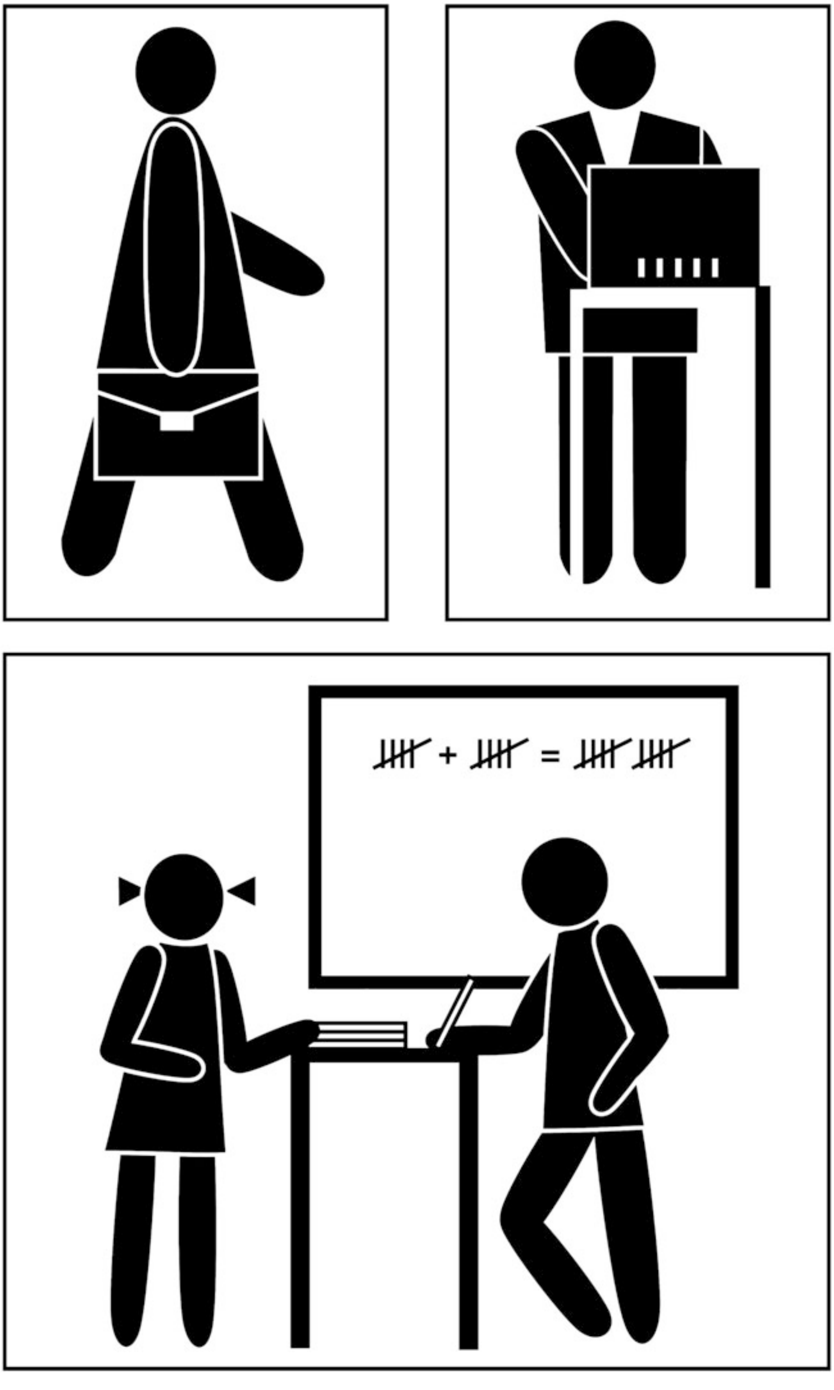
Part III
Understanding Sedentary Behaviour and Promoting Reductions in Time Spent Sedentary



Chapter 15
Models for Understanding Sedentary Behaviour

Nyssa T. Hadgraft, David W. Dunstan, and Neville Owen

Abstract With the recognition that prolonged periods of 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 determinants of sedentary behaviours. Conceptual models 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 the workplace. Within this perspective, an ecological model emphasizes the role of "behaviour settings"—context-specific environmental influences—as being of particular relevance. This chapter presents an approach informed by a behavioural epidemiology framework that draws on evidence about sedentary behaviour and health, and also policy contexts that influence sitting, to gain a greater understanding of the determinants of sedentary behaviour. To demonstrate how this approach may assist our understanding of sedentary behaviour in a particular setting, 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. A case study of an intervention trial addressing multiple levels of potential determinants of workplace sedentary behaviour is presented, emphasizing the importance of conceptually informed and practically grounded research to underpin approaches to sedentary behaviour change. We discuss some of the strengths and limitations of our approach and suggest opportunities for future research.

N.T. Hadgraft (✉) • N. Owen
Swinburne University of Technology, Melbourne, VIC, Australia

Baker Heart and Diabetes Institute, Melbourne, VIC, Australia

Monash University, Melbourne, VIC, Australia
e-mail: nhadgraft@swin.edu.au; neville.owen@baker.edu.au

D.W. Dunstan
Baker Heart and Diabetes Institute, Melbourne, VIC, Australia

Monash University, Melbourne, VIC, Australia

Australian Catholic University, Melbourne, VIC, Australia
e-mail: david.dunstan@baker.edu.au

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15.1 Introduction

As noted in previous chapters, research into all aspects of sedentary behaviour has increased considerably in recent years. As highlighted in Part II of this book, 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 based 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, 7]. 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.

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 conceptual models and frameworks 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

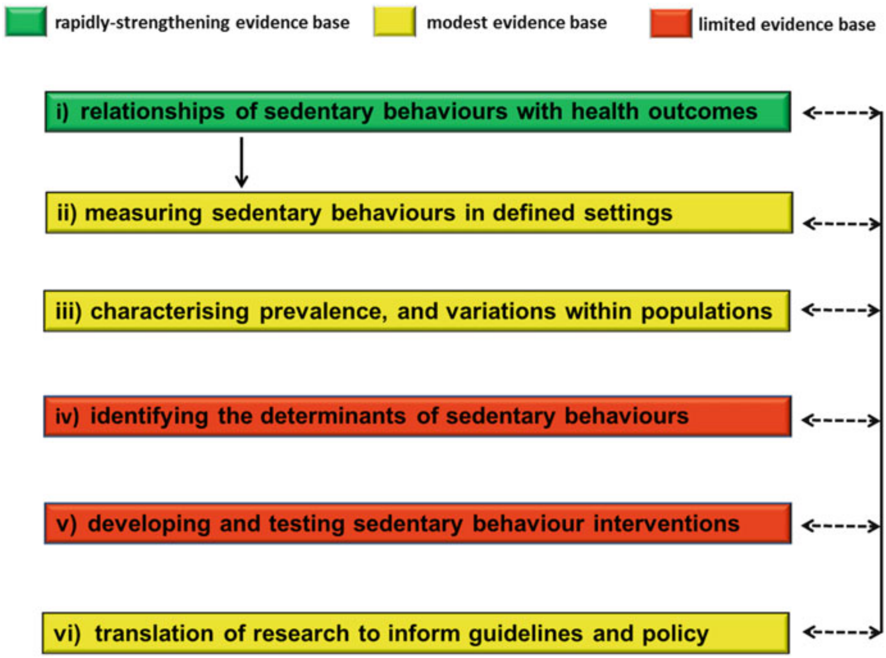

Fig. 15.1 Behavioural epidemiology perspective on understanding the determinants of sedentary behaviours

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 [8] 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 [9, 10]. 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 Novel 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 health-related behavioural and biological impacts [11–14].

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 to support people to shift some of their sitting time to light intensity activities, such as standing or slow walking; physical activity interventions tend to 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 in the emerging area of sedentary behaviour interventions. In this context, Biddle and Gorely [15, 16] provide an informative elaboration of some of the distinctions between the nature of the relevant behaviours and the factors likely to determine these behaviours, moderate-to-vigorous physical activity and 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, social norms, and typically by the physical environment—including furniture arrangements—of the domestic lounge room.

- *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 to 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 computers), and the workplace physical environment (in particular, available office furniture).

As noted above, there are some key differences in the attributes of moderate-to-vigorous physical activities and sedentary behaviours—particularly related to 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 and workplace sitting—are likely to be influenced by different factors. Biddle and Gorely [15] suggest that this key difference in the level of conscious processing is likely to have implications for the application of particular theories of behaviour to the study of 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 [17, 18]; 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). Recognizing the distinct determinants of physical activity and sedentary behaviour is particularly important for understanding these behaviours and appropriately intervening [8, 15, 19]. 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. 4 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] (see Chap. 24 for more details). The relationship between interpersonal or social influences with sedentary behaviour is also less clear from existing quantitative studies. A recent review by O’Donoghue and 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, 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 socio-cultural 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]. 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 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 and social and physical health influences [27, 28].

While the above provide only snapshots of the existing evidence pertaining to social determinants of sedentary behaviour (which are addressed in more detail in Chaps. 4, 16, 23 and 24) it highlights the need to broaden our thinking beyond individual-level factors and attempt to identify potentially modifiable environmental and social influences on sedentary behaviour. Conceptual models of the social

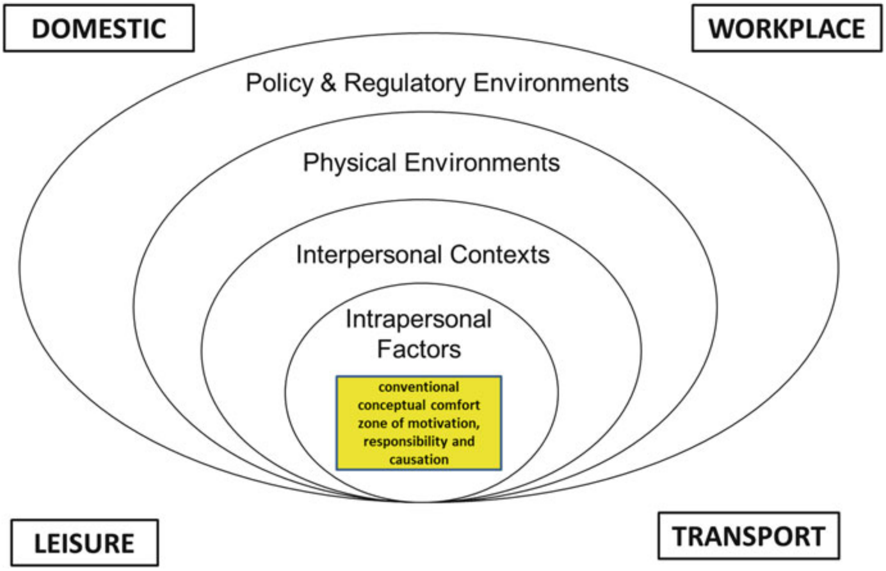

Fig. 15.2 A simplified ecological model of health behaviour

and environmental determinants of sedentary behaviour can assist with this process, but need to 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 [32].

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.

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 [33]. As an example, while a large body of research has focused on understanding attributes associated with television (TV) viewing time or overall sitting time [15, 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). Later chapters in this book will outline 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 to address some of these research gaps and improve 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 [34].

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 [35]. These ecological approaches largely arose after recognition that methods focused predominately on individual-level factors failed to achieve inroads in promoting healthy behaviours [35, 36].

Ecological models aim to recognize 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 emphasize 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 [37]. 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 [38].

Ecological perspectives of health behaviour have five key principles that can be used to guide research and understand the precursors to behaviour [35]:

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

We provide examples to illustrate each of these points later in the chapter (see Sect. 15.4.3).

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 [39]. For example, psychological influences highlight the importance of individually focussed solutions to addressing health behaviours, while a practitioner from an urban design background may emphasize the importance of environmental influences on behaviour [40]. A disadvantage of this approach is that it has the tendency to lead to narrow, silo-type approaches to analysing problems and developing solutions [39].

Increasingly it is being recognized 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 recognize and incorporate this complexity [41]. 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 [42] emphasizes 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 United States launched in December 2010, *Healthy People 2020*, was influenced by ecological principles and outlines the importance of addressing the social and environmental determinants of health, in addition to individual level factors [43]. 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 Compared to 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 [35]. The direct application of social-cognitive theories to sedentary behaviour is still somewhat limited [33]. 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, 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 [15]. Some studies have found evidence to support an association between habits and sedentary behaviour amongst university students [44] and older adults [45] 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 [44, 45], 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 [35].

15.4 An Ecological Model of Sedentary Behaviour

An ecological model of sedentary behaviour identifies four domains—*leisure, household, transport*, and *occupation* [8]. The range of potential influences and their relative importance is considered to differ in each of these domains [8]. 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 [33].

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 book? 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 that 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.

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' [46]—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 [8]. 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 [47]. 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 [48]. 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 becoming increasingly common [49], 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 [50]). For further details on sedentary behaviour interventions targeting different population subgroups and settings, please refer to Chaps. 17–22.

Further empirical research 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 significant body of research linking aspects of the built environment, particularly population density and access to destinations, with walking [51, 52] and with cycling for transport [53]. Following on from these findings, there has been interest in whether similar associations of environmental attributes with sedentary behaviours can be found.

A recent review of the evidence linking neighbourhood environmental attributes with sedentary behaviours by Koohsari and 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 Koohsari review 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 to guide research and understanding of sedentary behaviour, we will use the workplace as an example. As will be discussed in further detail in Chap. 18, of the four key domains of sedentary behaviour [17] 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 [54–56]. 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 [57].

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 [9]. Working adults spend a significant proportion of their waking hours at work and can be viewed as a captive audience for these messages [58]. 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 [59].

In workplace health promotion, ecological models are consistent with best-practice guidelines. For example, the World Health Organization's Healthy Workplaces Model [60] 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 emphasize the importance of considering the multi-level influences on health behaviour, in line with principles of an ecological model of health behaviour. In Chap. 18, examples will be presented of how a sedentary behaviour programme can address the keys to a healthy workplace outlined by this model.

Ecological Model Principles Applied to Occupational Sedentary Behaviour
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 [61]. 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 organizational policies and procedures [61–63]. 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 set-up 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 work day. 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 [64]. 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 [65]—indicating an interaction between environmental and social influences. In contrast, negative interpersonal interactions (such as concerns about noise projection with standing) may also influence take up or use of workstations that facilitate standing [65].

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 range of social norms, organizational 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/tea room 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*

   To date, few examples exist of workplace sedentary behaviour interventions that have been designed using an ecological framework. The majority of interventions in the published literature have focused attention on the discernible environmental influences by altering the physical workstations used by workers [66]. As many of these studies have been short-term pilot studies, the long-term sustainability of this approach has not been clear. However, 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.

Case Study: Stand Up Victoria

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 [67]. The intervention involved an

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
Organizational	● 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

environmental component, but also targeted organizational and individual factors thought likely to influence sedentary behaviour (Table 15.1). Within this ecological framework, social-cognitive theory was also used to guide the development of the intervention [67, 68].

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 [68].

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 [66, 69, 70]. However, as will be discussed further in Chaps. 16–25, there is some evidence to suggest that a multi-component approach targeting influences at the individual, organizational, and environmental level may lead to greater reductions in sitting time when compared with the provision of a sit–stand workstation in isolation [49]. 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 provides 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 [71]. 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 organizational, social, and physical environments at work.

While the use of ecological models within sedentary behaviour interventions is still in development, this example provides emerging 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 from Behavioural and Social Science

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 programmes 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 upscaled and usefully translated to broader scale interventions, not just applicable in smaller scale laboratory studies.

15.5.1 Limitations of Ecological Models

We have emphasized 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 [39]. 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 is that the application of models identifying multiple levels of influence can be difficult to design, evaluate, and measure, due to their complexity. Public health programmes 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. 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 recognized that the public health challenges we face are multi-faceted and will not be successfully addressed by applying a narrow mindset 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 [35] 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.

Recognizing 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 [72]. 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 [73]. While this model has only recently been proposed, it will be highly informative to see its use in future research.

15.6 An Ecological Model of Sedentary Behaviour: Research Opportunities

There is still more to be done to further our understanding of the most effective ways to influence and reduce sedentary behaviour. From the ecological model and associated principles we have outlined in this chapter, we propose 11 research questions to be addressed:

1. What are the broader and more generalizable 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? (e.g. across different age groups, among 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 exemplar organizations (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 Summary

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. Workplace sitting provides a case in point for how an ecological model can help to broaden our understanding of a key health risk behaviour and its determinants in a particular behaviour setting. The example presented provides a perspective on how interventions may be developed, drawing upon a model that takes into account the multiple levels of influence on health behaviours. Taking forward a rigorous and relevant research agenda within the framework of an ecological model of sedentary behaviour is challenging, but there are many new and potentially fruitful directions for research.

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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 focusses on sedentary behaviour at the individual level of analysis. Using the behavioural epidemiology framework, the chapter summarizes issues concerning individual-level knowledge and approaches. It focusses mainly on correlates and behaviour change. Correlates discussed include whether sedentary behaviour and physical activity are associated and the coexistence of other health behaviours. Barriers to sedentary behaviour change are considered. A number of psychological theories are covered that have been popular in physical activity research, and their application to sedentary behaviour is commented upon. Moreover, alternative perspectives are covered, including notions of behavioural economics, habit, and nudging. Coverage is given to sedentary behaviour interventions, including those involving education, prompting, and wearable technology. Behaviour change techniques that seem to be useful for successful behaviour change are covered.

16.1 Introduction: Psychological and Personal Factors

Sedentary behaviour is ultimately undertaken by individuals. However, any analysis of an individual behaviour cannot be done properly without due recognition of the wider social and environmental contexts and influences that are at play. The socioecological model, popular in the physical activity and sedentary behaviour literature, puts the individual at one of many levels, including social, environmental and societal levels of behavioural influence [1]. Please refer to Chap. 15 for further detail on the ecological model and its application to sedentary behaviour. For the purposes of the present chapter, the focus will be on the individual. This will include individual-level correlates of sedentary behaviour, individual barriers to being less sedentary, individual-level theories and frameworks, and interventions to

S.J.H. Biddle (✉)
Institute of Sport, Exercise and Active Living (ISEAL), Victoria University, Melbourne, VIC, Australia
e-mail: stuart.biddle@vu.edu.au

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Table 16.1 The behavioural epidemiology framework applied to sedentary behaviour at the level of the individual

Phase of the framework	Key issues	Example at the individual level
1. Measurement of sedentary behaviour	How do we measure sedentary behaviour in individuals?	An ecological momentary assessment diary assessing patterns of sedentary behaviour across the day
2. Establishing a relationship between sedentary behaviour and health outcomes	What is the evidence linking high levels of sedentary behaviour of individuals with health outcomes?	Showing effects of prolonged sitting on health biomarkers through a controlled lab study
3. Correlates of sedentary behaviour	What are the individual-level correlates or determinants of sedentary behaviour?	Identifying individual psychological variables that are associated with different levels of sedentary behaviour
4. Interventions to reduce sedentary behaviour	Can we reduce high levels of sedentary behaviour in individuals?	Testing behaviour change techniques (e.g. self-monitoring through wearable technology) to change sedentary behaviour
5. Translation of findings	Can we roll out intervention and other findings?	Applying results from approaches above to a wider roll-out of strategies (e.g. provision of wearable technology)

reduce sedentary behaviour that have been targeted at individual-level factors. However, it is not always easy to separate individual from, say, social and environmental approaches as they operate along a continuum of distal and proximal influences.

One framework that is helpful in understanding the landscape of the individual in the context of sedentary behaviour is the behavioural epidemiology framework [2]. This is applied to the individual in Table 16.1. For the current chapter, the main focus will be on phases 3 (correlates) and 4 (interventions).

An important issue to recognize by way of introduction is that individuals undertake a variety of sedentary behaviours across many different settings. These are listed in Table 16.2, although this is far from inclusive or complete. But it allows us to see that (a) we indulge in various sedentary behaviours which may have different correlates and require different interventions, and (b) behaviours will occur in different settings, each with its own social and environmental influences.

16.2 Individual Correlates of Sedentary Behaviour

In addition to the systematic review that was conducted for Chap. 4 of this book, several systematic reviews of the correlates of sedentary behaviour exist on young people [3–8], adults [9, 10], and older adults [11]. The findings for children and

Table 16.2 Different sedentary behaviours and their main contexts

	Home	Work/school	Travel	Community
TV	✓	✓		
Computer use[a]	✓	✓		
Reading	✓	✓	✓	
Working (e.g. desk work)	✓	✓		
General sitting	✓	✓	✓	✓
Sedentary socializing	✓			✓

[a]The use of computers is becoming ever more versatile, with tablet devices, for example, being used in increasingly diverse settings. For example, they could be used in "travel" when not driving. Hence, this table is indicative only

adolescents highlight significant gaps in our knowledge concerning the correlates of sedentary behaviour. 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 ("screen time") have received little attention. In addition, the findings suggest that the majority of correlates identified are unmodifiable correlates (moderators). These include body weight, body mass index (BMI), ethnicity, 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. [8] 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 time. Evidence concerning sex was inconsistent. Weight status tends to be associated with screen time but not overall sedentary behaviour, possibly reflecting dietary effects (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. Rhodes et al. [9] conducted a systematic review and reported that most of the studies used TV viewing as a measure of sedentary behaviour, were of a cross-sectional design, and focussed on socio-demographic and behavioural correlates. The review demonstrated that those who watch more TV tend to be less educated, older, unemployed or retired, and have higher BMI. In contrast, computer use was higher among younger, more educated adults, with computer game users more likely to be male. Although psychological correlates have not been widely studied, a sedentary attitude construct (e.g. preference, utility, and enjoyment) emerged as a strong positive correlate of all sedentary behaviours.

Greater depressive symptoms and lower life satisfaction also emerged as potential correlates. Rhodes et al. noted that there are differences in correlates by the type of sedentary behaviour investigated. For example, age and education were correlates of both TV viewing and computer use but related to these behaviours in opposite directions. Therefore, it is important to study multiple sedentary behaviours and to avoid generalized assessments of just "screen time" correlates.

From a review of 22 studies reporting correlates of sedentary behaviour in older adults, Chastin et al. [11] 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 for sex was inconsistent, as were trends on the correlates of marital status. TV viewing is less for those in employment, including 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.

In summary, many correlates identified across the lifespan, at the individual level, tend to show somewhat inconsistent trends 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 whether other health behaviours coexist with sedentary behaviours.

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. Unfortunately, some disciplines (e.g. exercise physiology) still do. But in the context of the contemporary sedentary behaviour literature, it has become accepted that sedentary behaviour, in a practical sense, refers to periods of sitting with low energy expenditure but excludes sleep [12]. This means that it is best seen as part of a continuum of "movement" behaviours, as shown in Fig. 16.1. The behaviours depicted are mutually inclusive 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 behaviour on the continuum will be more highly correlated than others over, say, a 24-h period. It is far more likely that time spent in 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 (shown as "low" light physical activity in Fig. 16.1), are more or less the opposite of sitting. The act of standing negates the act of sitting. It is more complicated, however, when analysing MVPA. To what extent, therefore, do high levels of sitting detract from taking part in, say, 1 h of MVPA daily? Given that there are 24 h in a day, it is logical to assume that any combination of sedentary and MVPA 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 [13]. The latter might be reflected in

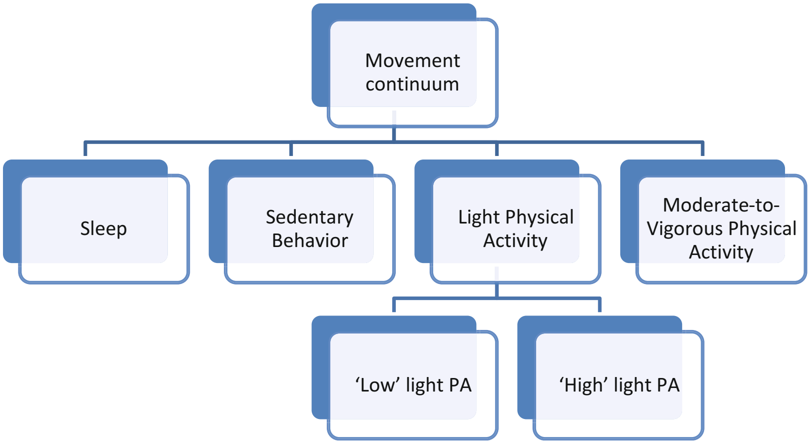


Fig. 16.1 A movement continuum, depicting sedentary behaviour

someone who is on their feet most of the day but does little or no MVPA or "exercise".

The above concepts, therefore, require an investigation of the correlates of both sedentary behaviour and physical activity. To understand if sedentary behaviour is associated with physical activity, a perusal of evidence concerning behavioural correlates is required.

One of the first to systematically document an association between physical activity and sedentary behaviour was Sallis et al. [14] in their review of the correlates of physical activity in young people. They reported that lower levels of physical activity were associated with more sedentary behaviour after school and at weekends. This highlights the potential importance of the context of sedentary behaviour given that two settings are reported rather than "total" sedentary behaviour.

In a study of temporal patterning of sedentary behaviour across weekdays and weekend days in adolescents, Biddle et al. [15] reported that while TV viewing was most likely to occur in the middle to late evening, physical activity tended to peak earlier in the evening. This suggests that the two behaviours may be able to coexist across the day. However, if an adolescent chooses to watch TV in the early evening, this logically would reduce their chance of being physically active, at least in the after-school period. This "critical hours" period has been highlighted in the literature [16].

Two systematic reviews have now been published that specifically address the association between sedentary behaviour and physical activity. Pearson et al. [17] reviewed children and adolescents, while Mansoubi et al. [18] reviewed evidence on adults. Pearson et al. conducted a comprehensive meta-analysis of 254 independent samples from 163 papers. As shown in Fig. 16.2, with the exception of reading, all sedentary behaviours are inversely associated with physical activity, but most are small associations. Homework, internet and reading involved only 3–5 studies.

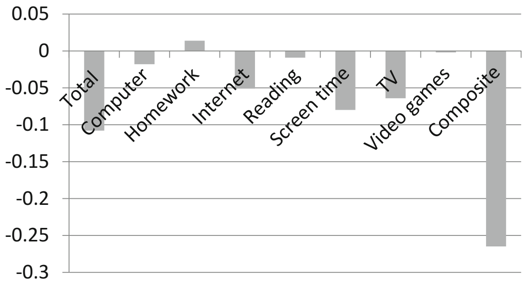


Fig. 16.2 Associations (Pearson's *r*) between different sedentary behaviours and physical activity in young people (adapted from [17])

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 objective measures of sedentary behaviour and for those judged as higher quality. The authors of the meta-analysis 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. [18] reviewed 26 studies where associations were reported between sedentary behaviour and physical activity. Sedentary behaviour measures comprised TV viewing, general screen time, occupational sedentary behaviour, "overall sitting time", and "overall sedentary time". Physical activity included work physical activity, active transport, leisure-time physical activity, domestic physical activity, walking, "general" physical activity, light physical activity, MVPA and "exercise". TV viewing was the most commonly assessed sedentary behaviour and showed inverse associations with physical activity that were small (50%), moderate (25%), and large (8%; one paper). TV viewing was inversely associated with all five papers studying exercise as the physical activity measure. Total sedentary time was inversely associated with light physical activity and MVPA. Additional analyses showed that larger associations were evident for studies using objective measures, and of higher quality, similar to Pearson et al. [17]. However, most associations across the full review revealed small-to-moderate associations only.

In conclusion, sedentary behaviour and physical activity are associated, but this association is generally small, is somewhat dependent on measurement and study quality, and may be a function of context or type of sedentary behaviour. It is clear that whatever association is evident, any form of "displacement" that might operate is likely to be small, and we should consider the two behaviours as largely independent. The only exception to this is when light physical activity is likely to be more strongly associated with total sedentary time. Overall, therefore, the practical outcome of this evidence is that we should promote sedentary behaviour reduction alongside increases in physical activity.

16.4 Sedentary Behaviour and Associations with Other Lifestyle Factors

Extensive epidemiologic research and emerging laboratory studies are showing that higher levels of sedentary behaviour can have adverse health consequences [19]. However, one question is whether this link is mediated by the coexistence of other health behaviours. For example, do those who watch a great deal of TV also have high levels of unhealthy snack consumption? To synthesize the evidence on the association between sedentary behaviour and diet, Pearson and Biddle [20] conducted a systematic review for children, adolescents, and adults. A total of 53 studies and 111 independent samples were analysed, with most on adolescents (72 samples), then children (24 samples), with fewer on adults (14 samples). Studies predominantly had a measure of screen time (mainly TV viewing) or total sedentary behaviour. However, a range of dietary outcomes was assessed, including fruit and vegetable consumption, energy-dense snacks, fast foods, and total energy intake.

Figures 16.3, 16.4, and 16.5 show the results for children, adolescents, and adults, respectively, for five key dietary outcomes. It is evident, first, that there are rather few studies for some age groups and outcomes and, second, the results are broadly consistent across the three age groups. 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. An updated review by Hobbs et al. [21] confirmed these findings. Moreover, they found a few studies investigating sedentary behaviour and diet in preschool children, an age group not reported by Pearson and Biddle [20]. Hobbs et al. concluded that "sedentary behaviour in preschool children seems to be trending towards an association with elements of an unhealthy diet, yet caution is required when interpreting results due to the paucity of studies" (p. 1183).

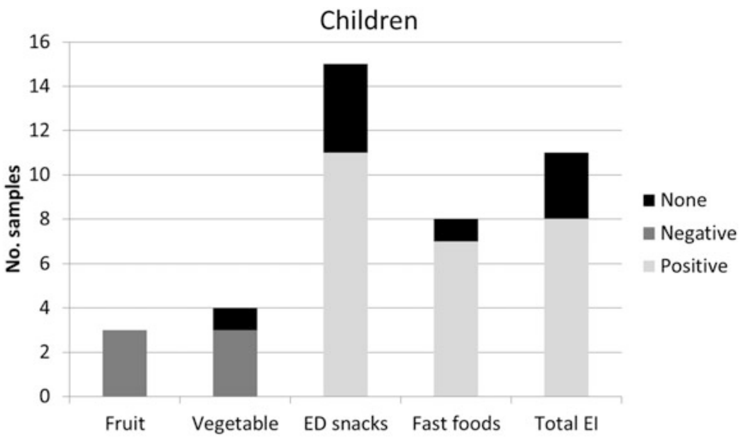


Fig. 16.3 Number of studies showing positive, negative, or no association between sedentary behaviour and different diet outcomes for children (adapted from [20]). Abbreviations: *ED* energy dense, *EI* energy intake

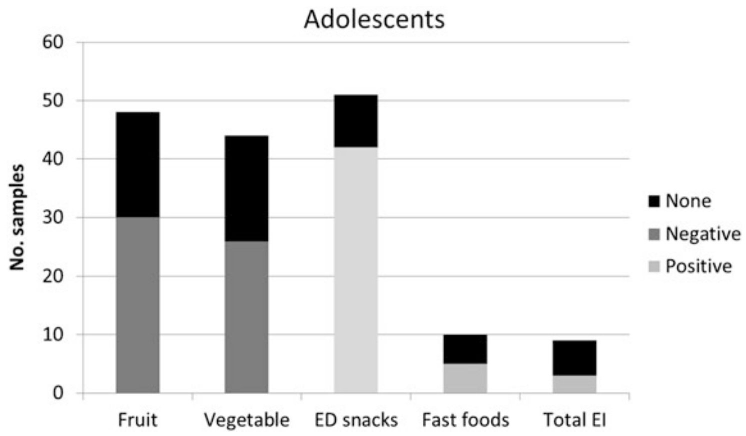


Fig. 16.4 Number of studies showing positive, negative, or no association between sedentary behaviour and different diet outcomes for adolescents (adapted from [20]). Abbreviations: *ED* energy dense, *EI* energy intake

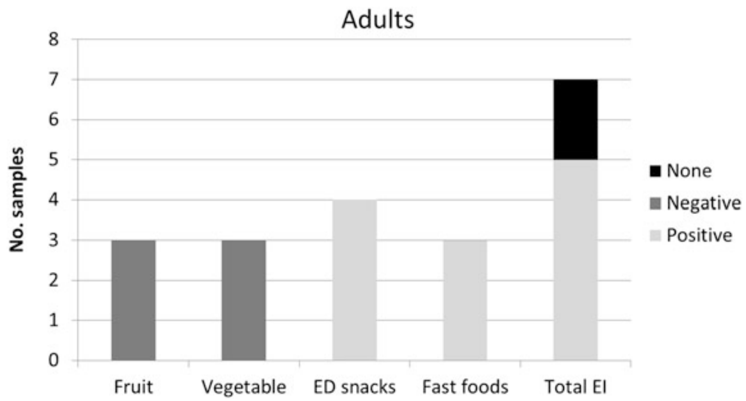
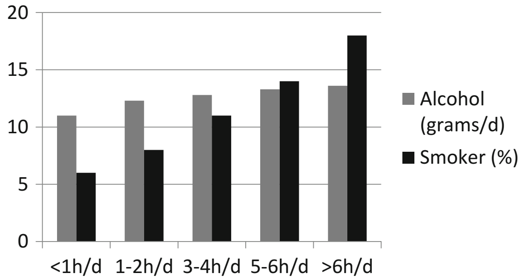


Fig. 16.5 Number of studies showing positive, negative, or no association between sedentary behaviour and different diet outcomes for adults (adapted from [20]). Abbreviations: *ED* energy dense, *EI* energy intake

In the more extensive review by Pearson and Biddle, the strength of association between sedentary behaviour and diet across all age groups 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.

Less evidence is available on the association of sedentary behaviours with other health behaviours. However, there is indicative evidence concerning alcohol

Fig. 16.6 Alcohol consumption and smoking across categories of TV viewing (adapted from [22])



consumption and smoking. Keadle et al. [22] reported large-scale population-level data from the National Institutes of Health (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 g/day for those with 7 or more hours per day. The increase was linear, as shown in Fig. 16.6, which also depicts a trend for smoking prevalence. However, the variability around the mean alcohol values was very high, leading to a very small effect size (0.06) when comparing the lowest with highest TV viewers. Moreover, the data are cross-sectional, and hence no inference on causality can be made. Prospective analyses of the NIH-AARP data focussed on predicting mortality and control for smoking as well as alcohol within a wider measure of diet quality.

The prospective study by Hancox et al. [23] is well cited for showing TV viewing in adolescence predicting BMI in adulthood. However, what is also interesting in this study is that in addition to an incremental increase in weight status across TV viewing categories, there is a parallel trend for smoking. This suggests a potential coupling of unhealthy behaviours.

A study in Belgium investigated changes in sedentary behaviour, other health behaviours and health markers in a sample of young people making the transition from school to higher education [24]. Data were collected in the last year of school and 1.5 years later at the beginning of the second year of college or university. BMI increased, especially in males, while sedentary behaviour changes were behaviour specific. TV viewing declined but internet use and studying increased. Alcohol intake also increased and was a predictor of BMI change. While sedentary behaviour and other behaviours changed in this transition period, it is not possible to conclude that sedentary behaviour is causing the change in, say, alcohol consumption. Social norms often dictate that alcohol consumption will rise during this transition anyway. Hence, more work is required on whether some sedentary behaviours trigger changes in other health behaviours, including diet, alcohol consumption and smoking. Moreover, these health behaviours could be strongly influenced by social and environmental context. While the author is old enough to remember academic colleagues smoking in committee meetings, this is now not possible due to both environmental and policy changes as well as social norms.

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. [25] conducted a qualitative "meta-synthesis" 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, 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 routinized 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.

One of the studies that formed part of the research synthesis reported by Minges et al. [25] was a small-scale interview study of nine obese children and their parents [26]. The interviews suggested that one barrier to reducing screen time in these children is that screen time itself is enjoyable, is easy to do, and develops competence at various tasks and games. Psychologists are well aware that this combination of factors is almost perfect for high levels of motivation! The challenge is to make sitting less and moving more both enjoyable and easy to do.

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 in the workplace, De Cocker and colleagues [27] said that several barriers were reported. These included productivity concerns, impracticality, awkwardness of standing, and the habitual nature of sitting.

16.6 Application of Models and Theories of Individual-Level Sedentary Behaviour

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." [28, p. 9]; it is a "coherent description of process" [29, 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 [30].

In physical activity research, it has been common to adopt intra-individual and interpersonal theories, with social and environmental theories being less commonly used [31, 32]. Whether such intra-individual theories are wholly applicable to sedentary behaviour has yet to be determined, but some theories or elements may have utility.

While the Health Belief Model could be considered a seminal approach to health behaviour theory [33], it has been more common in physical activity research to use social cognitive theory (SCT) [34], the transtheoretical model (TTM) [35, 36], and the theory of planned behaviour (TPB) [37]. Other approaches that have been used include self-determination theory (SDT) [38] and the health action process approach (HAPA) [39]. 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).

A recent 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 [40].

We have provided a comprehensive overview of the key theories applied to physical activity elsewhere [31, 41]. This section summarizes SCT, TPB, and TTM, and comments will be provided about their applicability to sedentary behaviour. A broader approach for behaviour change will then be discussed.

16.6.1 Social Cognitive Theory

Bandura's social cognitive theory (SCT) [34] suggests that we learn and modify our behaviours through an interaction between personal, behavioural, and environmental influences. We reflect on our actions, particularly in respect of thinking about the consequences of our behaviours (referred to as "outcome expectancies") and our own capabilities ("efficacy expectancies"). Thinking about consequences in sedentary behaviour could be simply thinking about the benefits and costs of being less sedentary. For capabilities, we will ask ourselves "can I do this behaviour?"—this reflects one's self-efficacy, which is a key element of SCT.

Bandura [34] 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)

Bandura identifies several main sources of self-efficacy beliefs, including prior success and performance attainment, imitation and modelling, and verbal and social persuasion. Performance attainment is thought to be the most powerful source of efficacy expectations because it is based on personal experience of success and failure. However, anecdotally, it seems that modelling of non-sedentary behaviour, such as seeing others stand in a meeting, may also be strong influences.

Self-efficacy is a popular topic of study within the physical activity domain and is often shown to be an important correlate of physical activity. However, its application to sedentary behaviour is still sparse.

16.6.2 Theory of Planned Behaviour

The TPB proposes that intention is the immediate antecedent of behaviour and that intention is predicted from attitude, subjective norm (normative beliefs), and perceptions of behavioural control. Ajzen and Fishbein [42] 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 recognize that attitudes have both cognitive and affective elements. The affective elements of attitude have usually been shown to be superior for behaviour change [43]. To this end we need more work on testing how we can elicit positive feelings associated with less sedentary behaviour when many sedentary behaviours are designed for apparent "pleasure" (e.g. comfortable chair, interesting TV programme).

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 [44] as "the perceived ease or difficulty of performing the behaviour" (p. 132) and is assumed "to reflect past experience as well as anticipated impediments and obstacles". 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 [45] conducted 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 sedentary behaviour questions for "general" sedentary behaviour and weekday and weekend contexts. School/work and leisure-time contexts were also included. Across these various analytic models, 9–58% of the variance in intentions was explained. For behaviour, it was 8–43%. The authors concluded that this "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'". However, no measure of habit was included. With unpublished data, we have found that TPB associations with behaviour are strongly attenuated by the inclusion of a measure of habit strength [46]. Moreover, Kremers and Brug [47] showed that intentions were unrelated to behaviour in adolescents with strong habits, and it was suggested that interventions to decrease sedentary behaviour should not just provide information to increase motivation. Reducing sedentary behaviour, therefore, may require disrupting environmental factors that automatically cue habitual behaviours.

Rhodes and Dean [48] applied the TPB in a cross-sectional study to understand the motives underlying four common sedentary leisure activities: TV viewing, computer use, reading/music, and socializing. A sample of just under 400 adults, including students, completed measures of the TPB for each of the four leisure behaviours and self-reported behaviour. The authors concluded that sedentary behaviours may be intentional and planned. Attitudes, but not PBC, seemed most strongly associated with intentions and behaviour.

16.6.3 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. Some claim that HAPA is superior to other social cognitive approaches because of its combination of stage and continuous approaches [49]. The model combines stages with self-efficacy, pros and cons, risk perception, intentions, and goal setting and has been tested in physical activity research [49] but not sedentary behaviour.

16.6.4 Self-Determination Theory

Self-determination theory (SDT) has become a popular approach in physical activity psychology [50], but little has been said about its likely use or relevance to sedentary behaviour other than computer gaming [51]. It is a multifaceted 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 context 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 [52, 53]. These might all apply to a range of leisure-time sedentary behaviours, such as computer use.

16.6.5 Other Theories and Frameworks

The intra-individual theories discussed so far are commonplace in health behaviour research. However, it could be argued that they are too narrow and fail to capture other important elements. The parsimonious "Behaviour Change Wheel" (BCW) [54, 55] is a highly useful framework that can be used at various levels, including individuals, groups, and communities.

There are three key elements to the BCW: sources of behaviour, intervention functions, and policy categories. In the BCW, the three main sources of behaviour (B) are capability (C), opportunity (O) and motivation (M)—the "COM-B" approach. Understanding the specific behaviour in question is critical. Sedentary behaviour, for example, can take many different forms and take place in different contexts. The COM-B framework allows for an analysis of the physical and psychological capabilities to undertake the behaviour, the social and physical opportunities, and both reflective and automatic forms of motivation (discussed later).

The intervention functions are the types of interventions that might be delivered and can include such factors as coercion, training, modelling, environmental restructuring, education, and persuasion. Interventions are likely to have more than one intervention function operating, such as including education and environmental restructuring. A good example of this might be the introduction of a sit-to-stand desk in the workplace (environmental restructuring) that has an education component covering the potential benefits and use of the desk.

The third element of the BCW comprises the policy categories that can be used to deliver the intervention functions. These can include guidelines, environmental/social planning, communication/marketing, legislation, service provision, regulation, and fiscal measures.

The BCW recognizes a dual-process approach to motivation through both reflective and automatic processing. Reflective approaches are common in psychology, and it is where people process information, think and reflect, and then, possibly, act out the behaviour. Automatic processing, however, is at a lower level of conscious processing, and it is where behaviours might occur through either environmental "nudging" or acts driven by affective responses (sometimes "gut reactions") but with little forethought or planning. For example, weighing up the pros and cons is reflective motivation. Once the reflective decision-making processes have taken place, the behaviour in question may or may not be undertaken. On the other hand, some behaviours will be undertaken in a much more automatic way. This is likely for many sedentary behaviours. Little or no thought may go into whether someone sits or not. Often it is automatic, driven by social conventions and environmental opportunities. If there are no seats, you can't sit down!

Automatic Motivation: Habits and Nudging

Automatic processing is associated with notions of "habit". 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 sitting at a desk at work or sitting 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 widescreen, multichannel, high-definition TVs. This will make the behaviour of sitting more habitual and will lessen the need for reflective decision-making.

These arguments and examples are consistent with behavioural choice theory advocated by Epstein and colleagues in studies on sedentary behaviour and physical activity [56, 57]. Behavioural choices are made on the assessment of the accessibility of the behaviour and the liking (reinforcement value) of the behaviour. Kremers et al. [58] 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 [59] 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.

Nudging and Sedentary Behaviour

Based on behavioural economics, the concept of "nudging" has been proposed [60]. 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" [61, p. 12] and is "designed to understand factors that influence choice among alternatives" [62, 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 often involves altering small-scale social and physical environments to cue desired behaviours [63]. So whereas this approach might not be considered "individual" in its orientation, it is difficult to separate the two.

A typology by Hollands et al. [63] 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, Hollands et al. found that over 70% of studies focussed 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. Nothing has been done on sedentary behaviour.

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 [64]. 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. car, phone, kitchen goods) based on looks and "feel" more than 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, as behavioural scientists, we must seek to find ways of making physical activity attractive and "affectively pleasing" and sedentary alternatives less so. Less of an emphasis on longer-term health outcomes is also recommended [65, 66].

16.7 Individual-Level Approaches to Reduce Sedentary Behaviour

Interventions designed to reduce sedentary behaviour have proliferated in recent years. Early work focussed on young people's leisure time, primarily TV viewing and then screen use [67], and subsequent intervention work has expanded into the community [68], workplace [69, 70], schools [71], and use of technology [72, 73]. 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

The majority of interventions for young people have been with children rather than adolescents and with a focus on TV viewing and screen time. A review of reviews has shown that the effects are modest across a range of interventions [67]. In addition to environmental changes (e.g. provision of a TV monitoring device), strategies can be classified as informational, behavioural, and social support. Informational strategies might include education, goal setting, and problem-solving, while behavioural strategies can include reminders, prompts, planning, and reinforcement. Social support was found to be important for children as the role of parents is often quite crucial to achieve sedentary behaviour change.

One of the first randomized controlled trials (RCT) for sedentary behaviour reduction in children was reported by Robinson [74]. 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. 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.

Results from this RCT are shown in Fig. 16.7. This depicts a clear reduction in TV hours per week for the intervention group, although the effect size just for this group is moderate (−0.55) due to large variability in the data. The intervention was primarily designed as a weight management trial, and raw BMI data shown in Fig. 16.7 show that both intervention and control groups increased their BMI over

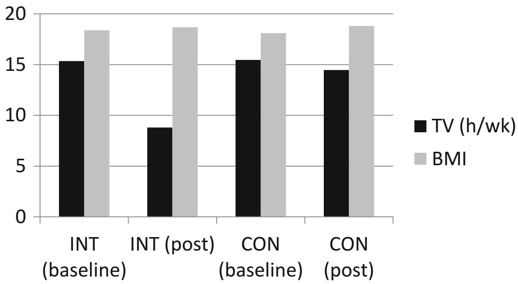


Fig. 16.7 Intervention and control group scores for TV viewing and BMI at baseline and post-intervention reported by Robinson (adapted from [74]). Abbreviations: *INT* intervention group, *CON* control group

the time course of the trial. This is not unexpected for this age group. However, an effect in favour of the intervention group is shown through differences in BMI change between the two groups after adjustment for baseline and confounders (not shown in Fig. 16.7). Overall, however, while the trial shows changes in sedentary behaviour, the intervention itself is very extensive, with many weeks of education and participation in a total avoidance of screen time. Therefore, it is questionable how feasible this is to roll out. For further detail on specific interventions targeting sedentary behaviour in children and adolescents, please refer to Chap. 17.

16.7.2 Interventions for Adults

Initial intervention research focussed on young people. However, in the past few years, there has been an explosion of interest in sedentary behaviour with adults, mainly through the context of work. Much of this has focussed on changes to the office environment, such as provision of sit-to-stand desks, but some have used more individual approaches.

In a randomized controlled trial conducted in workplaces in the Netherlands, Verweij et al. [75] examined the effectiveness of a draft occupational guideline aimed at preventing weight gain through employees' physical activity, sedentary behaviour and dietary behaviour. The guideline included strategies to prevent weight gain and was designed for use by occupational physicians. Participants were randomized to either a usual care control group comprising 249 employees with 9 occupational physicians or an intervention group of 274 employees with 7 occupational physicians. The intervention was delivered by the occupational physicians who had received behaviour change training suitable for brief consultations. Intervention participants received up to five 20–30 min counselling sessions over 6 months. Participants could choose which target behaviour they would like to discuss (decreasing sedentary behaviour, increasing physical activity or reducing snacking). The counselling sessions covered pros and cons of behaviour change, perceived confidence to change, goal setting, and potential barriers to change. Sedentary behaviour, physical activity, and dietary behaviour were all assessed through self-report at baseline and immediately post intervention.

At the end of the 6 months, participants in the intervention group had significantly lower sedentary behaviour at work (−15 vs. −3 min/day) and increased fruit intake (+1.5 vs. −0.8 pieces/week). It was concluded that guideline-based care can result in less sedentary behaviour at work and increased fruit consumption, but work is required to increase adherence by the occupational physicians to the guideline and to enhance attendance by participants.

Employing prompting software on computers at work is another individual approach to reducing sitting time at work. This type of software provides prompts and advice on the screen at regular intervals, such as reminding users to take a break. In a small-scale randomized trial, Evans et al. [76] investigated the effect of installing prompting software on work computers to reduce long uninterrupted sedentary bouts and total sedentary time at work. One group ($n = 14$) received a brief education session on the importance of reducing prolonged sitting at work, while the other group ($n = 14$) received the same education along with software for their computer that reminded them to stand up every 30 min. Sitting time was measured objectively using an inclinometer ("activPAL") device for 5 days prior to the intervention and for the 5 days of the intervention. The main outcome measures were the number of bouts of sitting longer than 30 min and the total amount of sitting accumulated in bouts longer than 30 min. Results showed that during the intervention period the education-plus-prompt group reduced the number and duration of sitting events longer than 30 min, and this compared to a lack of change in the education-only group. Please refer to Chap. 18 for further detail on workplace programmes aimed at limiting occupational sitting.

We conducted a RCT aimed at reducing sedentary behaviour in younger adults at risk of type 2 diabetes [68]. The intervention comprised a 3-h educational workshop and self-monitoring. Each individual in the intervention arm was invited to attend a single group-based structured education workshop delivered by two trained educators aimed at targeting knowledge and perceptions of risk factors for type 2 diabetes and promoting sedentary behaviour change. The workshop was based on previous structured education programmes [77]. Participants were given a small self-monitoring device which also prompted standing up after prolonged periods of sitting. The primary outcome was objectively assessed sedentary behaviour. Results showed that the intervention was not successful in reducing sedentary behaviour for the intervention group compared to controls. It was concluded that a single-session educational approach with self-monitoring, "even when based on prior experience and using a patient-centred approach, is simply not potent enough to bring about sedentary behaviour change" (p. 8). The population of young adults who were at risk of, rather than been diagnosed with, type 2 diabetes were difficult to recruit to the workshops and may also be reluctant to pursue much behaviour change. Chapter 20 provides further detail on interventions directed at reducing sedentary behaviour in persons with pre-existing disease.

The use of technology is one behaviour change approach that is starting to be applied to sedentary behaviour. Bond and colleagues [73] recruited a small number of overweight/obese middle-aged adult participants to a study that utilized smartphones for self-monitoring and promoting of sedentary behaviour change. Displays on the phone showed a dial depicting the number of minutes left until the next activity (non-sedentary) break, an activity prompt, a display showing whether the activity goal had been met, and a reward indicator. Participants had three physical activity (sedentary break) counter-balance conditions, each for 7 days: a 3-min break after sitting for 30 min; a 6-min break after sitting for 60 min; a 12-min break after sitting for 120 min.

Results showed that the use of smartphone technology was successful in reducing sedentary behaviour. The 3-min condition was most successful, with a 47 min/day reduction in sedentary behaviour. This was followed by the 6-min condition (45 min/day) and 12-min condition (26 min/day). The majority of this time was replaced with light physical activity and some by MVPA.

Prompting sedentary behaviour reductions using phones has also been reported by Kendzor et al. [72]. They achieved a reduction in daily minutes of sedentary time of 24 min, although the effect size comparison with the control group was small (−0.24).

16.8 Use of Behaviour Change Techniques

Behaviour change techniques (BCTs) are important "active ingredients" that individuals may use to reduce their sedentary or other health behaviours. A recent review has been published on the use of certain BCTs in 26 sedentary behaviour interventions in adults [78]. Interventions were also rated as being "very promising" (39%), "quite promising" (21%), or "non-promising" (39%), depending on the outcomes of the intervention. Figure 16.8 shows the key individual-oriented BCTs reported in this review. A subsample of studies focusing only on the workplace was also analysed.

Results show that several techniques might be effective, including self-monitoring, goal setting and feedback. These elements can act as part of a feedback loop whereby people monitor their sedentary time, receive feedback, and set goals to change their behaviour. Further self-monitoring and feedback can allow for reinforcement of behaviour or altering of goals.

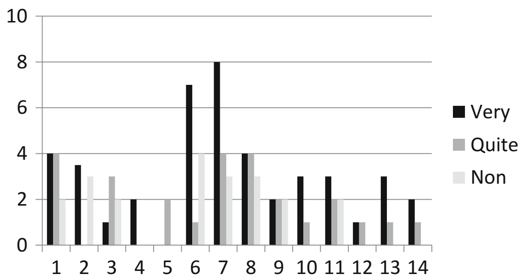


Fig. 16.8 Sedentary behaviour change techniques used in interventions reported by Gardner et al. [78]. *Key*: (1) problem-solving, (2) goal setting (outcome), (3) review behavioural goals, (4) discrepancy between current behaviour and goal, (5) commitment, (6) feedback on behaviour, (7) self-monitoring [12], (8) information on health consequences, (9) prompts/cues, (10) behavioural practice/rehearsal, (11) behaviour substitution, (12) habit formation, (13) pros and cons, (14) social reward

16.9 Evaluation and 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 discussed in this chapter, 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. Using the behaviour change wheel as a framework, it is important to recognize that successful interventions are likely to be the result of several factors:

- Analysing the behaviour itself using the COM-B framework. For example, there are multiple sedentary behaviours taking place in different settings.
- Recognizing various intervention functions or ways of approaching behaviour change. This might involve education, persuasion, or other methods. We need to analyse what is both feasible and acceptable to individuals for behaviour change.

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 is making inroads into individual, social and environmental changes, thus allowing for some success.

16.10 Summary

Sedentary behaviour research has gained huge momentum over the past decade or so. 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 behaviour change in the face of a social, cultural, and physical environment that encourages sitting or lack of movement.

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Chapter 17
Specific Interventions Targeting Sedentary Behaviour in Children and Adolescents

Jo Salmon, Harriet Koorts, and Anna Timperio

Abstract It has been 17 years since the first interventions to reduce children's sedentary behaviour were published. However, child and adolescent engagement in sedentary behaviour remains high. There have been more than 40 interventions to reduce children's and adolescents' screen time, but strategies to reduce or break up overall sitting throughout the day have been infrequently studied. Reducing sitting in the school setting via active breaks and an active curriculum, and environmental changes in the classroom (e.g. sit–stand desks) show promise. The home and transport settings have infrequently been targeted. 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 programmes 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 be integrated into current systems and target not just the individual, but sociocultural norms and physical, organizational, and policy environments to effect lasting and wholesale changes in sedentary behaviour at a population level.

17.1 Introduction

Objective measures show that children are sedentary (sit or recline while expending less than 1.5 metabolic equivalent units of rest) for more than 60% of their waking hours [1]. While rest is physiologically important for recovery after exertion,

J. Salmon (✉) • H. Koorts • A. Timperio
Institute for Physical Activity and Nutrition, Deakin University, Burwood, Australia
e-mail: jo.salmon@deakin.edu.au; harriet.koorts@deakin.edu.au; anna.timperio@deakin.edu.au

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excessive periods of sitting throughout the day can be harmful to health. The health effects of total volumes of sitting is still emerging for child populations [2]; however, there is more consistent evidence of adverse effects from engaging in excessive amounts of particular sedentary behaviours (e.g. television viewing) [3]. This evidence has been recognized by many government agencies which have subsequently released public health guidelines to limit the amount of time children and adolescents spend in electronic media (screen time) for non-educational purposes to 2 h/day (or 1 h/day for preschool-aged children) [3–6]. Please refer to Sect. 1.4 for further details on sedentary behaviour recommendations.

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 [7]. In North America, self-reported media use doubled from the early 1960s (37 h/week) to 2009 (75 h/week) [8]. Clearly, there is a need for effective interventions in child and adolescent populations. For additional details on sedentary behaviour prevalence estimates in children and adolescents, please refer to Chap. 4.

In spite of substantial research into the efficacy of health promotion interventions, there has not been a corresponding increase in the use of effective programmes in practice [9]. 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 programme diffusion: dissemination (e.g. how well information on the programme is spread); adoption (e.g. whether the setting chooses to uptake the programme); implementation (e.g. how well the programme is delivered during trials); and sustainability (e.g. whether the programme can be maintained over time) [9]. If sedentary behaviour interventions are to have a sustained impact in 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 at scale is required [10].

17.2 Conceptual Framework for Sedentary Behaviour Interventions

There has been a recent call in the physical activity field for policy-relevant research and programmes that align with organizational policies and targets and the political will of the government [11]. If research placed greater focus on intervention effectiveness, reach and adoption, resource/cost demands, contextual factors, and implementation requirements, the usability of research for policy makers would likely increase and the uptake of interventions into practice would improve [12]. 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. Scalability can be defined as being able to implement an efficacious programme under real-world conditions with a representative percentage of the population and retain effectiveness [12]. In addition, programmes should focus on key settings or contexts in which children 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 [13], these theories are often not useful for understanding and influencing children's sedentary behaviours. One reason for this is that sitting behaviours tend to occur habitually and automatically, without conscious thought. With children, habitual sitting behaviours may 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 under the control of parents/carers, teachers, and other adults who are responsible for them and their behaviour and come with their own expectations. For example, the expectation of a teacher for children to sit still 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. Therefore, strategies that support children to break sitting habits and normalize standing and moving in settings traditionally associated with sitting behaviours are needed.

Figure 17.1 depicts a simple conceptual framework for guiding sedentary behaviour interventions that acknowledges the importance of programme 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), achieve a long-term sustained impact, and that are also ideally 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 that resides within the education system. This then informs which agents of change to target (e.g. school principals, teachers, parents) and the context of the target (ideally a programme will be flexible to suit different populations and situations). Intervention targets should consider individual (e.g. habit), sociocultural (e.g. norms, parental/carer, and teacher influences), organizational (e.g. organizational readiness to change), physical environmental (e.g. no alternative to sitting in class), and policy aspects.

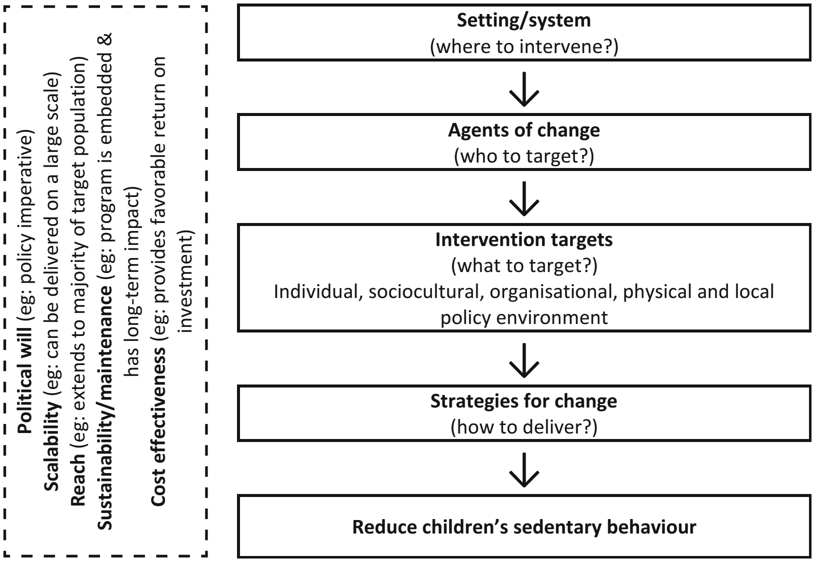

Fig. 17.1 Conceptual framework for scalable, policy-relevant interventions to reduce children's and adolescents' sedentary behaviour

Programme flexibility is related to improved implementation, ensuring initiatives are more likely to fit the user and organization's existing needs and practices [9]. Providing information on how to adapt an intervention for improved contextual fit is a critical aspect of a dissemination strategy [14]. For instance, children's sitting habits could be modified through changes to pedagogical approaches to curriculum delivery in school (e.g. active lessons) and outside of school (e.g. active homework). Sociocultural changes could include making it acceptable and "normal" to stand and move during class lessons. Changes to the physical and local (school) policy environment 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 integrated into current systems to change not just the individual, but sociocultural norms. The following sections provide an overview of strategies to reduce children's sedentary behaviour and consider whether these strategies have considered scalability and policy relevance.

17.3 Interventions to Reduce Children's Sedentary Behaviour

It has been 17 years since the first interventions to reduce children's and adolescents' sedentary behaviour, targeting television viewing time, were published [15, 16]. There have been numerous narrative and systematic reviews synthesizing evidence of the effectiveness of interventions to reduce children's sedentary behaviour [17], many with a focus on health outcomes such as overweight and obesity [18–20]. 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 synthesized the growing literature on reducing children's daily sitting, particularly during school hours. The specific features and focus of these interventions are summarized in the following sections.

17.3.1 Screen Time

Campbell and Hesketh [17] reviewed four intervention studies that aimed to reduce screen time in preschool-aged children. These were delivered in a variety of settings (preschool, childcare, health and community centres, and home). All of them focused primarily on educational programmes with parents and/or children involving either written materials or face-to-face delivery (one intensive programme delivered 39 weekly sessions to children, but only seven of those sessions targeted television viewing [21]). Two of the studies reviewed reported significant changes in television viewing time among preschoolers.

Since that review, a small number of published studies have focused on reducing sedentary behaviour in this younger age group. The Melbourne Infant Feeding Activity and Nutrition Trial (InFANT) programme was a cluster randomized controlled trial (RCT) with 542 first time parents and their 3-month-old infants (at baseline) who were randomly selected from 62 parent groups attending Child and Maternal Health Centres [22]. Parents received six 2-h sessions delivered by a dietician over 15 months. The programme focused on parental knowledge, skills, and social support around infant feeding, diet, physical activity, and television (TV) viewing. At the end of the intervention, children whose parents received the InFANT programme watched television for 16 fewer minutes per day compared with children in the control condition. The estimated cost of the programme was AUS$500 per family, which allowed for the fact that a trial recruits an artificially small number of participants relative to the workforce employed. As the programme took advantage of an existing child and maternal health centre setting (parent groups in Australia are usually set up by these centres after birth of the first child), the potential scalability of the programme is strong.

Overall, approaches to reduce screen time in preschool-aged children have primarily focused on the parents/carers with mixed success. Strategies to change the home environment have been studied less frequently. Some programmes (e.g. InFANT) discouraged parents from allowing children to have a television or other electronic devices in the bedroom; none of the interventions actively employed strategies to change the home environment to reduce young children's screen time. However, most delivered interventions through existing settings or systems, such as preschool, childcare, or health and community centres.

A review of ten systematic review and meta-analyses papers [23] and four systematic reviews have synthesized evidence from more than 40 interventions to reduce screen time in 5–17 year olds [18–20, 24]. Almost an equal proportion has been delivered in home/family or school settings, and only a small number of trials have been conducted in the primary care setting. Most of the interventions to reduce screen time had a strong focus on education/curriculum teaching children about the negative effects of excessive screen time and providing the children with skills to engage in alternative more active pursuits.

A number of interventions also targeted changes to the home environment including: advice to parents to remove the television from the child's bedroom and use of a television allowance unit to television sets and computer monitors in the home which limits the amount of time for which these devices can be switched on [16, 25–29]. On the whole these approaches appeared effective, although population reach and cost of the allowance units might be prohibitive for many families. A significant consideration in the implementation of strategies to reduce children's screen time is the constantly changing landscape of entertainment technologies, many of which are small and mobile.

In youth, for example, it appears that television viewing is declining and being replaced by other media. In North America, excessive TV viewing (>3 h/day) among youth is declining (from 43% to 35% between 1999 and 2009) [30], but self-reported media use doubled from the early 1960s (37 h/week) to 2009 (75 h/week) [8]. In other countries, such as the Czech Republic, the total amount of time spent watching television declined from 564 to 336 min/week (boys) and from 398 to 299 min/week (girls), while computer use increased from 280 to 552 min/week (boys) and from 60 to 328 min/week (girls) [8]. While health evidence and public health guidelines recommend limiting children's screen time to less than 1–2 h a day, identifying strategies for reducing screen time that remain current (in terms of technology) and that are scalable (e.g. accessing the family home across the population) may be challenging.

17.3.2 Sedentary Transport

Just as there have been reductions in some types of screen use, there have been large increases in the number of children driven to school by car. In Australia, the percentage of 5–9 year olds driven to school increased from 23% in 1991 to 67% in 2008 [31]. In the UK, car trips to school increased among 5–10 year olds from 27% (1989–1991) to 43% (2008) [32]. A systematic review of interventions for promoting active transport to school incorporated evidence from 14 studies [33]. Most of the studies ($n = 10$) used quasi-experimental designs with very few incorporating a control group, and only three studies reported on changes to sedentary transport (car travel) [34–36].

All three of these interventions 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) about cost of using a car versus active alternatives and climate change information. The pilot study with primary school children in Sydney, Australia, by Zaccari et al. [35] also used a travel diary, engaged local media, and held a school assembly to coincide with a statewide walk to school initiative. The local council conducted a safety audit of all key travel routes to school and identified potential road safety improvements. A 3.4% reduction in car trips to schools and a corresponding increase in walking to school were reported. The study by Wen and colleagues [34] (also with Australian school children) sought to improve the local neighbourhood by working with local councils. A 42% decrease in the number of children travelling to school by car in the intervention group was reported compared to a 32% decrease in the control group. In the UK, Rowland et al. [36] reported no change in car travel to school in the experimental (24%) or control groups (23%). No environmental changes were targeted in this study.

In summary, a surprisingly small number of interventions have been conducted to reduce sedentary transport in children and none were identified that targeted adolescent sedentary transport. As with the screen-based interventions, the studies that targeted changes to the physical environment appeared to show promise, although it is difficult to judge this based on the quasi-experimental study designs and the fact that environmental changes were not actually implemented during the interventions that reported on changes in car travel. Further research on the effectiveness of strategies to reduce sedentary transport among children and adolescents is clearly needed.

17.3.3 Sitting at School and Home

While television viewing does not appear to be increasing over time (as described above), the time spent sitting in class at school and at home is substantial and is likely to have increased (although no trend data on this is available). In the USA, the time spent studying or doing homework increased between 1981 and 1997 [37]. Novel strategies are needed to assess effective ways to reduce children's sedentary behaviour. A recent systematic review [38] and commentary review [39] synthesized and discussed the implications of a growing literature on the impact of height-adjustable desks and standing classrooms on children's sedentary behaviour. Studies have used a variety of furniture in the classroom that provide the opportunity for children to stand during class lessons including stand-based, sit-stand, or height-adjustable desks. 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. [38] identified eight studies, most of which reported small-to-moderate effect sizes (es) on reducing children's sitting time (es: 0.27–0.49), some for up to an hour less a day, and stronger effects on increasing children's time spent standing (es: 0.38–0.71).

There have also been pedagogical approaches to reducing sitting in class through active curriculum. A number of 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. On the whole, these approaches have been effective in reducing and breaking up children's sitting in class and throughout the day. In addition to environmental and pedagogical changes in the school setting, the Transform-Us! cluster RCT also incorporated active homework to reduce sitting at home as well as at school. Apart from screen-time interventions, few studies have examined novel approaches for reducing and breaking up sitting at home. In summary, most studies targeting sitting (as opposed to screen time) have used height-adjustable desks in classrooms, but have been small pilot studies. Very few have examined the longer-term effects of this approach on children's sedentary behaviour and the ensuing health and cognitive impacts. Even fewer have examined or tested suitability of implementation of these strategies "at scale".

17.4 Interventions Implemented at Scale

Taking a successful intervention from a controlled research condition and testing it within a real-world environment is the crucial step for scalability [12]. Intervention efficacy under controlled research conditions provides an indication of impact. Alone, intervention impact does not predict replicability at scale. Whilst large-scale implementation trials are recommended as a way to examine population impact [40], implementation trials frequently fail to replicate the effects observed under controlled intervention conditions.

The Dutch Obesity Intervention in Teenagers (DOiT) was a multi-component school-based obesity prevention programme that targeted adolescents aged 12–16 years in the Netherlands that was tested at scale [41]. The programme included classroom and environmental components to prevent adolescent weight gain and demonstrated efficacy through positive reductions in some measures of adiposity, reduction in sugar-sweetened beverage consumption, and screen-time viewing in an efficacy trial [41]. However, following the large-scale implementation of DOiT in a real-world context, the intervention did not have significant effects on screen time [42]. These reduced effects were attributed in part to challenges with implementation fidelity and adaptations to the programme following the dissemination process. Lack of organizational "buy-in" to the programme and consistent implementation of strategies to be delivered as intended have been identified as 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 [12, 14].

"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 fifth grade children in disadvantaged areas of Melbourne, Australia [43]. The real-world translatability of this programme was tested as a modified intervention, "Switch-2-Activity", in 2009 among 1566, 9–12 year old children [44]. 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 programme was subsequently adopted by the Department of Health and Human Services in Victoria, Australia, and offered to schools as an online programme over an 8 year period.

In summary, few interventions targeting children's sedentary behaviour have been implemented at scale. Even fewer have reported the cost-effectiveness [22], reach, or sustainability of the programme. As the evidence base of efficacious programmes 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, there have been few interventions that have attempted to reduce or break up overall sitting among children and youth. Most of these existing studies have focused on the school setting via active breaks and active curriculum, with some more recent studies trialling environmental changes in the classroom through the introduction of standing desks, though these studies have been very small [38, 39]. The home and transport settings have rarely been targeted. There is much scope to reduce sitting in these settings 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.

The majority of sedentary behaviour interventions have focused on children. Teachers and parents have been the most commonly targeted agents of change, and programmes 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 organizational 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 are 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 programmes is to remain relevant. New technologies for entertainment purposes are constantly coming onto the market, and television viewing appears to be declining in some countries [8, 30] and being replaced by alternative screen-based behaviours. 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 [45]. There is scope for interventions to harness new technologies to deliver strategies to reduce children's sitting time. For example, using wearable devices to monitor sitting time, incorporating time limiting devices into screen-based products for children, 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. 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.

A surprisingly under-studied area identified in this chapter is sedentary transport. While active transport initiatives have tested the effectiveness of active travel plans, such as mapping a safe route to school or supervised walk to school programmes [30], few studies have directly targeted reducing car dependency among children and adolescents. Those living within walking or cycling distance are the most obvious initial targets of such programmes. As are those parents who make the trip for the sole purpose of driving their child to school. Forty percent of parents who drive their child to school return home after the school drop-off [46]. Using global positioning system (GPS) units to track students en route to and from school may be one potential solution to overcome parents' concerns about safety [47]. Identifying and testing solutions to overcome sociocultural and environmental barriers can be daunting, but not insurmountable. Ideally, they would be developed in line with government policy and with other considerations for implementation (e.g. cost effectiveness, scalability, reach, sustainability).

Various studies have explored the complex process of implementing evidence-based programmes in the school setting [23], yet there is far less research regarding the most effective approach for systematically translating evidence-based programmes into practice. Cost-effectiveness and sustainability are rarely reported. Previous attempts at implementing evidence-based interventions in real-world settings have been criticized for lacking consideration of end-users and variability in their environmental and/or organizational contexts [40]. The lack of research which tests the real-world applicability and relevance of sedentary behaviour interventions makes replication and generalizability to other contexts difficult. Currently, we know less about the core components required for intervention success and the extent that programmes can be modified to suit local contexts whilst retaining positive outcomes [9] 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 will greatly advance our knowledge of this area and is what is required if the field is genuine about reducing population prevalence of sedentary behaviour and benefiting the current and future health of our youth.

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Chapter 18
Workplace Programmes Aimed at Limiting Occupational Sitting

Genevieve N. Healy and Ana D. Goode

Abstract On a typical working day, 50% of waking hours is spent in the workplace. This means that over the course of a lifetime, for most adults, a lot of time is spent at work. The workplace has a direct influence on the physical, social, economic, mental, and social well-being of workers and in turn the broader community. Moreover, many of the influences on behaviour, including sedentary behaviour, can be addressed within this setting. Given this, the workplace has been identified by the World Health Organization as a priority setting for health promotion. This chapter provides an overview on the workplace as a setting for addressing prolonged sitting time and programmes that have addressed this behaviour. Specifically, this chapter will: summarize evidence on how much workers sit; outline best practice approaches for addressing prolonged workplace sitting time; provide an overview of interventions that have targeted workplace sedentary time; and identify 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.

18.1 How Much Do Adults Sit at Work?

Since the 1960s, there has been a considerable increase (>40% for many countries) in time spent sedentary [1]. These changes are also reflected in the occupational domain, where increased computerization and modernization 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

G.N. Healy (✉) • A.D. Goode
School of Public Health, The University of Queensland, Brisbane, QLD, Australia
e-mail: g.healy@uq.edu.au; a.goode@sph.uq.edu.au

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100 calories in this time [2]. 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 [3].

Traditionally, occupational activity has been broadly classified by job role or other relatively crude categorical measures [4]. This has limited our understanding of individual-level variations in workplace activity and associated impacts on health [5] and work outcomes. This was highlighted in a 2010 systematic review of occupational sitting and health risks, where wide heterogeneity in study designs and measures was found [5]. The review recommended the use of measures with demonstrated reliability and validity to enable understanding of dose–response relationships [5]. This gap is, at least in part, being addressed through the recent advances in measurement technology. Affordable devices are now available that can measure not only time spent in different activities and postures, but also when the activities are occurring. Coupled with context-specific data (such as diaries of work times), this has provided valuable insights into workers' activity both in and out of the workplace.

Much of the activity monitor evidence to date has been from office workers. Using postural-based monitors, it has been observed that, on average, over two-thirds of the office work day is spent sitting, with the remainder of time primarily spent standing or in light intensity activities [6–9]. 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 office-based workers) from four organizations who were participating in the Stand Up Australia programme of research [7, 8, 10, 11]. Although there is relatively little variation by organization (overall mean

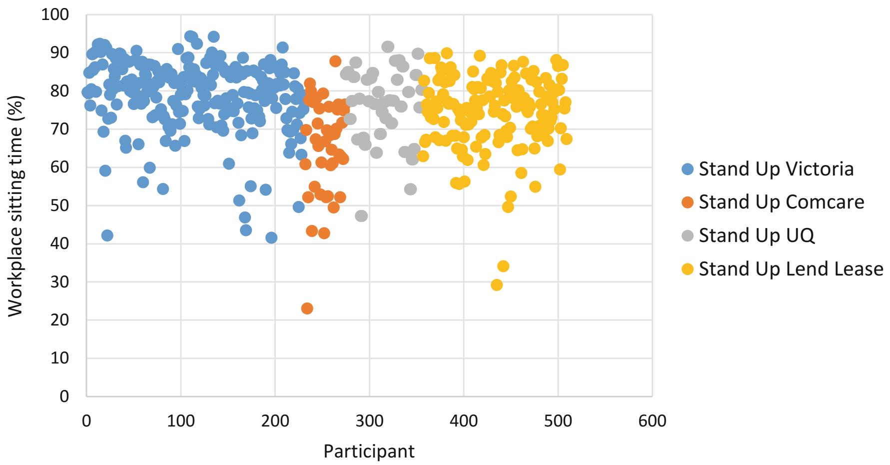

Fig. 18.1 Variations in total workplace sitting time (% of total worktime) in 496 participants from four organizations who participated in the Stand Up Australia programme [7, 8, 10, 11]

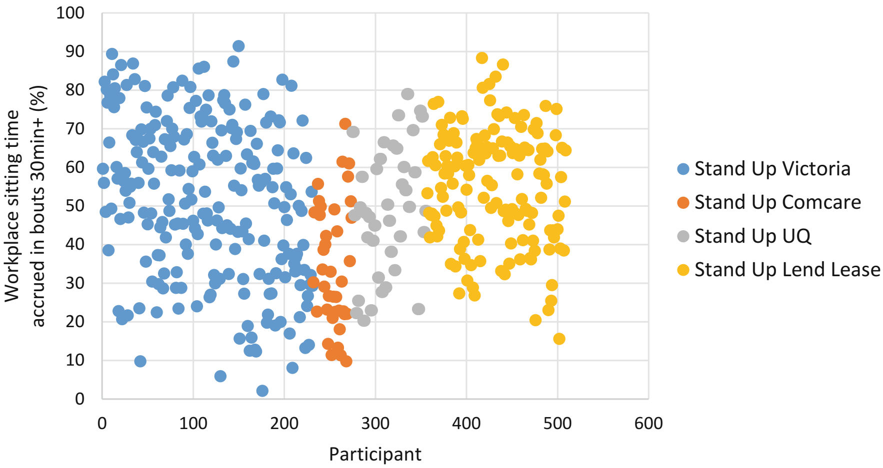

Fig. 18.2 Variations in prolonged workplace sitting time accrued in bouts of 30+ minutes (% of total workplace sitting time) in the Stand Up Australia programme [7, 8, 10, 11]

76%, standard deviation 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 workplace sitting time is accumulated, which is particularly important given the increasing evidence on the links between prolonged, unbroken sedentary time and poor cardiometabolic [12] and musculoskeletal health [13]. In office workers, it has been observed that a considerable proportion of workplace sitting time is accrued in prolonged, unbroken bouts of at least 30 min [6, 14]. 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 workplace sitting time was accrued in prolonged, unbroken bouts of at least 30 min in the 496 participants. However, some participants accrued <10% of their workplace sitting time in this form, whereas for others, more the 85% was accrued this way. When considered across all working hours, 40% of work hours on average (SD 18%) was spent in sitting bouts 30 min or greater in this group of participants ($n = 496$).

Activity monitor data has also been used to compare sedentary time of various occupational categories. Using hip-worn accelerometer data from the U.S. 2003–2004 National Health and Nutrition Examination Survey (NHANES), occupational categories with the highest proportion of time spent sedentary during an average day (i.e. including both work and non-work time) were engineers, architects, and scientists (65.0%) and management-related occupations (60.3%), while those with the lowest average daily sedentary time were waiters and waitresses (39.8%) and cleaners, hand packagers, labourers, and other helpers (42.4%) [15]. Examining work hours specifically, a study in 15 male bus drivers observed that 44% of work time was spent sedentary compared to 59.5% in non-work time [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 [17]. 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 [17].Collectively, this evidence suggests that exposure to sedentary time is high across multiple occupations, including both traditional white and blue collar fields. Indeed, it has been argued that the modern office may be failing to provide a safe system of work [18]. 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 [19]. The recommendations highlight the importance of regular changes in posture, including the avoidance of prolonged standing [19]. 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 [19]. Of key importance to note is that the evidence informing these recommendations is in most cases very 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 programme is for the dynamic workplace to become the norm. That is, for regular postural change to be a habitual, subconscious behaviour enabled by good workplace design, relevant organizational policies, high levels of knowledge, and a supportive organizational culture are required. 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 programme (including resources and job demands), and situational/organizational factors—all of which can be changeable and non-static [20]. Programme design factors to support buy-in, implementation and sustainability include allowing flexibility to adapt the programme to best suit organizational needs, the context, and the level of organizational readiness for change [20]. 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 mobilized. The programme should also have processes and mechanisms to be able to rapidly incorporate and implement new knowledge as the evidence base advances [21]. Examples to achieve this include through communication tools such as a web page and/or ongoing collaboration with researchers in the field [22].

Workplace health promotion models [23–25] provide an important framework for designing, implementing, and evaluating programmes 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 [25]. 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 organizational norms and policies [27, 28]. Some influences are more modifiable than others, and some are likely to have a greater impact on activity than others. Any programme 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 organizations and individuals.

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 [29]. 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 behaviourally based outcomes, as well as indicators of health. 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 culture.

Public health guidelines and recommendations regarding sedentary behaviour are only recently emerging [30, 31]. Hence, public health awareness and knowledge of the health impacts of too much sitting is 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 [32]. Prompts delivered via the computer [33, 34] or through the chair [35] can also be used to raise awareness and have been shown to elicit reductions in prolonged, unbroken workplace sitting time [33, 35]. Wearable technologies [11] and smartphone applications [36] also offer potential for real-time behaviour prompts and use as an intervention tool. Notably,

Table 18.1 Examples of how a sedentary behaviour programme can address the five keys to a healthy workplace as outlined by the World Health Organization (adapted from [25])

Keys to a healthy workplace	Possible application to a workplace programme targeting reductions in sedentary behaviour
Key 1: Leadership commitment and engagement	● Present a business case for the introduction of a programme to gain upper management support ● Establish the resources available to be committed to the programme (e.g. sit–stand desks; headphones to enable standing telephone calls) ● Evaluate, and where appropriate, adapt current policies and practices to support the programme (e.g. standing meetings; accessible stairwells) ● Secure and formalize management and stakeholders's 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 programme across multiple levels of the organization
Key 2: Involve workers and their representatives	● Actively involve workers in all stages of the programme 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 programme committees ● Create both informal and formal opportunities for staff to share experiences and provide feedback on the programme (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 sit–stand workstations [26] ● Recommend gradual changes to sitting time
Key 4: Use a systematic, comprehensive process to ensure effectiveness and continual improvement	● Regularly (at least annually) evaluate organizational policies and practices related to the programme and employee knowledge and use of programme strategies ● Regularly evaluate the impact of the programme 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 programme, including project action plans. Ensure that there is input from representatives across multiple levels within the organization ● Ensure programme approaches are evidence-based. Consult industry experts in programme design and evaluation as appropriate and enable mechanisms for the integration of new evidence

(continued)

Table 18.1 (continued)

Keys to a healthy workplace	Possible application to a workplace programme targeting reductions in sedentary behaviour
	● Provide publically accessible reports on the impact of the programme ● Collaborate and consult with other workplaces to discuss how they are delivering and evaluating programmes 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 programme into organization-wide health and well-being initiatives ● Set programme-specific targets as part of annual reviews ● Review and modify the programme to suit the level of organizational readiness and existing culture

interventions that target the individual should be undertaken with consideration to the multiple influences on behaviour, as highlighted above.

The physical environment can have a strong impact on activity levels. Increasingly, workplaces are shifting towards “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 [37]. Findings from natural experiments have shown that moving to these more activity-permissive buildings may have beneficial impacts on activity [38–40]. 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) [38, 39]. Changes to the physical environment can also be made on a smaller scale. For example, centralizing printers and wastepaper baskets or providing access to stairwells.

One physical environment intervention rapidly gaining attention 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 [41–44]. For example, in the meta-analysis by Neuhaus and colleagues [41], 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 no detrimental impact on work performance [41, 43].

The majority of 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 <US$300), accompanied by the increased media attention on the health impacts of too much sitting, have seen rapid uptake in their use. 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, organizational 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 organizational, environmental (including sit–stand workstations), and individual level; one who received the sit–stand workstations only; and, a control group [8]. At 3 months, the multicomponent group had a nearly threefold greater reduction in workplace sitting time (−89 min per 8 h workday) compared to the workstation only group (−33 min per 8 h workday), with differences maintained at the 12-month assessment [45]. It is important to ensure that choice and installation of an activity-permissive workstation is done with the 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 [26].

Although less tangible than the physical environment, creating a supportive social environment is likely to be key for programme uptake and sustained change. Strategies for addressing the social environment include ensuring a participative approach, where employees are engaged in the changes, enlisting programme champions to role model the strategies and promote the programme, and demonstrated upper management support such as through participation in the programme, and relevant modifications to policies and practices (e.g. modifying dress codes to support the wearing of more “activity-friendly” footwear).

Increased computerization has meant that time spent in job tasks that required some activity (e.g. walking to the printer, filing papers) has substantially decreased [46]. 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, that 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 don’t allow for individual variability in posture preferences. Activity substitution is also commonly adopted as a strategy [7]. For example, walking to see a colleague rather than emailing or having standing or walking (rather than sitting) meetings. In addition to potentially increasing levels of incidental activity [47], 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 [16, 48, 49] should be identified and, where possible, addressed.

A 2015 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 information and counselling and policy changes were inconsistent [44]. The review noted the low quality evidence informing the field to date and highlighted the need for high quality cluster-randomized controlled trials testing the effect of different interventions on sitting time. Such trials are emerging [10] and will provide key guidance for policy and practice in this field.

18.4 Key Gaps and Opportunities for Workplace Programmes Addressing Prolonged Sitting

The rapidly accruing evidence base and increasing public awareness of the health impacts of too much sitting has 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 [50]. There is an ideal opportunity to capitalize on this strong industry interest to rapidly generate evidence to address the several gaps that remain in this rapidly emerging field. 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 through the use of objective, postural-based activity monitors
- Gaining clearer understanding of existing policies and practices regarding addressing prolonged sitting across various occupational sectors
- Rigorous, high quality cluster-randomized controlled trial evidence on effectiveness, acceptability, and sustainability across a range of different intervention approaches, including those with low resource implications
- Understanding organizational- and individual-level differences in how programmes are taken up, implemented, and sustained to inform what works best and for whom
- Evidence on the impact of programmes on a range of factors in addition to activity, including knowledge and awareness, organizational culture, policies and practice, health outcomes, and work outcomes to support the business case for uptake into practice
- Evaluation of the cost-effectiveness of interventions and determination of the relative cost-benefits of various strategies
- Understanding the impact of intervention programmes on activity outside of the work setting in relation to compensation and generalization [51]

Addressing these gaps is critical for building the business case for change and providing evidence on return on investment for workplaces. There are several opportunities available 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 organizations. Wearable technologies also provide opportunities as an intervention and/or self-monitoring tool and could be utilized as an affordable adjunct to support intervention messages. Models such as the dynamic sustainability framework [52] provide a foundation to evaluate how interventions are translated into practice and adapted 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 programmes to reduce workplace sitting. As noted above, there are also now cluster-randomized controlled trials underway that will provide rigorous evidence on the effectiveness, acceptability, and sustainability of intervention changes [10, 53, 54]. Finally, a multidisciplinary approach will be needed to maximize 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 [55]. 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, and workplace sitting is 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. 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. Utilizing a multidisciplinary approach, incorporating a best practice framework, will be critical for achieving sustainable success.

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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 groups of the population and they have the highest rates of chronic acquired disease and disability. Research suggests a link between time spent being sedentary and ill health. Therefore, there is an immediate and urgent need to understand how to decrease the amount of sedentary behaviour in which an elderly individual engages. However, to date, very few studies have attempted to reduce sedentary time in the elderly, with half focusing primarily on reducing sedentary time and half focusing on increasing physical activity. Within these interventions, there are striking similarities in design of the study as well as primary purpose of the study. However, large variation in methodology such as measurement tools used to assess sedentary behaviour, theoretical grounding of the interventions, and interventional structure is apparent. Results of these studies have shown that sedentary behaviour can change. Interventions have shown these decreases in sedentary behaviours to be about 30 min, a relatively small portion of the waking day (~3%). The changes in sedentary behaviour can happen rapidly, but it is not fully understood whether these changes can be enhanced with the application of different behavioural theories or interventional techniques. Further, it is not known whether these changes in sedentary behaviour can be sustained.

A.M. Swartz (✉)
Department of Kinesiology-Exercise Science and Health Promotion, College of Health Sciences, University of Wisconsin-Milwaukee, Milwaukee, WI, USA
e-mail: aswartz@uwm.edu

W.A. Welch
Department of Preventive Medicine, Northwestern University Feinberg School of Medicine, Chicago, IL, USA
e-mail: whitney.welch@northwestern.edu

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19.1 Introduction

Our waking hours are spent in both sedentary and active behaviours, from walking to sitting and eating to socializing with friends to cleaning the house. 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 in which we reside. 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 or sitting and have more choice in how to occupy 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 down the river, finish reading the book that they started earlier that week, watch a television (TV) programme, 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 the experiences they have lived in their country, city/town/village, and home with their family, friends, and acquaintances. This lifetime of experience paired with knowledge and current life situation has cultivated into their current lifestyle behaviours, or how they interact with the world on a regular basis.

On average, elderly adults spend approximately 8–9 h (55–65%) of their waking day (approximately 15 h) in sedentary pursuits such as watching TV, 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 per day (Harvey, 2013), 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 5% each year after age 65 years [2]. Please refer to Chap. 4 for further detail on the prevalence of sedentary behaviour among older adults.

As has been shown in Part II of 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 (ADLs) and instrumental activities of daily living (IADLs) [3–5]. These negative health complications that result from too much sedentary behaviour appear to be independent of health enhancing physical activity, at least in the adult [3, 6–10] and elderly adult populations [5].

Despite the fact that the field of sedentary behaviour research is in its infancy, scientists, healthcare 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 more to learn. This chapter aims to review the current knowledge focusing on approaches to reduce sedentary behaviour among the elderly. Specifically, this chapter will detail 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. For further details on sedentary behaviour and ageing, please refer to Chap. 13.

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 in the elderly, there are few interventions that aim to reduce sedentary behaviour in this segment of the population. Within these interventions, there were striking similarities in design of the study as well as primary purpose of the study. However, large variation in methodology such as measurement tools used to assess sedentary behaviour, theoretical grounding of the interventions, and interventional structure is also present. Considering these similarities and despite these variations, changes to sedentary behaviour are fairly homogenous.

19.2.1 Design of Studies to Reduce Sedentary Behaviour

One of the notable similarities of these interventions was the design of the studies. All of these studies were pre-post experimental [11–15], assessing within subject change over time in response to the intervention. Only one of the studies included here employed a control group that provided usual care for hypertension, allowing more robust conclusions to be drawn regarding the effectiveness of the intervention [11]. In addition to the similar designs of these studies, four of the five studies that have intervened on sedentary behaviour were designed to determine the feasibility of an intervention to reduce sedentary behaviour [12–15], which is an important first step in interventional research before applying the intervention to a larger group. Only one study was designed to specifically reduce sedentary behaviour [11] in the elderly. As this area of inquiry matures, it is important for scientists to design studies that include a control group to allow stronger and more resilient conclusions to be drawn about this important topic.

Interventions to reduce sedentary behaviour have included sample sizes of less than 70 individuals, with one of the five studies including fewer than 50 participants [11] and two including 25 or fewer participants [13, 14]. Four of the five studies included samples with a mean age of 68 years or older [11–14], and one study reported a mean age of 59 years and included individuals aged 45 and older

[15]. Three studies included a majority of participants being female, ranging from 70 to 75% [12, 14, 15] female, with the other studies having approximately half the sample being female (40% female, Fitzsimons et al.; 56% female Chang et al.). Two studies explicitly recruited sedentary individuals [12, 14], and all were community dwelling. 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 on adults aged 80 years and older.

19.2.2 Methodologies Utilized 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 for another reason: enjoyment of watching their favourite TV show, rest and rejuvenation, or sitting to visit with friends. 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. Objective tools included the Actigraph accelerometer (GT1M- [12], GT3X- [14]) and the ActivPAL inclinometer [13, 14]. Subjective tools also varied, including the Measure of Older Adults' Sedentary Time (MOST; [15]), the Sedentary Behaviour Questionnaire [13], the International Physical Activity Questionnaire (IPAQ) [11, 14], and a diary [11]. Given the variation in the validity of these sedentary behaviour assessment methods (see Chap. 2), comparison of intervention responsiveness and efficacy becomes difficult and warrants consideration.

19.2.3 Theories Employed in Sedentary Behaviour Interventions

Most current interventions designed to disrupt sedentary behaviour have been guided by theory, with the Behavioural Choice [12, 14] and Social Cognitive [12, 14, 15] theories being the most popular. For further details on models and theories applied to sedentary behaviour research, please refer to Chaps. 15 and 16. The Empowerment Theory [11] and the Ecological Model [13] have also been applied, with other studies contrasting different theoretical approaches, such as by King et al. who examined social cognitive theory and self-regulatory principles of behaviour change, social influence theory, and operant conditioning principles and emotional transference within a technology platform [15]. As is typical in physical activity interventions, these interventions largely, but not exclusively [13, 15], focused on individual level factors that determine behaviour. 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 in its infancy [16].

19.2.4 Sedentary Behavioural Intervention Length and Characteristics

In addition to similarities and differences in methodology, there are also similarities and differences in the interventional structure and the length of the interventions. Two interventions were 7 days in length and applied different interventional structures [12, 13]. Gardiner et al. [12] employed the “Stand Up for Your Health” intervention where participants were encouraged to stand up every 30 min throughout their waking day. Participants completed one face-to-face goal setting consultation and received one individually tailored educational mailing. Fitzsimons et al. employed a consultation, based on the Ecological Model and the participant’s baseline data, to reduce their sedentary behaviour [13]. Participants set their own goal as to where, when, and how much they would reduce their sedentary behaviour. Three interventions were 8 weeks in duration and also applied very different interventional structures [11, 14, 15]. Rosenberg et al. delivered a modified version of the “Stand Up for Your Health” intervention through five 20-min phone calls delivered at baseline, and weeks 2, 3, 5, and 7, with the goals of reducing sitting time by 2 h per day and increasing the number of sit-to-stand transitions by 15 per day [14]. Chang et al. delivered an intervention that included weekly meetings lasting 110 min that included lifestyle modification education, group discussion, and an exercise session. Participants were also instructed to exercise 2 days per week at home. Finally, King et al. reported the results of three theoretically guided interventions delivered through smartphone applications (“apps”) [15]. The apps were either analytically, socially, or affectively framed custom apps that could be used by the participant on a daily basis. Therefore, in addition to numerous theories employed by this small number of interventions, there was large variation in intervention structure, goals for reducing sedentary behaviour, and participant contact with other participants or study staff.

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 subgroup. On average, it appears that reductions in sedentary behaviour are quite homogenous, regardless of intervention, resulting in reductions in sedentary behaviour of about 30 min or approximately 3% of the waking day. Of course, the data is variable, but these results are seen after short-term and longer duration interventions and with subjective and objective methods of assessing sedentary behaviour. Gardiner et al. [12] 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, and Fitzsimons et al. [13] demonstrated a significant decrease in ActivPAL-assessed sitting or lying time by 24 min/day or 2.2% of the waking day, both after a 7-day intervention. Similarly, Rosenberg et al. [14] showed a decrease in ActivPAL-assessed sedentary behaviour by 27 min/day (−3% of waking day) after an 8-week intervention. Sedentary behaviour changes measured by questionnaire varied substantially, with King et al. reporting a decrease in TV viewing (assessed by MOST) of 29 min per day after an 8-week intervention [15]. Chang et al. [11] reported a much larger decrease in IPAQ sitting time of 76 min/day after an 8-week intervention, over double the amount seen in the other studies. This larger decrease in sedentary time could be due to the tool used to assess sedentary behaviour or the fact that the intervention focused on exercise rather than physical activity. Taken together, it appears that changes in sedentary time on the order of 30 min, over a short period of time, can be expected from interventions that reduce sedentary behaviour. Whether this change in sedentary time is sufficient to impact health in this population, and whether this change in sedentary behaviour can be sustained long term, remains to be determined.

Because waking hours are filled either with sedentary pursuits or active behaviours, when sedentary behaviour is decreased, it must be replaced with activity of some level. As a result of the reduction in sedentary behaviour seen in Gardiner et al. [12], the sedentary behaviour was replaced almost entirely with moderate-to-vigorous physical activity (moderate-to-vigorous physical activity increased from 3.6 to 4.6%). King et al., Fitzsimons et al., and Chang et al. also showed increases in physical activity as a result of the decrease in sedentary behaviour, with King et al. [15] showing increases in walking by 14 min/day and moderate-to-vigorous physical activity by 27 min/day as assessed by the CHAMPS[1] Activities questionnaire for older adults; Fitzsimons et al. [13] showed increases in stepping by 13 min/day with no change in standing, steps/d, or sit–stand transitions, and Chang et al. [11] showed substantial increases in physical activity equating to approximately 107 min/day at 3 metabolic equivalents (METs) or 53 min/day at 6 METs. However, it should be noted that the control group in Chang et al. [11] also showed substantial increases in physical activity. In contrast, Rosenberg et al. showed similar magnitude increases in standing (+25 min) as to the decrease in sitting (−27 min), with no changes in walking, steps, or sit-to-stand transitions [14]. Therefore, there is no clear activity (standing or moving) or intensity of activity (light or moderate-to-vigorous) that replaces sedentary pursuits in the elderly population.

[1]CHAMPS—Community Healthy Activities Model Program for Seniors

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 Impact 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 [17, 18]; (2) improving both physical activity and nutrition behaviours [19]; (3) changing both physical activity and sedentary behaviour [20]; (4) examining the feasibility of a physical activity intervention [21]; or (5) to improve cardiometabolic risk [22]. In addition to assessing their primary aim, these studies also measure the interventional impact on sedentary behaviour. All of these studies have used a randomized control trial study design to assess their primary question [17–22], but the intervention length varied, ranging from 12 weeks [18, 21], to 24 weeks [20], to 6 months [17, 19, 22]. Most studies included participants with a mean age in the 1960s [18–20, 22], with one study including participants with a mean age in the 1970s [21] and one with the mean age in the 1980s [17]. Two studies included overweight or obese elderly adults with type 2 diabetes [18, 20], one included overweight or obese participants [22] and one included elderly living in a nursing home or care facility [17].

19.3.2 Methodologies Utilized 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 included the Actigraph accelerometer (7164) [18, 20] and the ActivPAL inclinometer [21]. Subjective assessment tools include the IPAQ [19, 22] and the Longitudinal Aging Study Amsterdam questionnaire [17]. 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, with similarities to those studies with a primary aim to change sedentary behaviour. Theories included the

Cognitive Behavioural theory [18, 20] and Social Cognitive theory [19, 21]. Only one study did not explicitly state the theory applied [17]. Two studies also used Motivational Interviewing [18, 20, 22] as a technique to change physical activity behaviour. Therefore, despite the fact that when you change sedentary behaviour, you are trying to remove a negative behaviour and when changing physical activity behaviour, this incorporates the process of adding a positive behaviour; these results suggest that theories that have been applied to change physical activity behaviours may be transferable to assist in changing sedentary behaviours.

19.3.4 Intervention Length and Characteristics

The structures of the interventions also varied. Mutrie et al. [21] aimed to increase walking through the use of a pedometer, a walking programme, and two consultations with a trained professional over the 12-week intervention. De Greef and colleagues [5] delivered 5 cognitive-behavioural group lifestyle intervention sessions in 12 weeks, with a booster session after 22 weeks in addition to a pedometer to change physical activity and sedentary behaviour. In a follow-up study in 2011, DeGreef and colleagues [6] again aimed to change physical activity and sedentary behaviour through a 24-week intervention that included a pedometer, a single face-to-face session, and seven telephone consultations. Burke et al. [1] aimed to change physical activity and nutritional behaviours through education, goal setting, and 6–10 phone calls and/or 2–5 emails over the 6 month intervention. Kallings and colleagues delivered a 6-month physical activity prescription intervention that included patient centred counselling where they were provided an individualized exercise prescription and counselling to help them set their own goals [22]. Finally, Chin A Paw and colleagues [3] assigned participants to a twice a week resistance training programme, a functional skills training programme, or a combination of the two over a 6-month period. Most of these studies included frequent contact with study staff and some form of goal setting, while only a few gave explicit instructions to change sedentary behaviour.

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 (compared to the control group) in sedentary behaviour, decreases ranged from a reduction in Actigraph-measured sedentary behaviour of 23 min after a 24-week intervention [20] to a 72 min/day decrease in Actigraph-measured sedentary behaviour after a

12-week intervention [18]. Mutrie et al. showed a significant decrease in ActivPAL-measured sedentary behaviour by 48 min over 12 weeks (compared to control group) [21]. Finally, Burke et al. showed a 50.7 min/day decrease in IPAQ-assessed sedentary behaviour after a 6-month intervention [19]. Only one study did not show a change in sedentary behaviour as a result of the 6-month intervention [17]. However, this intervention focused on changing habitual physical activity through engaging in strength and/or functional training two times per week. Additionally, although Kallings et al. showed a significant within group decrease in IPAQ[2]-reported sedentary behaviour (−2 h/day), the change was not significantly different than the control group (−1 h/day) [22]. 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 will significantly reduce sedentary time in as little as 12 weeks, regardless of the subjective or objective sedentary behaviour assessment tool employed.

19.3.6 Sustainability of Changes in Sedentary Behaviour in Response to Physical Activity Interventions

A few studies followed up on the sustainability of the intervention. Mutrie et al. showed a 41-min reduction in sedentary behaviour after a 12-week intervention and a 12-week follow-up period, only a 7-min increase in sedentary behaviour from the end of the intervention to the end of the follow-up period [21]. De Greef and colleagues showed a significant decrease in sedentary behaviour (−23 min/day) after a 4-week intervention focusing on physical activity and sedentary behaviour [20]. The reduction in sedentary behaviour was still significantly lower (−12 min/day) than baseline after 1 year, albeit an attenuated effect. Alternatively, results from De Greef et al. were not as favourable [18]. Despite showing a significant reduction in sedentary time (−72 min) in the intervention group compared with controls after the 12-week intervention, after 1 year sedentary behaviour levels of both the intervention (−6 min from baseline) and control (−15 min from baseline), groups returned to baseline levels of physical activity. Therefore, based on the results from these studies, the sustainability of changes in sedentary behaviour as a result of these interventions remains inconclusive.

According to accelerometer data, most of the change in sedentary behaviour was largely replaced with light-intensity physical activity [18, 20]. According to self-report, changes in sedentary behaviour were accounted for by increased strength exercises, walking, and vigorous intensity activity [19] or by physical activity of at least moderate intensity [22]. 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

[2]IPAQ—International Physical Activity Questionnaire

sedentary behaviour, and this replacement behaviour is likely dependent on the physical activity intervention applied.

A few studies evaluated the effects of changes in sedentary and physical activity behaviours on cardiometabolic risk factors [18, 22] or constipation [17]. Although favourable changes were seen in some cardiometabolic risk factors [22], due to changes in both physical activity and sedentary behaviour, the effect of sedentary behaviour cannot be determined.

19.4 Summary

Very few studies have attempted to reduce sedentary time in the elderly, with half focusing primarily on reducing sedentary time and half focusing on increasing physical activity. Studies have shown that sedentary behaviour can change. To date, interventions have shown these decreases in sedentary behaviours to be a small portion of the waking day (~3% or a 30 min change). The changes can happen rapidly, but it is not fully understood whether these changes can be increased with the application of different behavioural theories or interventional techniques. Further, it is not known 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 should engage in?* Some sitting is healthy and restorative for the 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 well-being of an 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 types of interventions will produce the largest and most sustainable change in sedentary behaviour?* The studies reviewed in this chapter have not included interventions that have attempted to alter the social or physical environment for an elderly to reduce sedentary time—most have relied on education, self-regulation, and goal setting. 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 particularly effective with worksite interventions (sit-stand work stations). Therefore, future interventions should focus on altering social and environmental aspects to reduce sedentary behaviour. Finally, *What 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 [16]. Interventions within the elderly have relied on Social-cognitive theory, Behavioural choice theory, and Empowerment theory, with some studies not mentioning the theory(ies) employed. Therefore, future research should focus on determining those theories, techniques, and intervention components that have the largest impact on sedentary behaviour.

Given that the 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. The human body is designed to be moving and active, and there are negative consequences of inactivity as is evidenced by our 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, there is a great need for further research in this area.

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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 it discusses areas of future research and methodological issues associated with this research.

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 [1, 2]. 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 [3, 4]. 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 [5–14]. Figure 20.1 shows average daily objectively measured sedentary time derived from publications using the National Health and Examination Surveys

S.A. Prince (✉)
Division of Prevention and Rehabilitation, University of Ottawa Heart Institute, Ottawa, Canada
e-mail: s.prince.ware@gmail.com

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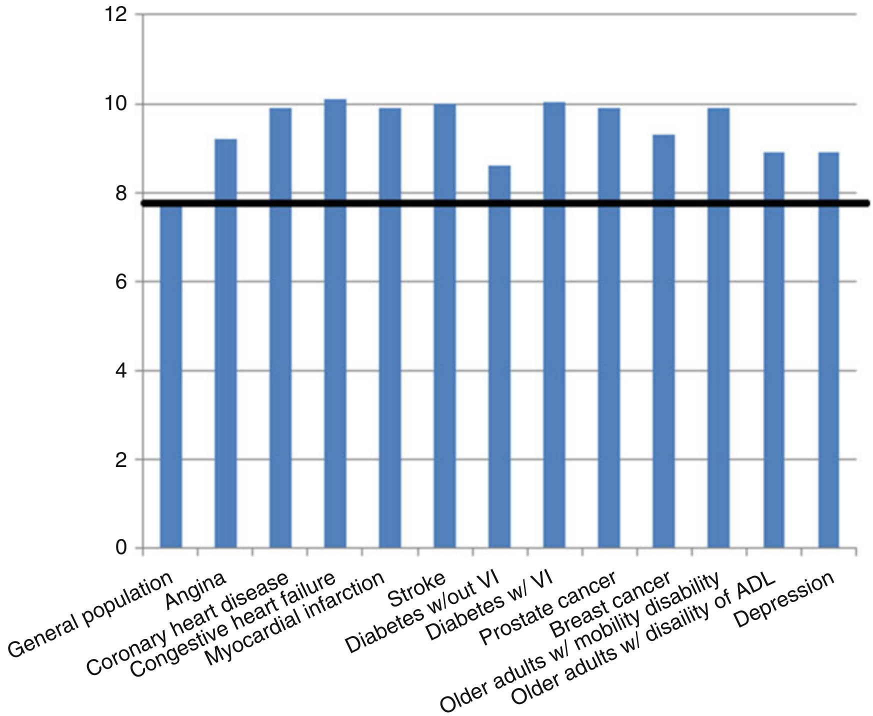

Fig. 20.1 Objectively measured sedentary time (hours/day) across select disease and disability groups. Data come from various publications reporting on sedentary time from the National Health and Examination Survey (NHANES) [7–14]. *ADL* activities of daily living, *VI* visual impairment

(NHANES) in the United States [7–14]. While greater amounts of sedentary time have been shown to be associated with an increased likelihood of developing many of these diseases [15, 16], it may further increase after the onset of 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 [17–19]. Unfortunately, research has shown that interventions which focus on physical activity, but not sedentary behaviours, are not likely to yield meaningful reductions in sedentary time [1]. 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 [20]. 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 [5]. Replacing sedentary time with light or higher intensities of movement can likely improve health risk and physical functioning [21–23], especially among individuals already at greater risk.

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 [3]. Most of the interventions included multiple components; many used pedometers [24–26] along with face-to-face [26–29], group coaching [25, 28, 30], and/or telephone support [26, 29, 30]. One of the interventions used one-on-one video coaching sessions in individuals with multiple sclerosis [24]. 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 *activ*PAL™). Dosing of the interventions ranged from a single visit (to explain the use of a device) [31] to an intervention that included a total of 11 telephone sessions with a health coach [32]. In addition, two interventions also included reminders via text messages [27] and postcard prompts [32]. Other components of interventions included a website [24], study newsletter [32], participant handbook [30, 32], and/or diary [24–26, 28, 30].

Only two of the interventions exclusively targeted sedentary behaviours [27, 31]. 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 [31]. 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 increased number of breaks. The study also reported a high acceptability of the technology by participants [31]. 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 [27]. This intervention, although underpowered, showed promising results for reducing sedentary time and good feasibility [27].

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

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 [25]	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 control group	• Significant between-group effect for PA, intervention group significantly ↑ PA over intervention period, but was not maintained at 1 year • No significant effect on BMI, weight, BP, cholesterol, HbA1c
De Greef, 2011 [26]	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 [31]	SB	• Smartphone app (*NEAT!*) + intervention accelerometer • Noise or vibration prompts upon 20 consecutive minutes of sedentary time	Pre-post pilot $N = 7$	1 month	Accelerometer sedentary time (% wear time), breaks in sedentary time, intensity of breaks, duration of breaks	• ↓ sedentary time (8.1 ± 4.5%, $p = 0.003$) • ↓ breaks in sedentary time (15.8 ± 8.8 breaks, $p = 0.003$) • ↑ break duration (1.0 ± 0.5 min)	• High acceptability of the technology • App allowed participants to be more conscious of sitting time • Majority would use the app in the future
Stroke							
English, 2015 [29]	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 change in either group • No between-group difference in MVPA

(continued)

Table 20.1 (continued)

Author, year	Focus	Intervention components	Design and sample size	Duration	SB outcome	SB findings	Other findings
Cancer							
Lynch, 2014 [32]	PA, diet quality, weight management, alcohol, tobacco, SB	• Telephone-delivered, multiple behaviour change • 11 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 • 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	• None reported
Rheumatoid arthritis							
Thomsen, 2014 [27]	SB	• Three motivational counselling sessions of 60–90 min 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 h/day, while the control group increased by an average of 0.15 h/day • Between-group difference was −0.45 h/day	• None reported

Multiple sclerosis							
Klaren, 2014 [24, 33]	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 h/day of sitting time compared to control	• Significant and positive effect of intervention on fatigue severity, depression, anxiety, and self-reported PA • No significant effect on pain, sleep quality, or physical health-related quality of life
Hypertension							
Chang, 2013 [28]	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 min and was significantly greater than control group ($t = -3.03$, $p = 0.004$) • Control group ↓ weekly sitting time by 60.45 ± 630.29 min	• No between-group differences in change in depression • Intervention group showed greater gains in self-efficacy for PA, perceived health, and total PA

(continued)

Table 20.1 (continued)

Author, year	Focus	Intervention components	Design and sample size	Duration	SB outcome	SB findings	Other findings
Psychotic disorders							
Baker, 2014 [30]	Diet, PA, SB	• Eight manual-guided telephone sessions • Feedback and goal setting (using motivational interviewing) • Goal ≤2 h 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 min/day • Total weekday sitting time decreased significantly by an average of 143 min/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 • No improvement in depression scores • Overall high programme 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

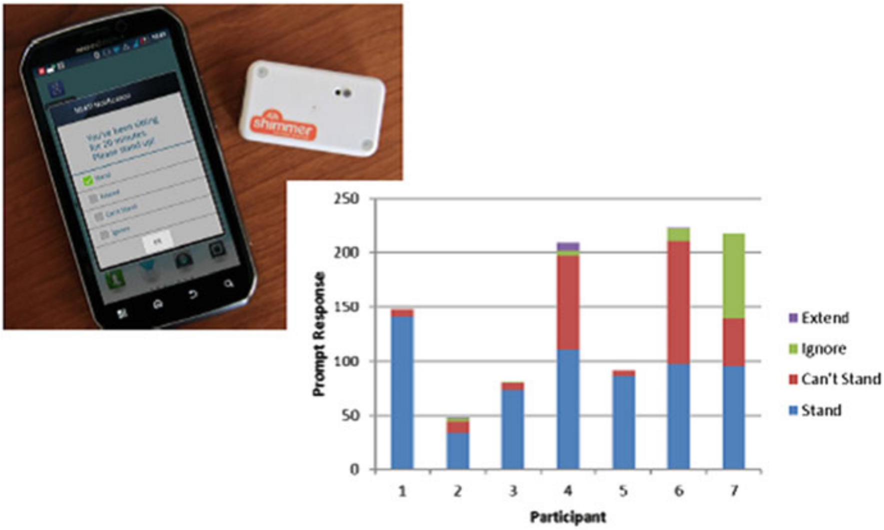

Fig. 20.2 *NEAT!* app and accelerometer and participant responses to reminders [31]

and a pedometer [24, 26]. 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 [34]. The intervention in individuals with type 2 diabetes showed significant reductions in sedentary time at 1 year compared to baseline measures [26]. The other, in multiple sclerosis patients, reported significant reductions in highly prevalent symptomatic outcomes including fatigue, depression and anxiety [24]. 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 [28]. 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 [28]. 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 [35–41]. The feasibility of using wearable technologies such as the Fitbit® (www.fitbit.com) [37, 38] and the Polar V800 (Polar Inc., Denmark) [40], and the use of SMS or text messaging to smartphones [35], 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" [42]. 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 [42].

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 establishing 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 [43]. 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 [44–47]. Technologies such as wearable devices (e.g. Fitbit, Jawbone UP, Polar activity trackers, *activ*PAL3™ 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 [48]. The use of text messaging can provide a quick, inexpensive, and effective tool for behaviour change [49].

Step counters as part of an intervention have been shown to reduce sedentary time among adults [50]. Some devices (e.g. Jawbone UP, *activ*PAL3™ VT, Apple Watch, Garmin vívosmart® 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 [51–53], 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 [51, 54, 55], 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 [56]. 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, *activ*PAL™) 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.

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Chapter 21
Specific Approaches to Reduce Sedentary Behaviour in Overweight and Obese People

Dori E. Rosenberg, Sara Ann Hoffman, and Christine Ann Pellegrini

Abstract Sedentary behaviour reduction could be a health-promoting strategy for individuals with overweight and obesity who may have substantial barriers to engaging in moderate-to-vigorous-intensity physical activity. Several intervention studies have explicitly targeted sedentary behaviour reduction in adults with overweight and obesity. Nearly all are small, short-term (only one lasted longer than 12 weeks), acceptability, and feasibility studies. Findings suggest that reducing sedentary time is feasible with reductions of up to 110 min per day. A variety of approaches have been tested including smartphone applications, workplace pedal machines, and television restriction. In the small number of studies measuring health outcomes, there was some evidence of improvements in waist circumference, blood pressure, and physical function, but none of the studies reduced weight. Overall, more research is needed from randomized trials with longer follow-up periods and more intensive interventions to determine if there are health benefits for reducing sedentary time among overweight and obese populations.

21.1 Introduction

Interventions have begun to target individuals with overweight and obesity as the available evidence suggests that this subgroup of the population spends similar amounts of time, if not more, engaged in sedentary behaviours than other groups. Estimates suggest that overweight or obese adults spend up to 10 h per day or 66% of their waking hours sitting [1, 2]. One reason for targeting individuals with overweight and obesity relates to the need for health-promoting interventions in a population with a very high burden of chronic conditions and rising healthcare costs

D.E. Rosenberg (✉)
Kaiser Permanente Washington Health Research Institute, Seattle, WA, USA
e-mail: rosenberg.d@ghc.org

S.A. Hoffman • C.A. Pellegrini
Group Health Research Institute, Seattle, WA, USA
e-mail: sara.hoffman@northwestern.edu; c-pellegrini@northwestern.edu

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[3, 4]. Nearly 70% of adults in the USA are classified as overweight or obese, with total medical costs attributed to obesity reaching $147 billion per year [5, 6]. Another rationale is that this population may stand to gain the largest health improvements from a potential reduction in sedentary time with concomitant increases in standing, light-, moderate-, and/or vigorous-intensity physical activity. The barriers to moderate-to-vigorous physical activity are higher among individuals with overweight and obesity [7]; thus, alternatives 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 among individuals with overweight and obesity.

The benefits of physical activity are well established; however the amount of adults meeting the recommended guidelines are low [8]. Common barriers to regular participation of physical activity include lack of time, motivation, and cost [9]. Additional barriers specific to overweight and obese populations include mobility-limiting comorbidities, displeasure with activity, fear of injury, fatigue, and joint pain due to excess weight [7, 10]. The additional barriers may contribute to the lower levels of activity observed in adults with overweight or obesity as compared to adults classified in the normal weight range [2].

For those who are unable to meet physical activity recommendations, the 2008 Physical Activity Guidelines suggests the avoidance of inactivity [2]. While interventions should continue to promote moderate-to-vigorous-intensity physical activity, targeting a reduction of sedentary behaviour may be an additional strategy to help increase overall activity levels among overweight and obese adults. Consistent evidence indicates an inverse relationship between sedentary time and light-intensity physical activity [11, 12]; thus, targeting a reduction in sedentary time among overweight and adult populations may be a feasible, first step recommendation for those struggling to meet general activity guidelines. 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/or the prevention of additional weight gain. For instance, Levine and colleagues [13] have suggested that adults with obesity could increase their daily energy expenditure by approximately 350 kcal by replacing 2 h 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. For a detailed description of the relationship between sedentary behaviour and adiposity, please refer to Chap. 6.

21.2 Effects of Existing Studies to Reduce Sedentary Time

Studies have targeted different goals with respect to reducing sedentary behaviour among overweight and obese populations. For example, studies have focused on decreasing television viewing, general sedentary time, and workplace sitting, as well as the promotion of more frequent breaks from sitting. Across these targets, interventions have varied greatly in both the intensity of the programme and types of strategies used to facilitate sedentary behaviour change. The majority of completed studies are small, short-term feasibility studies; however many of the interventions demonstrate great potential in reducing sedentary time in populations with overweight and obese adults. Prior reviews have examined studies that target increasing physical activity levels but also measure or target decreasing sedentary time [14, 15], but were not focused on overweight and obese populations. Observed effects on sedentary time are generally small or non-existent when in the context of a physical activity or combined physical activity and sedentary behaviour intervention. Therefore, this chapter reviews only studies that explicitly sought to improve sedentary behaviours and had at least one treatment group solely focused on sedentary behaviour reduction.

One of the earliest studies targeting sedentary time for weight loss among adults with overweight and obesity used a strategy of television viewing restriction [16]. The study employed a television lockout device that turned off the television automatically after a preprogrammed limit was met. The lockout device was set at 50% less per week than during a baseline monitoring period. Participants in the intervention group ($N = 20$; mean body mass index (BMI) = 31.8 kg/m^2) had nearly a 3-h per day reduction in objectively measured television viewing compared to a ~45-min reduction in the control group ($N = 16$; mean BMI = 32.3 kg/m^2). Energy expenditure was significantly higher in the intervention group (119 kcal/day) compared to controls (−95 kcal/day), yet the reduction in BMI was not significant between the two groups.

Since this initial study, several feasibility and acceptability studies have been conducted. Kozey-Keadle and colleagues conducted a 1-week pre-posttest study among overweight working adults ($N = 20$; mean BMI = 33.7 kg/m^2; 75% female) [17]. Participants were provided information on health risks from prolonged sitting, strategies to reduce sedentary time, and a pedometer with a goal of 7500 steps per day. Over 7 days, accelerometer-measured ("activPAL") daily sitting time reduced by 5%, about 48 min. Participants also increased their steps by about 1750 steps/day.

In another short-term feasibility study, Judice and colleagues completed a 4-week crossover randomised trial. Participants ($N = 10$; mean age = 50; mean BMI = 32.6 kg/m^2; 50% female) were provided with hourly alerts on their work computers that provided a prompt to break up their sitting time and walk for 7 min [18]. Behaviour change was facilitated through motivational phone calls, text message reminders, and daily self-monitoring of steps. activPAL-assessed sitting time reduced by 110 min/day during the intervention week. The intervention group resulted in greater differences in the time spent standing (0.77 h/day) and stepping (1.09 h/day) as compared to the control group.

Another study included adults over 60 years with overweight and obesity in a pre-posttest feasibility study [19]. Participants received an 8-week phone-based health coaching programme based on social cognitive theory and the ecological model. Participants ($N = 25$; mean BMI = 34 kg/m^2, range = 27–40 kg/m^2) reduced their sitting time, measured by the activPAL, by about 30 min per day.

Several randomised pilot studies are moving beyond initial outcomes evaluating only the acceptability and feasibility of a specific intervention. Adams and colleagues conducted a quasi-experimental study with 64 participants (mean BMI = 36.44 kg/m^2; ages 35–85) who were randomised to one of two conditions: (1) intervention or (2) waitlist control [20]. The intervention group received a 6-week intervention based on social cognitive theory which included two in-person sessions, e-mail contacts, and a pedometer [20]. Actigraph-measured sedentary time did not significantly change among the intervention participants; however self-reported sedentary time decreased by 12 h per week. Participants reported high satisfaction with the 6-week intervention.

In a 12-week intervention, participants ($N = 57$; mean age = 44; mean BMI = 35.1 kg/m^2; 68% female) were randomized to receive either exercise (40 min, 5 days per week of moderate-intensity exercise), sedentary reduction (counselled to use strategies to increase non-exercise physical activity and decrease sedentary time using pedometers), exercise + sedentary reduction, or no-treatment control [21]. Significant reductions in activPAL-measured sedentary time were observed in the exercise + sedentary reduction (10.3%; about 70 min per day) and sedentary reduction only (7%; about 48 min per day) groups, whereas the control group had significant increases in sedentary time (6.5%).

Biddle et al. conducted the longest intervention trial to date, with primary outcomes at 12 months [22]. Young adults at risk for type 2 diabetes ($N = 187$; mean age = 33; mean BMI = 35; 69% female) were randomized to a control condition (information on risk factors for diabetes) or a sedentary reduction intervention involving a 3-h group education workshop, self-monitoring device ("Gruve"; MUVE, Inc., USA), and a follow-up phone call at 6 weeks to review progress and discuss goals. Sedentary time measured by Actigraph accelerometer reduced non-significantly by 17.4 min/day and 13.8 min/day in the intervention and control groups, respectively. Similarly, activPAL-assessed sitting time did not differ between groups at 12 months (9.55 h/day sitting intervention and 9.6 h/day in controls). Unexpectedly, both conditions increased sitting time by 35 min from baseline levels. The intervention group had significant reductions in self-reported sitting (−3.45 h/day).

Environmental changes are another one of the many strategies being used to explore their influence on sedentary time. Most of the studies completed to date occur in workplace settings where participants are provided with sit-to-stand workstations or pedal machines. Few of these trials have explicitly focused on overweight or obese individuals. One 12-week trial randomized participants ($N = 40$; mean age = 45; 90% female; mean BMI = 32.4 kg/m^2; 70% white) to either an active sitting intervention or no-treatment control condition [23]. Participants in the active sitting condition were provided with a portable pedal machine to use at work, access to a motivational website (based on social cognitive theory), and a pedometer. Sedentary time, measured by the StepWatch activity monitor, reduced by 59 min per day in the intervention group (compared to a 56-min increase among controls).

Several other studies aimed to reduce sedentary time using various innovative tools and approaches in adults with overweight or obesity. In a feasibility study with nine adults with diabetes (mean BMI = 37.4 kg/m^2; ages 21–70; 77% female; 77% black), the effects of a smartphone application on sedentary time were examined [24]. Specifically, the *NEAT!* smartphone application and a Bluetooth-enabled accelerometer were used to promote awareness of sedentary behaviour and prompted users to stand up after detecting 20 min of consecutive sitting. Percent of the day spent sedentary assessed by Actigraph was reduced by 8.1% (approximately 60 min), and light activity increased by 7.9%; 88% reported they would want to keep using the technology.

In a similar 4-week within-subjects study, participants ($N = 30$; mean age = 47.5; mean BMI = 36.2 kg/m^2; 83% female) were given a smartphone intervention (B-MOBILE) to reduce sedentary time with three different conditions with varying sedentary break recommendations [25]. Participants received one in-person education session and were provided with an Android smartphone with B-MOBILE. Break conditions were tested in a counterbalanced order and included 3-min physical activity break after 30 sedentary minutes, 6-min break after 60 sedentary minutes, or 12-min break after 120 sedentary minutes. Percent of time spent sedentary, assessed by SenseWear armband device (BodyMedia, Inc., Pittsburgh, PA), significantly reduced for all three conditions compared to baseline (−47.2 min for 3-min conditions, −44.5 min for 6-min conditions, and −26.2 min for 12-min conditions). The 3-min physical activity break condition resulted in significantly greater reductions in percent time spent sedentary than the 12-min break condition. Percent of light and moderate-to-vigorous physical activity also significantly increased for all conditions.

21.2.1 Influence of Interventions on Health Outcomes

Only four of the above studies evaluated whether a sedentary reduction intervention improved health markers. The health outcomes most commonly assessed included BMI, waist circumference, and blood pressure. The majority of the studies saw improvements in outcomes [20–23]; yet the improvements observed were typically not different between randomised conditions. It is unclear whether the lack of differences observed is due to little effect of the intervention or if the studies were not adequately powered to detect differences across conditions. Only one study examined changes in mental and functional health, finding that an 8-week intervention in older overweight and obese adults resulted in improved depressive symptoms and physical function [19]. Six of the studies reviewed above measured weight, and none demonstrated significant reductions. Consequently, while laboratory studies have suggested that the metabolic/energy cost of standing is higher than sitting [26], longer and more intensive interventions may be needed to result in weight loss solely produced from reduced sitting time. When combined with dietary changes, sitting reductions may have the potential to yield larger weight changes.

21.2.2 Summary and Future Studies

Overall, there are few studies that explicitly sought to target individuals with overweight and obesity. Although a few studies did not find reductions in objectively measured sedentary time [20, 22], the majority of studies completed found reductions ranging from 30 to 110 min/day. Future randomized controlled trials with larger sample sizes and longer follow-up periods will help to gain a clearer picture on the potential of interventions to reduce sedentary time in this population. Several trials are currently underway. For example, a 13-month randomised trial is being conducted with 80 office workers (BMI 25–40 kg/m^2; ages 40–67) [27]. The intervention includes a one-time health consultation with a nurse and a treadmill workstation to use for an hour each day. In a separate 6-month multicentre randomized trial, 232 patients with a BMI between 25 and 35 kg/m^2 and between ages 25 and 65 years will be studied at primary care clinics [28]. The intervention group will receive stage-matched information on the risks of sedentary behaviour and will be invited to complete two to five in-person or phone sessions with a trained professional. The results from these trials as well as others will help to provide additional insight on the effectiveness of interventions to reduce sedentary behaviour in adults with overweight or obesity.

21.3 Lessons Learned from Qualitative Studies

Qualitative studies are further exploring the facilitators and barriers to sedentary behaviour reduction in individuals with overweight and obesity to elucidate whether strategies used in interventions are acceptable. Interestingly, many barriers to reducing sedentary behaviour differ from barriers to engaging in physical activity, particularly due to the habitual nature of sedentary behaviour. Sedentary behaviour is regulated by both controlled and automatic motivational processes [29]. Thus, many individuals note that they are unaware of how much time they actually spend sitting, which may contribute to lower motivation to want to reduce sedentary time [30]. Many additional barriers arise to reducing sedentary behaviour including environmental, social, and personal barriers. Work, school, and home environments often do not promote standing or engagement in light-intensity activity, so the default becomes sitting [30]. While it may be possible to stand in some environments, an additional barrier may be the perceived lack of social acceptance of standing in certain environments (i.e. standing in the back of a room during a lecture or meeting) [22, 30]. Others often feel physically and mentally tired after a long day at work and prefer the enjoyment of sedentary leisure behaviours like watching television over other non-sedentary activities [30, 31]. Furthermore, many overweight and obese individuals had difficulty identifying feasible strategies and alternative behaviours to sitting [30]. Participants also seem to struggle with the difference between sedentary time and being more physically active. This confusion often leads individuals to try to increase their physical activity rather than reducing their sitting time [22, 31]. Future interventions should be sure to provide clear strategies about how individuals can go about reducing sedentary time. Although many barriers exist to sedentary behaviour reduction, environmental changes that promote standing and activity (e.g. standing desks), clear strategies to reduce sitting time, problem-solving personal barriers, and reminders to cue breaks from sitting (because of the automatic nature of sitting) may help to lower the time overweight and obese adults spend in sedentary behaviour.

21.3.1 Measurement Issues

One of the challenges in determining the effectiveness of sedentary reduction interventions is the use of various subjective and objective measures of sedentary behaviour outcomes. One study with no effect used accelerometers [20], which have been noted to be less sensitive to change [32, 33] and could be particularly problematic to use around the waist for overweight and obese populations and those with slow gait speeds [34, 35]. Currently, the activPAL is considered the field-based standard for accurate assessment of sitting and standing time [32, 33], although it is not always utilised due to costs. Studies using self-reports find larger decreases in sitting time with devices [19, 20, 22]. Future studies should include device-based measures as sitting behaviours suffer from poor recall.

21.3.2 Limitations in the Evidence Base

Completed studies to date are also primarily short term (i.e. 12 weeks or less). One study did examine changes over a 12-month period; however the lack of changes observed may be due to the low intensity of the intervention [22]. The intervention provided education and promoted the use of a monitor designed to interrupt sedentary time. One conclusion from that study is that low-intensity interventions may not effectively alter sedentary time among populations with overweight and obesity; higher-intensity interventions or more technologically advanced interventions (e.g. provision of real-time feedback on sitting time) may be needed.

Few existing studies measured health outcomes other than weight. Some changes in health outcomes were found in waist circumference [20, 23], blood pressure [21, 23], physical function [19], and depressive symptoms [19]. Only one study measured physical function as an outcome, which could be important considering the reductions in mobility that can occur with weight gain [36]. The focus on sitting less could potentially improve strength and conditioning and serve as a gateway to helping people with overweight and obesity become more physically active over time.

21.4 Summary

Few interventions have specifically targeted individuals with overweight and obesity even though a solid rationale exists for targeting this group. Completed studies found sedentary behaviour reduction to be an acceptable, feasible, and potentially effective strategy to use in a population that has a high health burden and many barriers to being physically active. More evidence is urgently needed on how sitting less could improve the health of those with overweight and obesity and the role specifically played in weight loss. Ultimately, continuing to build an evidence base will inform guidelines that could be used by clinicians to support the health of their patients who have overweight and obesity.

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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 sedentary behaviour 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 of sedentary behaviour among immigrants, the longer they live in the United States. This chapter describes the prevalence of sedentary behaviour and factors associated with sedentary behaviour 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 next steps for reducing sedentary behaviour using the African American Collaborative Obesity Research Network (AACORN) paradigm as an exemplar model for creating culturally appropriate interventions.

22.1 Introduction

Sedentary behaviour has been defined by the Sedentary Behaviour Research Network (SBRN) as "...any waking activity characterized by an energy expenditure $\leq$1.5 metabolic equivalents *and* a sitting or reclining posture [1]". 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 [2–5]. Sedentary behaviour has also been associated with increased

M.C. Whitt-Glover (✉) • A.A. Price • B. Odum
Gramercy Research Group, Winston Salem, NC, USA

Winston-Salem State University, Winston Salem, NC, USA
e-mail: mwhittglover@gramercyresearch.com; priceaa@wssu.edu; odumbreana1@gmail.com

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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 [5–7]. The American Academy of Pediatrics currently recommends avoiding use of 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 [8]. Historically, the push to achieve national recommendations for daily physical activity among adults has not included recommendations for reducing sedentary behaviour. While there still are 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" [9, 10].

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 ages 6–11 spent 5.9–6.1 h per day in sedentary behaviour [11]. 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 [12]. 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) [13]. 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 [14, 15]. For more details on the prevalence of sedentary behaviour among children and adults, please refer to Chap. 4.

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 [16]. A study of ~2000 Chinese men and women living in New York City evaluated the impact of immigration on obesity and related risk factors [17]. Physical activity at work, during travel, and during recreational activities was assessed using a questionnaire. When 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 [18].

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, afterschool, 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" [19]. 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 [20]. 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 [21–23]. 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 [19].

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 work stations, changing workplace layouts to require more walking (e.g. locating printers further away from work stations), 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 [24–26]. A recent Cochrane review identified 20 qualitative and 6 quantitative studies focused on reducing sedentary time in workplace settings in adults [26]. 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 [27]. 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 [27–32]. 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 [33–36]. 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 [37], feelings among girls of being incompetent or embarrassed during physical activity and preferring to engage in sedentary behaviour rather than participate in physical activity [38], concerns about personal appearance and preference for sedentary behaviour to preserve hairstyles [39], feelings among girls that physical activity is "babyish" and better suited for boys [38], and preference for a larger body type that is more supportive of sedentary behaviour than engaging in physical activity [39] 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 [40–42]. 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 [43, 44].

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 [45–48]. 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 [49]. 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 [50, 51]). 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 [52].

Concerns about safety may be an additional cultural factor that can influence sedentary behaviour. As mentioned previously, concern for 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 [53]. Other racial/ethnic subgroups, particularly undocumented immigrants, may face similar fears with regard 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 (CARDIA) Study, discriminatory experiences were associated with increased screen time among African American men [54]. Stressors associated with lower income/high poverty, un- 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 are needed that can successfully address and decrease sedentary behaviour. 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 [55].

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 [56]. 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 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).

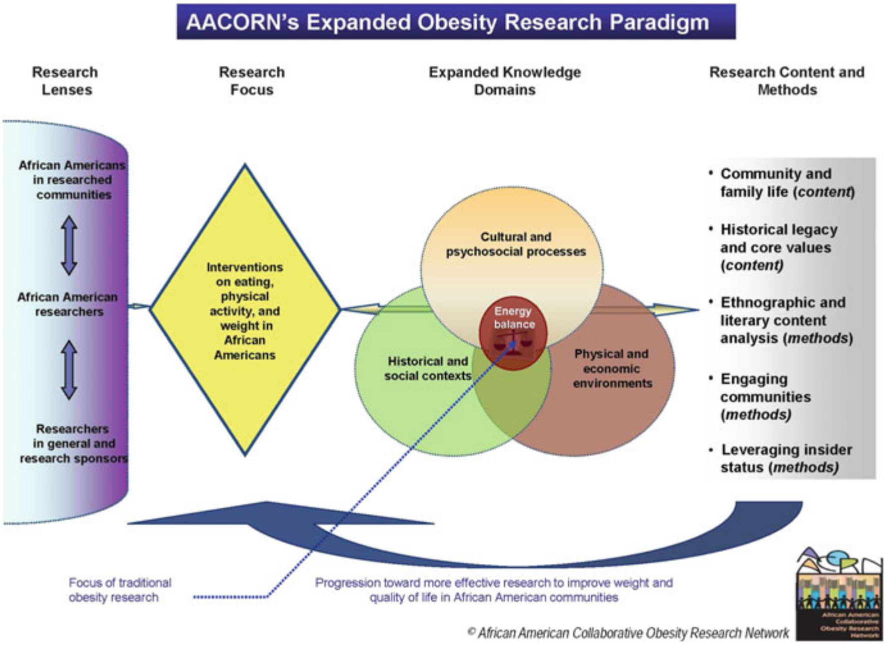

Fig. 22.1 The expanded obesity research paradigm of the African American Collaborative Obesity Research Network (AACORN)

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 for 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 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 about 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 has the potential for major public health impact.

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Chapter 23
Sedentary Behaviour at the Community Level: Correlates, Theories, and Interventions

Sarah L. Mullane, Mark A. Pereira, and Matthew P. Buman

Abstract This chapter provides a succinct 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; 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 organizations 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, multilevel 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.

23.1 Models and Theories of Community-Level Sedentary Behaviour

Community-level settings—schools, worksites, neighbourhoods and other public spaces—have been re-engineered to minimize human movement and muscular activity [1]. Ultimately these changes have caused people to move less and sit more. The factors of sedentary behaviour influence have previously been divided into five categories: demographic, biological, psychosocial, behavioural, and environmental [2]. We discuss numerous demographic, psychosocial, and environmental factors that influence community-level sedentary behaviour within three main

S.L. Mullane • M.A. Pereira • M.P. Buman (✉)
Arizona State University, School of Nutrition and Health Promotion, Tempe, AZ, USA
e-mail: slmullan@asu.edu; perei004@umn.edu; matthew.buman@asu.edu

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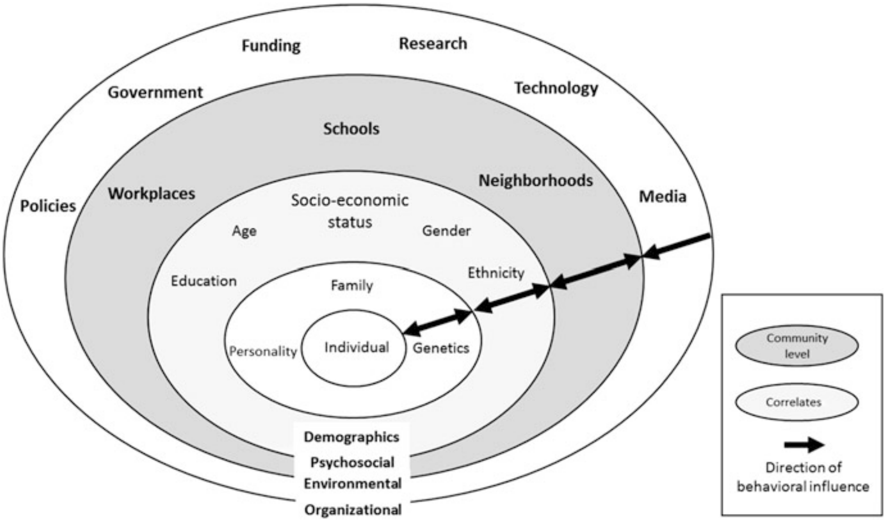

Fig. 23.1 A summary of the community correlates and determinants of sedentary behaviour

environments—youth communities (schools), adult communities (worksites), and both adult and child communities (neighbourhoods) [3]. For biologic and behavioural factors at the individual level, please refer to 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 (Fig. 23.1), which may play a pivotal role in the feasibility and efficacy of future community-level interventions.

23.1.1 Theoretical Overview: What Is Sedentary Behaviour?

In the free-living, fully functional, 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] [4]. 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 (TV); using a computer; playing video games, board games, and cards; sewing; talking on the telephone; reading; working in sedentary occupations that require sitting while doing paperwork, computer work, phone calling, business meetings, etc.; and sitting while transporting by care, bus, train, plane, ferry, etc. Due to measurement challenges, it is often difficult to distinguish sedentary time from light physical activity that includes standing and "fidgeting", "moving about" intermittently. It is suggested that increases in sedentary lifestyles, urbanization, and changes in modes of transportation, each have a contributory effect to the rising rates of sedentary behaviour [5], all of which can be targeted at the community level.

23.1.2 Schools: Youth Communities

Children are naturally born active [6] but are exposed to opportunities and environments that cause them to be sedentary on a daily basis [7, 8]. Sedentary behaviour for children may include sitting in the classroom, sitting during lunch time, watching television, playing computer games, completing homework, and passive transport [7, 8]. Most commonly, childhood sedentary behaviour is measured in relation to "screen time"; however, non-screen time sedentary behaviour accounts for 60% of overall sedentary time in school-aged children [9]. The education system is influential during the early stages of psychosocial and physical development as children spend 30–40% of their time in school [10, 11]. Approximately 95% of American children are enrolled in schools and spend ~30 h per week at school [12]. Two recent studies observed that primary schoolchildren spend 62–70% of their school time in sedentary behaviours and only 9–16% of their school time in moderate or vigorous physical activity in the United Kingdom and Canada, respectively [13, 14]. Synonymous with the adult workplace, time at school is responsible for the highest proportion (47%) of all non-screen sedentary time in children [15]. Therefore, the school environment presents an opportune community setting for sedentary behaviour reduction strategies [16–18].

23.1.3 Workplaces: Adult Communities

Sedentary behaviour is still a widely unrecognized 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 towards service economies (away from manufacturing) and associated technological advances (e.g. email, telephones, computer networks). Over the past 50 years, as the percentage of private jobs involving moderate-to-vigorous physical activity has fallen by more than 58%, occupational physical activity has decreased by an estimated 142 kcal/day [19]. American adults currently spend over 7.5 h/day engaged in sedentary behaviour, most of which occurs at work where 70–90% of their time is spent sitting [20–26]. Despite a 110 min/day differential between occupational and leisure-time sedentary behaviour, adults do not appear to compensate for excessive sedentary time during work by increasing light physical activity or moderate-to-vigorous physical activity outside of work [21, 22]. Despite what is known about the correlates of moderate-to-vigorous physical activity [27] and to a lesser extent sedentary behaviour in general [28], very little is known regarding specific correlates of occupational sedentary behaviour.

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. There have been three recent extensive review papers written on theoretical models of how neighbourhood characteristics impact physical activity and/or sedentary behaviour [29–31]. 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, please refer to 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 hypothesized 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 [18], grade level [32], socio-economic impacts [33], and more indirect factors such as attitudes towards active transport [34] and climactic barriers [3], which may influence sedentary behaviours at the community level.

23.1.5 Demographic Factors

At the school community level, recent research has identified several demographic associations between sedentary behaviour and the school environment. A study of primary schoolchildren ($n = 1025$) aged 10–12 years in Belgium, Greece, Hungary, the Netherlands, and Switzerland wore accelerometers for at least 6 consecutive days [35]. The results indicated that European schoolchildren spent 65% of their time at school in sedentary activities and 5% in moderate-to-vigorous physical activity, with small differences between countries. Gender differences were apparent. Girls spent a significantly larger amount of school time in sedentary activities (67%) than boys (63%), and spent less time in moderate-to-vigorous physical activity (4% versus 5%). These observations are supported by previous research that identified gender 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 Estonia [13] and England [36]. Progression into higher education is also associated with increased pressure to study and accompanying prolonged periods of sitting [18, 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 half of their daily sitting being accrued during occupational pursuits [37]. While this is slightly lower than previous studies [21, 22], it represents a substantial amount of overall sitting being accounted for within this context. Among demographic correlates, younger age appears to be an important correlate of sedentary behaviour. Two recent cross-sectional studies have reported younger age being associated with higher reports of overall occupational sitting [37, 38], while another [39] reported younger age being associated with fewer breaks for sitting while at work [39]. Furthermore, individuals of higher body mass index (BMI) reported greater occupational sitting [37]. Men, individuals of higher education, individuals of higher income, and individuals with more poorly self-rated health all appear to be more likely to engage in higher levels of occupational sitting. A recent study of randomly selected Australian adults has identified occupational status and job classification characteristics associated with occupational sitting [38]. Part-/full-time employees reported higher levels of occupation sitting than casual employees. Also, white-collar/professional employees reported higher levels of occupational sitting than blue-collar employees [38]. Finally, time during the workday also appears to be associated with sitting and standing time. In a sample of UK office-based workers, temporal associations with activPAL-derived standing were examined on both weekday and weekend days. Standing time was most commonly observed from 07:00 to 10:00 and 17:00 to 20:00 h on weekdays (presumably during commuting to and from work hours), whereas standing time was consistent from 10:00 to 18:00 on weekend days [40].

The resources available to a community (money, time, space, and staffing) may affect sedentary behaviours. It is reported that schools in low socio-economic communities have a distinct lack of resources [33] and exhibit high migration rates of the best-qualified teachers [41]. Such resource constraints may restrict the time, space, and staffing available to implement innovative teaching, workplace, or neighbourhood strategies that aim to reduce sedentary behaviour. Interestingly, a study investigating the prevalence of sedentary behaviour in public versus private schools in Ghanaian adolescents found that students from private schools exhibited significantly higher sedentary behaviour levels to those from public schools [9.91 ± 6.37 versus 4.78 ± 5.71 h/day, respectively] [42]. However, a distinction between school and afterschool time was not made; instead it was concluded that private school students were from families of higher socio-economic status (SES) (77.4% vs. 31.3%) and therefore had access to screen devices, the internet, and computer games at home. Whether the private versus public school environment has a direct impact on sedentary behaviour during the school day would provide much needed insight and should be a consideration for future research. Other demographic comparisons are more inconsistent. In a cohort of primary schoolchildren, parental education or ethnicity was not associated with time spent in sedentary or physical activities [35], which is in contrast to previous work reporting differences between subgroups based on parental education and ethnicity [43]. For example, grade level and the school gender ratio (mixed-gender or same-gender schools) may have an impact on gender differences within the school environment and should therefore be a consideration for future research.

23.1.6 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" [44] 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 "sit still" [18]. 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. Duncan et al. [39] found that perceptions of greater job autonomy were associated with increased sitting breaks. Other beliefs and attitudes related to occupational sitting have been associated with reported sitting. Individuals who viewed sitting less at work as valuable reported less sitting, and individuals who perceived greater control over their ability to sit less at work also reported less sitting. Interestingly, the relationship between perceived control and occupational sitting was only present among part-/full-time employees and white-collar/professional employees and not blue-collar or casual employees [38]. Modifying these communal perceptions and social norms is a clear challenge in community environments [45].

The learning and working environment is 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 5.2 million students take at least one online course of any kind [46]. Whether introducing further "screen-time" to a learning environment may be detrimental is not yet known. 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 how it is delivered could be designed to promote breaks to sitting time (i.e. segmented lectures <30 min). 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 such causal relationships.

23.1.7 Environmental Factors

At the environmental level, correlates and determinants of sedentary behaviour exhibit a complex and multi-faceted relationship. For example, methods of transport to school and work are directly related to the neighbourhood. Additionally, 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. Microenvironmental features within the workplace are increasingly being recognized as important factors associated with occupational sitting. Local connectivity (i.e. ability to use different routes to travel through a workplace) has been positively associated with more frequent sitting breaks. Visibility of co-workers across a range of office spatial configurations—private-enclosed, shared, and open plan—was positively associated with more frequent breaks from sitting. However, in open-plan spatial configurations, closer proximity to other co-workers was negatively associated with more frequent breaks from sitting [39]. A recent study using proximity sensors and activPAL-derived sedentary time analysed patterns of sitting by workplace locations in UK office buildings [47]. Not surprisingly, the majority of sitting occurred 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 area. The vast majority of stepping behaviours occurred in the corridors of the workplace. Environmental changes such as sit-stand desks are also extending to the school community. 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 to their child walking to school were strong correlates of children being driven to school [35]. Such factors may indirectly impact the hypothesized innate activity set point (termed the "activitystat") [48]. This theory suggests that children compensate for reduced sedentary behaviour by increasing it at another time point that has 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. A report conducted by The National Center for Safe Routes to School (2011) [49] indicated that in the 50-year time period between 1969 and 2009, the number of children aged 5–14 years walking or cycling to school has decreased by 35%. A survey conducted by the Centers for Disease Control and Prevention (2005) [50] indicated that six barriers (distance to school, traffic-related danger, weather, "other" barriers, crime, school policy) prevented parents from allowing their children from walking to school. Distance to school was identified as the primary barrier. 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. Building schools on the edge of the community became a solution to increased inner city land costs [51]. This has also led to larger schools and larger catchment areas. Traffic danger is reported as the second parental barrier. As communities have accommodated increased motor vehicle traffic volumes, opportunities to walk and cycle have suffered. Many places have no sidewalks, and where they are present, they may be in need of maintenance [49, 50].

Private vehicle use has grown exponentially in the past 50 years. Therefore, the contemporary social norms in the United States and being accustomed to driving have made it easier to avoid active transport. Crime prevalence (both perceived and real) and school policies were also identified as parental barriers to active transport. Whether schools allow children to walk or bike to school and 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. 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 [52]. A recent review revealed equivocal seasonal effects due to methodological inconsistency [53]. However, another study investigated specific climate correlates such as daily ambient temperature or rainfall. Ambient temperature emerged as a main predictor in all sedentary behaviour models, with lower sedentary behaviour levels being associated with higher ambient temperature levels. 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 as an important factor to consider in sedentary behaviour reduction programmes in schools, workplaces, and neighbourhoods. This influence may differ in climate-extreme countries or periods of the year, so cross-cultural comparisons across different seasons are warranted [3].

A majority of the health evidence relating to sedentary behaviour at the community level stems from studies of self-reported TV viewing and relationships with overweight and obesity [16]. Research on sedentary behaviour independent of physical activity and focusing on measures other than screen time is lacking [35]. Similarly, research conducted during school or work hours is largely dominated by the correlates and determinants of physical activity rather than sedentary behaviour [7]. Despite these research gaps, we anticipate that the ongoing paradigm shift will lead to an increase in interventions specifically dedicated to objective measures of sedentary behaviour in school, workplace, and neighbourhood settings [8].

23.2 Community-Level Sedentary Behaviour Interventions

Publications regarding physical activity interventions at the community level are prevalent; however, more recently, interventions focusing on reducing sedentary behaviour are emerging. 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 and have increased in very recent years (Fig. 23.2). For the purpose of the chapter, we do not discuss all interventions listed in Fig. 23.2 in detail but identify them to illustrate the 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 increasing physical activity and reducing sedentary behaviour. Findings have proved to be inconsistent. A study conducted by Robinson [54] randomly assigned

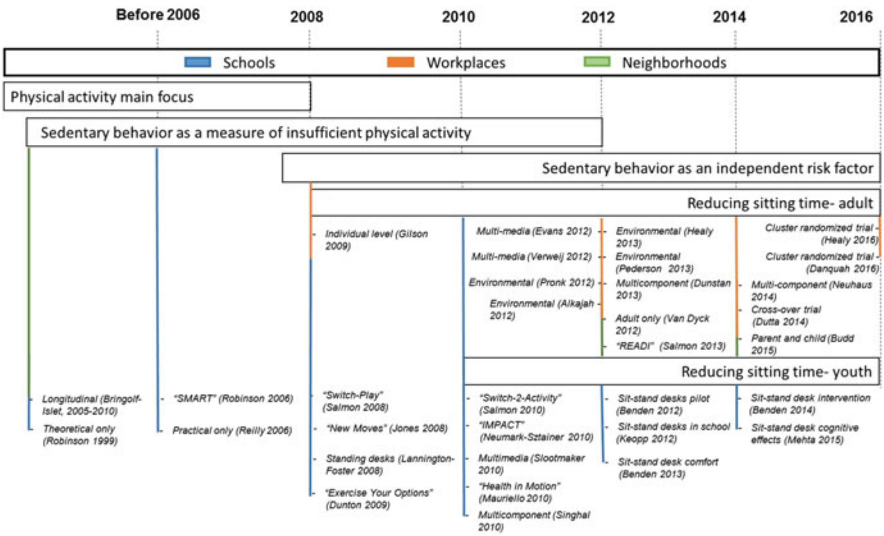

Fig. 23.2 The evolution of sedentary behaviour interventions

third and fourth graders in one of two public elementary schools to receive an 18-lesson, 6-month classroom curriculum to reduce TV, videotape, and video game use, in addition to lessons promoting physical activity. No structured practical lessons (sedentary behaviour or physical activity based) were implemented; all content was delivered via traditional teaching methods in the classroom. The intervention group consisted of 92 children (8.95 ± 0.6 years) vs. 100 children (8.92 ± 0.7 years) in the control group. Overall, reduced levels of TV use were reported (8.80 versus 14.46 h/week); however, no significant changes were reported in video tape 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 [55]. Children in the treatment group significantly decreased their weekday TV viewing (1.14 vs. 1.96 h/day), weekday video game playing (0.19 vs. 0.52 h/day), and Saturday video game playing (0.31 vs. 0.9 h/day) compared to the control. 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-randomized trial called "Switch-Play" was delivered to 311 children in grade level 5 [56]. 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 (4) 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 upon social cognitive theory [57] and targeted self-monitoring, decision-making, identifying alternative activities, intelligent viewing, and advocacy (via posters and role playing) to reduce TV viewing time [56]. 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 [58]. To further investigate teaching methods solely reliant on behavioural modification content, Salmon et al. (2011) conducted a follow-up intervention "Switch-2-Activity" [16] based on the BM arm of the "Switch-Play" intervention [56]. This translational study aimed to determine real-world feasibility and efficacy of the BM intervention. A total of 908 children aged between 9 and 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, gender emerged as a significant moderator of the intervention. Small but positive effects on boys' self-reported weekend screen time were shown (20 min 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 (aged 4.25 $\pm$ 0.3 years) using practical sessions with no theoretical lessons [59]. 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 [60].

There is a need to consider cohorts within communities based on factors such as age and gender, which may influence the type of strategy and content delivered theoretically and/or practically. Furthermore, age and gender may also be associated with different levels of risk. For example, it is documented that physical activity decreases during adolescence [61] and youth spend a great deal of their time both at home and in school being sedentary [35, 62]. Therefore, interventions that aim to reduce sedentary behaviour and increase physical activity among adolescents in a school-based environment are urgently needed. However, current findings show conflicting results. In a systematic review conducted by Hynynen et al. [17], only four studies that targeted sedentary behaviour in adolescent populations (15–19 year olds) were identified [63–66]. Of the four, only one objectively measured sedentary behaviour via accelerometry [63]. The remaining three utilized measures of TV viewing time [64, 65], board games and tuition classes [65], and the 3-Day Physical Activity Recall (3-DPAR) questionnaire previously mentioned [66]. Although very different in experimental design, both Neumark-Sztainer et al. [66] and Slootmaker et al. [63] reported significant treatment effects. Slootmaker et al. [63] utilized 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.

We posit that 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 (Fig. 23.2). It was not until more recent years that research conducted in adult-based populations reported the importance of changing posture, moving more, and avoiding long periods of sitting [67–70]. 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 [71], 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 paradigm shift currently in effect. 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 exhibited 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 [72]. 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 that time, increasing physical activity was the goal of that study. More recently, a pilot study conducted by Benden et al. [11] monitored nine children (ages 6–8) across two semesters (each semester = 5 months). One semester utilized traditional desks, while the other utilized 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 [11]. The results indicated a mean difference of 0.29 kcal ± 0.12 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 ± 0.5 years) [73]. Although a 19% increase in pedometer activity was recorded and no negative behavioural effects were detected in the classroom, results were not statistically significant. Statistical significance may have been detected in a larger sample size, which highlights the need for larger-scale studies. In response to this need, a larger intervention (N = 374) was conducted by Benden et al. [74]. 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. The conclusions 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. [75]. The results indicated no significant differences between traditional desk and sit-stand desk use on evaluated ergonomic support and discomfort. 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. (2012), 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. [74], neurocognitive effects were also evaluated using a comprehensive battery. Positive effects for reaction times, response times, and error rates were detected [76]. However, the cognitive results were not compared to a control group, reducing the ability to draw conclusions from these findings. Replication of large-scale experimental designs that include cognitive effects as a primary outcome is 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 meta-analysis of physical activity-focused interventions to reduce sedentary behaviour concluded a lack of evidence to support the efficacy of these approaches for modifying sedentary time [77]. More specific to the workplace, Gilson et al. [78] conducted a 10-week pedometer-based intervention to increase incidental walking at work in white-collar university employees. Results indicated significant increases in overall steps; however, there was no concurrent reduction in workplace sitting time. The use of computer prompts (i.e. point-of-choice prompts on a computer) has received mixed results. Two short-term studies evaluated the use of computer prompts + standardized information, relative to information alone. Evans et al. (2012), 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 number of 30 min continuous bouts of sitting [79]. Pedersen et al. (2013), which focused on prompts to increase sitting breaks with walking in a longer 13-week intervention, reported significant reductions in sitting time of 55 min per day [80]. Finally, a single study tested the effects of five brief sessions of motivational interviewing by occupational physicians that focused on reducing sedentary time, increasing physical activity, increasing fruit and vegetable consumption, and reducing energy intake from snacks [81]. Significant reductions were observed for sedentary time at work and fruit and vegetable consumption—but not other behavioural targets—at the 6-month follow-up.

23.2.4 Physical Changes to the Workplace Environment

The use of multilevel, 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 past 10 years. Neuhaus et al. (2014) reported the results of a meta-analysis of 38 studies with a pooled effect size of 77 min reduction in sedentary time/8-h workday [82]. Other health-related outcomes showed no impact. The efficacy of the interventions reviewed was highly variable, and the authors noted large variations in study quality, and the vast majority of the studies only reported short-term outcomes ($\leq$3 months). More recently, Tew et al. (2015) conducted a more exclusive systematic review of controlled trials (both randomized and non-randomized) of the efficacy of height-adjustable workstations only on occupational sitting time. The authors identified five studies, four of which were non-randomized designs [83–86] and one was a crossover trial [87]. All studies included a control condition with no environmental change, and all studies showed significant reductions in occupational sitting relative to control. However, it should be noted that the authors rated all of the studies of low methodological quality with high risk for selection bias (i.e. due to non-randomized designs). Furthermore, a Cochrane review in 2016 [88] reviewed the effects of sit-stand desks and concluded there were significant reductions in total sitting and sitting episodes lasting 30 min or longer. A sit-stand desk alone decreased workplace sitting by about 0.5–2 h per day. When combined with information and counselling, sit-stand desks reduced sitting at work in the same range. Sit-stand desks also reduced total sitting time (both at work and outside work) and the duration of sitting episodes that last 30 min or longer. The preliminary, yet promising, results of these trials suggest studies with randomized designs of longer duration are needed to provide more solid evidence for the use of activity-permissive workstations. A number of these studies are ongoing in Finland, Australia, the United Kingdom, and the United States, with the majority of these studies conducting group-randomized trials of multiple worksites with study durations of 1 year or longer. Two of these studies have recently reported their initial findings. Both studies delivered programmes that targeted individual, social, environmental, and policy factors, alongside the installation of sit-stand workstations, to reduce sedentary time. Danquah et al. [89], in a 3-month intervention among Danish public and private health workers (n worksites = 19; n subjects = 317), observed 48-min/8-h workday reductions relative to a usual practice control. Healy et al. [90], in a 12-month intervention of Australian public health workers (n worksites = 14; n subjects = 231), observed 45-min/8-h workday reductions relative to a usual practice control. These studies provide the strongest 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 this 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 organization 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 multilevel approaches to reducing occupational sitting [91, 92], which may include policy- and organizational-level approaches named above, it is difficult to identify the unique impact these approaches may have on sitting. Gilson et al. [78] conducted a randomized controlled trial testing two approaches—a route-based walking group or an incidental walking group—relative to a control, on steps/day and self-reported occupational sitting. The route-based group was asked to walk briskly on predefined routes during work breaks. The incidental walking group was asked to engage in walking during work through informal means, including the use of standing/walking meetings and walking to talk with co-workers instead of sending emails or making telephone calls. Both intervention groups, during the 10-week intervention, increased overall step count/day while control decreased. Self-reported occupational sitting showed very small and non-significant reductions during the intervention period. 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

Bringolf-Isler et al. [93] 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. Physical activity and inactivity was assessed by accelerometers and each child's home address was linked to the objective environmental data. 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 socio-economic 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.

Aside from objectively measured neighbourhood characteristics, perceptions of the environment may influence sedentary behaviour. 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 [94]; 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. Very similar results for 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. [95] hypothesized 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, USA. 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.

Another study of perceived neighbourhood environmental characteristics included sedentary behaviour of adults in the United States, Australia, and Belgium [96]. Across all regions, 6014 adults were recruited from high- and low-walkability neighbourhoods and high- and low-income neighbourhoods. Thus, this project had a great deal of diversity in geography, infrastructure, and socio-economic factors. Transport-related sitting and total time spent sitting were assessed with the International Physical Activity Questionnaire (IPAQ), while environmental perceptions came from the Neighbourhood Environmental Walkability Scale. Motorized transportation time, one measure of sedentary time, was predicted (inversely) by an index including number of destinations with a 20-min walk of home, perception of few cul-de-sacs, good walking and cycling facilities, and traffic safety. Perceived aesthetics and proximity of destinations had an inverse association with total sitting time. No clear differences emerged between men and women or, interestingly, across countries.

Heterogeneity of results for sedentary behaviour reduction strategies at the community level is prevalent and continues to inhibit our understanding. Although insightful results are presented in earlier interventions, a fundamental component missing is demonstrating how to practically reduce sedentary behaviour by simply "standing and moving more". Tackling this both theoretically and practically has now become the new challenge. The lack of environment-level techniques may be related to financial resources and difficulty to implement change at a macro level. Initiating major changes in the school's physical environment without efficacious evidence may be considered too risky and costly [17]. 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 utilize the often-limited resources that are available in community or school settings [97]. It should be considered that not all the 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 BCTs include self-monitoring, feedback, and social support [98] and are now used in several forms, such as activity monitors, web-based applications, and mobile phones [99]. With the abundance of technological strategies, there has been a shift from face-to-face interventions towards multicomponent interventions to reduce sedentary behaviour using self-monitoring devices, web-based support, and sophisticated mobile media [100]. 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 [101]. As a result, we have seen a burgeoning industry for accelerometer-based wearable activity monitors [102], online support platforms, online feedback platforms, and mobile apps targeting the consumer market [103]. These platforms vary in medium (wrist-worn device, phone, email), delivery (textual, visual, sound, vibration), and content (personalized, 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 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 that 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 an estimated 3.3 million units sold in 2014 [99]. Based on the growth rates recorded in 2014 [104], it is anticipated that almost 60 million fitness trackers will be in use by 2018, 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 [99]. Feedback strategies include simplistic prompts that serve as a "reminder" to stand up or move at a set time and frequency (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 (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.

There is supporting data to show that EAMs may be an effective tool to reduce sedentary behaviour. A recent study conducted by Barwais et al. (2015) evaluated the effectiveness of wearing a commercially available EAM [Gruve, Gruve Technologies, Inc., Anoka, MN, USA] for 4 weeks. The multidimensional behavioural intervention utilized 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 helpful prompt for behaviour change and to achieve the set goals. The online software enabled participants to visualize sedentary patterns with simple 24 h/day graphs and charts. Motivational support was provided via a personalized homepage and goal setting 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). Another 4-week intervention assessed breaking up prolonged periods of sedentary behaviour time with brief physical activity breaks (e.g. walking). Thirty overweight and obese adults were regularly prompted via an Android smartphone [105]. Results indicated that the smartphone-based intervention reduced sedentary time by 2 h/day from the average 9.8 h/day. A study involving overweight and obese office workers examined the feasibility of reducing the amount of time spent in sedentary activities by using targeted messages. These targeted messages contained information about potential health risks associated with sedentary behaviours and recommended they replace time spent in sedentary activities with standing and light-intensity activity [106]. Time spent in sedentary activities was measured using wearable monitors and self-reporting tools. The findings showed that participants reduced the amount of time they spent in sedentary activities by 48 min/day over a 16-h waking day [106]. These results suggest that EAM use may be an effective sedentary behaviour reduction strategy; however, the longevity of the effects is still unknown.

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 h	Vibration and alert	Numerical display on the device
Garmin vivofit	Yes	1 h	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 1 min 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 min each hour	Move reminder visually flashes at 45 and 50 min of inactivity	Links with iOS app, send reminder to mobile device. If you move at least 5 min 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 min	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 aa a log not a sensor
Break Time app	No	Manually set inactivity interval and alerts	Alert only	For iOS and Mac. Serves as an alert system, does not provide feedback or GUI

(continued)

Table 23.1 (continued)

Electronic activity monitors (EAMs)				
Platform	Detects inactivity	Period of inactivity	Type of alert	Feedback
Get Moving app	Yes	Manually set inactivity interval and alerts	Customizable alerts of your mobile phone	Tracks as a pedometer, the clock starts when inactivity is detected. Provides 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) [79]	No	Reminder sent every 30 min	Simple reminder	Does not provide objective "sitting time" feedback
Email	No	Daily, weekly, biweekly	Motivational, educational	Varied—may provide feedback on the number of times a user read or viewed email. Does not provide objective "sitting time" feedback

23.3.2 Mobile Apps

Currently 90% of Americans own a cell phone, of which 64% own a smartphone [107]. 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 [103]. 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 towards reducing sedentary behaviour [103]. A recent study compared three different apps (analytic, social, and affect apps) designed to reduce sedentary behaviour [103]. Distinct elements of each were as follows: *analytic app*, user-specific goal setting; *social app*, avatars representing other participants allowing for comparison; and *affect app*, an avatar used to reflect how active/sedentary the user was. A reduction in sedentary behaviour was achieved using all three apps; however, the *affect app* was least effective. Understanding why and when such interventions are effective is reliant on systematic user-centred experimental studies.

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 [21]. Email strategies can be tailored to provide motivational and educational support that exploits habitual email interaction. Software lends itself more to regular reminders [79]. Email-based strategies show inconsistent results. An intervention to reduce sedentary behaviour among obese women utilized face-to-face sessions combined with email messages and pedometer information for informed self-evaluation and goal setting. Significant decreases in sedentary time were reported [108]. Kaiser researchers also conducted a 16-week trial of the A Lifestyle Intervention Via Email (ALIVE) programme on 787 employees, 351 of them in the email intervention group and 436 in a control group. All participants took a short, online questionnaire at the beginning of the study and received immediate feedback on their diet and exercise habits. Participants in the intervention group set small health-improvement goals for themselves. Once per week, they received an email containing individualized suggestions on ways to get closer to that goal. Each email contained a link to a Web site where participants could get extra tips, learn more, and track their progress. In addition to weekly suggestions, participants also received reminder emails. According to the survey completed post intervention and during a follow-up 4 months later, the people in the email intervention group had increased their activity-level intake more than those in the control group. However, a study recently conducted by Bort-Ruig et al. [100] indicated that in the workplace environment, email-only strategies were not effective. As previously mentioned, the workplace intervention conducted by Evans et al. [79] 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 [79]. This suggests that multicomponent strategies are most effective. Combining both reminders with educational support (via email) is required to educate but also prompt the user. Although wrist-worn devices, mobile platforms and apps, and software/email support may each show some individual promise, research suggests that multicomponent strategies are more effective than single component [109]. This may prove particularly key for long-term interventions as the user progresses through various stages of behaviour change [110]. It would therefore be prudent to examine the health benefits of decreases in the amount of time spent in sedentary activities in a longitudinal study comparing various multicomponent strategies.

23.3.4 The Role of the Media

The Center for Disease Control recently affirmed the influential role that the media can play in health behaviours [111]. Commercial marketing principles of combining mass media with product distribution were well established long before their adoption into the public health domain [112]. 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 systematic review indicated that combining mass media health communication campaigns with distribution of health-related products related to the behaviour is likely to be effective in influencing the intended health behaviours [111]. Health communication campaigns apply integrated strategies to deliver messages designed to inform, influence, and persuade target audiences' attitudes about changing or maintaining healthful behaviours [113]. Messages can be transmitted through a variety of channels, such as traditional mass media (e.g. TV, radio, newspapers), the internet and social media (e.g. websites, Facebook, Twitter), small media [114] (e.g. brochures, posters, fliers), group interactions (e.g. workshops, community forums), and one-on-one interactions (e.g. hotline counselling) [115].

Media coverage on the topic of sedentary behaviour is rising rapidly. News networks, newspapers, and online media are now discussing the independent effects of sedentary behaviour to that of physical activity. To gauge the evolution of sedentary behaviour as a media concern, we ran a systematic, advanced Google search using the exact phrase "negative effects of sitting". The search dates were restricted to each individual year from 2005 to 2015. The total number of results found and the total "news" results found per year were documented and are presented in Fig. 23.3. In the last 10 years, the number of online news articles on "the negative effects of sitting" has increased from just 1 in 2005 to 81 in 2015. Overall results (websites, news articles, blogs, images, videos) show an increase from 2 to 913 search results with content denoting the "negative effects of sitting". Although a simplistic technique, the results clearly show how the detrimental effects of sedentary behaviour are now being reported more commonly. As this trend continues, the opportunity to design multicomponent interventions is

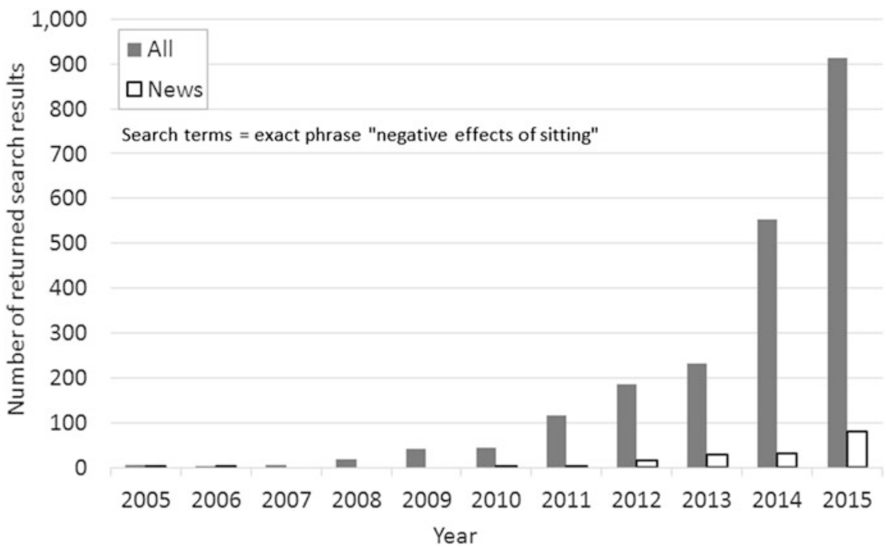

Fig. 23.3 The evolution of media coverage on sedentary behaviour interventions

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, “Worldwide Social Network Users: 2013 Forecast and Comparative Estimates”, nearly one in four people worldwide will use social networks in 2013 [116]. The number of social network users around the world will rise from 1.47 billion in 2012 to 1.73 billion this year (an 18% increase). By 2017, the global social network audience will total 2.55 billion. 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 instead 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/or 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 programmes 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-centred 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. Chronic effect results would provide invaluable data regarding how adaptive the technology may need to be to withstand likely fluctuations in user interest over time.

23.4 Organizations Promoting Health Behaviour

Changing attitudes and behaviours is reliant upon organizational research, funding, and support at local, national, and international levels. Governing bodies and policymakers that influence health, education, and welfare each 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 organizations.

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" [117]. Worksites, schools, and neighbourhoods pose numerous challenges within different contexts—environmental, organizational, 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 organizations such as the Sedentary Behaviour Research Network (SBRN). The SBRN is the only organization 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 organizations and communities.

23.4.2 Funding Organizations

Funding organizations 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 organizations 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 organizations 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 Organizations

One of the most notable health organizations with an extensive reach and influence in all aspects of health is the World Health Organization (WHO). The WHO is a specialized 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 programmes. At the school level, Health Behaviour in School-aged Children (HBSC) was formed as part of a WHO initiative. This is a cross-national, school-based research study to collect 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 4 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 not only aids research understanding, but it 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 Finland, recent national recommendations on the reduction of sedentary time explicitly identified schools as one of the key influential settings [17]. Similarly, in 2011, the Canadian Society for Exercise Psychology revised the Physical Activity and Sedentary Behaviour Guidelines for children (5–11 years of age) and youth (12–17 years of age) and in 2012 released the first guidelines for younger children (0–4 years of age) [118, 119]. The WHO has the ability to reach an expansive population. Ensuring that scientific research is communicated effectively and appropriately should be a main focus. Working with funding organizations to prioritize 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" [120]. For example, collaboration between HealthPartners and Ergotron facilitated the occupational sitting "Take-a-Stand" project (2011) [91]. 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 utilization [121].

23.5 Evaluation of Community-Based Interventions

Overall, it is clear that addressing the correlates of sedentary behaviour at the community level may be one method to slow the significant impact of sedentary behaviour on both child and adult health. By identifying socio-demographic correlates of work-time, school-time, and leisure-time sedentary behaviour, higher-risk subpopulations 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, they 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, the vast majority of studies continue to rely on self-reported sitting. Since context of sitting remains challenging to sense 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, 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 (with the exception of Duncan et al. [39]) 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 either Australian or UK samples of desk-based employees. These samples may not be generalizable 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 gender, grade level, occupation, location, public vs. private schooling, worksite leadership, and teaching strategies. Future interventions must focus on multilevel approaches that unify various local coalitions and influence health, education, welfare, and government policies. Initial results indicate that both objectively measured neighbourhood characteristics as well as individual perceptions of characteristics appear to be important. Furthermore, findings may differ depending on socio-economic 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 dose and frequency of breaks to sitting time may reduce the potential negative effects of prolonged sedentary periods. Understanding the dose-effect 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 organizational, socio-economic, 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 efficacious strategies. Overall, at the community level, there is a predominance of cross-sectional studies, which may inhibit the determination of causality between variables. More randomized controlled trials should be conducted to confirm deleterious effects attributed to some sedentary behaviours. Future epidemiologic studies need to assess multiple sedentary behaviours as there is growing epidemiologic evidence that certain sedentary activities are more detrimental for health than others. To increase the current knowledge of sedentary behaviour, future studies must incorporate emergent objective and more accurate methods (i.e. geolocation data combined with acceleration signals in mobile phones, small video cameras, and inclinometers) to obtain an accurate measure and contextual information of sedentary behaviour [122]. 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 [123]. 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 of chronic effects and how to optimize the design in various environments and contexts is 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 optimize intervention strategies. Integrating behavioural science theory with an iterative user-oriented design process is needed to optimize multicomponent 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 unhelpful strategies. Advances in technology should be utilized 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 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 multilevel approaches that include individual, community, and organizational levels, across and within different settings, will produce longer-lasting results [97]. Ultimately, a combined effort of strategies that target sedentary behaviour as an independent risk factor, across multiple settings, such as schools, workplaces, and local neighbourhoods, is required.

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Chapter 24
Sedentary Behaviour and the Social and Physical Environment

Trish Gorely and Gemma 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 level of analysis. The chapter summarizes 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 young people, adults, and older adults. 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 interrelationships between individuals, the groups they operate within and the physical and social context. There is evidence to suggest that incorporating environmental modifications into sedentary behaviour interventions is likely to be effective for both young people and adults.

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), organizational/community factors

T. Gorely (✉)
School of Health, Social Care and Life Sciences, Centre for Health Sciences, University of the Highlands and Islands, Old Perth Road, Inverness IV2 3JH, Scotland
e-mail: trish.gorely@uhi.ac.uk

G. Ryde
Faculty of Health Sciences and Sport, University of Stirling, Stirling FK9 4LA, Scotland
e-mail: gemma.ryde@stir.ac.uk

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(see Chap. 23), social context or circumstances, the physical environment, and wider sociopolitical 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 environment 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 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 or not 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 Young People

The home and school environment are important settings in which young people spend the majority of their time. Systematic reviews of the correlates or determinants of sedentary behaviour in young people have identified only a few consistent home-based social factors associated with sedentary behaviour. A number of systematic reviews have reported an inverse relationship between parental rules around screen use and sedentary behaviour in children and early adolescents [3–5]. Results in preschoolers are conflicting, with one systematic review reporting a positive relationship [6] and two reporting an indeterminate relationship [7, 8]. One study reported within the Maitland et al. review [5] investigated the relationship between the physical environment and the social environment and found an inverse relationship between parental rules and television (TV) use only when there was a TV in the bedroom. There is evidence that parents are role models for sedentary behaviour, as parent electronic media use or sedentary time is positively associated with electronic media use in young children [4, 7, 8], 10–12-year-olds [3], and early adolescents [5]. Positive relationships have also been found between family support and sedentary time [5]. 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 causes conflict between parents and children and between siblings [9].

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 [10–12]. The basis for this conclusion was that although a variety of social correlates have been examined within prospective studies, specific social correlates having been studied too few times for conclusions to be drawn.

Friends and peers may also influence the health behaviours of young people, particularly as they get older [13]. 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, Minges et al. [9] reported that the absence of peer social support networks promoted screen time. In addition, Sawka et al. [13] 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 [14]. 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 [15]. Finally, using a measure of popularity, Strauss and Pollock [16] reported that as an individual's popularity increased, daily TV time decreased. The findings of the Sawka et al. [13] 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. [17] 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. [3].

24.2.2 Adults

Two systematic reviews have examined the correlates of sedentary behaviour in adults aged 18–65 years [18, 19]. The early review by Rhodes et al. [18] did not identify many potential social environmental correlates. In contrast, O'Donoghue et al. [19] identified two domains of social correlates: family-related factors and social factors. 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), 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.

A key behaviour setting for many adults is the workplace and the social environment at work including cultural norms, and colleague expectations are likely to contribute towards how sedentary we 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. Alternately, 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. To date, there is little research on the effects of the workplace social environment on sedentary behaviour at work and no systematic reviews. De Cocker et al. [20] adapted an existing questionnaire from the physical activity workplace literature to suit sedentary behaviour and assessed the prevalence, correlates, and moderators of sedentary behaviour in Australian employees which included some social environmental factors. They found neither social norms about sitting less at work nor social support to sit less at work was associated with occupational sitting time.

Bennie et al. [21] looked at social environment correlates of taking short activity breaks at work, which were defined as any interruption in sitting time during a typical work hour. They found that most social factors (most work colleagues take short physical activity breaks, seeing work colleagues taking short physical activity breaks, and management support for short breaks) were associated with frequency of breaks in women only (bivariate model), but these associations did not remain in the final multivariate statistical model.

Again, as with the previous reviews by Rhodes et al. [18] and O'Donoghue et al. [19], these results are unexpected as social factors have been shown to play an important role in physical activity at work. This could be related to limitations in the assessment of the social environment with issues on how we measure the worksite social environment previously raised in the physical activity literature [22].

24.2.3 Older Adults

Older adults have the highest levels of sedentary behaviour within the population. They are also the least studied group. Chastin et al. [23] in a systematic review of correlates of sedentary behaviour in older adults found a limited evidence base comprised mostly of cross-sectional studies with a prime focus on personal factors. There was a lack of key information on determinants at other levels of the social ecological model. Chastin et al. identified only two studies that reported on interpersonal factors. In one study, loneliness was associated with a small increase in TV time [24], and in another, those living alone watched more TV than those in shared accommodation [25]. 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 Young People

There is some evidence that having a TV in the bedroom is associated with greater sedentary behaviour [5, 7, 26], although this relationship is not consistent across reviews [3, 10]. It is possible that this relationship may be changing with changes in technology and the way people consume TV [10]. Mixed results have been reported for the relationship between number of TV sets in the home and viewing time in young people [3, 5, 26], and the effect may be stronger in girls compared with boys [26]. When synthesizing qualitative studies, Minges et al. [27] concluded that the ready access to screen-based entertainment in the home promoted screen time and that 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 [5]. As with the school social environment, little attention has been given to how the physical environment of the school influences sedentary behaviour [3, 17].

24.3.2 Adults

O'Donoghue et al. [19] found only a limited number of studies that had examined physical environment influences on sedentary behaviour in adults, and few factors have been studied often enough to draw conclusions. At the home level, they 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 were positively associated with TV and internet usage. There was some evidence for the influence of neighbourhood characteristics on sedentary behaviour. For example, the presence of green spaces in the neighbourhood was negatively associated with sedentary behaviour and living in a rural area was associated with more time spent sitting for transport. Weather was consistently reported as a barrier and was positively associated with total sitting time. Inconsistent results were found for the relationship between sedentary behaviour and characteristics of the neighbourhood such as walkability, aesthetics, proximity to destinations and facilities, traffic safety, residential density, and crime. However, there is some evidence that these relationships may depend on the type of sedentary behaviour examined. Further research is required to determine the potential impact of neighbourhood characteristics on sedentary behaviour.

Similar results were reported in a review looking specifically at neighbourhood environmental attributes and adult's sedentary behaviour [28]. In this more focused review, it was reported that people living in urban areas had lower levels of sedentary behaviour compared to residents of regional areas. In addition, there was some evidence that having better access to destinations (e.g. leisure facilities, public open spaces) was associated with lower levels of sedentary behaviour, and this result is more consistent when domain-specific (e.g. transport related, leisure time) rather than total sedentary time is examined. In addition, inconsistent or non-significant results were reported for walkability, social and safety issues, aesthetics, and route-related characteristics (e.g. lower traffic and pedestrian infrastructure). Kooshari et al. [28] 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).

The physical environment in which adults work could affect sedentary behaviour. This may include aspects such as furniture design, workplaces with poor transport connections and ample parking for cars, lack of active transport facilities such as bicycle parking or showers and how the physical workplace is configurated including space to move about and visibility and aesthetic appeal of stair wells [1, 21].

As with the social workplace environment, more work is needed to assess how the physical work environment influences our sedentary behaviour, but some examples are emerging. For example, Bennie et al. [21], as well as addressing the effect of the social environment on breaks in sitting, assessed the influence of the physical environment on breaks. They asked one question relating to whether there is limited space available at the workplace to take a short physical activity break. No associations were reported for either men or women. As another example, Duncan et al. [29, 30] subjectively assessed spatial configuration of office layouts as a correlate of occupational sitting. Employees were asked questions relating to routes and passageways around the office, how easy it is to navigate and access areas of the building, and about being able to hear and see your coworkers. Duncan et al. [30] reported that for shared and open-plan offices, workers who perceived that there was more local connectivity took more breaks from sitting. The same result was not found in private offices. Likewise, in open-plan offices only, coworker proximity was associated with more breaks in sitting, and in all office types, the more visible your coworkers are, the more you break from sitting.

There is also interesting research emerging related to objectively measuring the workplace physical environment and sedentary behaviour. The Active Buildings project [31, 32] based at University College London, aims to increase our understanding of how we accumulate steps as well as sitting time in buildings and to use this evidence to address spatial configuration of offices. Employees are asked to wear a novel radio frequency indication tracking device to record where and when they move about the office in addition to a device that measures sitting time. Work in this area is ongoing but likely to generate interesting data on how the physical environment influences sitting time at work.

24.3.3 Older Adults

In their systematic review of correlates of sedentary behaviour in older adults, Chastin et al. [23] identified only four studies that had examined physical environmental factors and sedentary behaviour, and no factor had been studied often enough to draw firm conclusions. At this point in time, there is conflicting evidence for the effect of rural versus urban residence on sedentary time and very limited evidence for the potential influence of type of housing, the presence of cultural facilities or green spaces, transportation options, and the availability of places to rest. The authors concluded that there is a need for more work exploring the potential determinants of sedentary behaviour in older adults.

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 interplay between influences at different levels of the social 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.

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 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 [33, 34]. 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 [35]. In the future, when the situation is encountered, it cues the automatic habitual response [36]. For example, a child receives a computer game console for their birthday. They play with this on the couch in the lounge at home. Over time, the act of sitting down in the lounge at home becomes sufficient to automatically cue the habitual response to look for the console and play computer games. 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 [36] suggest that in order to break habits, it is first necessary to identify the social and environmental cues for a behaviour. Individuals can then either restructure their personal environment or plan new responses to those cues.

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. [13] showed mixed results in adolescents, social network analysis has not been widely used in sedentary behaviour research and may be one approach that would be helpful. A social network can be defined as "the web of social relationships that surround individuals" (p. 190) [37] and consists of nodes (individual people, groups, or organizations) that are joined by ties (relationships between nodes) [38]. 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 [39]. The basis for 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. 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 [39].

The theoretical underpinning for interventions based on social network analysis is diffusion of innovations theory [40]. 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 [40] describes five categories of people: (1) innovators (want to be the first to try an innovation), (2) early adopters (usually represent opinion leaders, are 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 [41] 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 subgroups within the network. The second approach, segmentation, uses network analysis to identify segments or groups of people to change at the same time. Valente [41] 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 subgroups), 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, 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 which 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. [38, 42]) and refer to Chap. 26 of this book. There is no one single systems theory, but all focus on the different levels of influence from the social ecological model and the complex interrelationships between them [43]. From a systems theory, perspective individuals “are complex adaptive systems…embedded within other complex adaptive systems (such as dyads, groups, organizations, communities, and societies)” (p.148; [38]). According to Bartholomew [38], 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 (small “changes” can have large effects and vice versa); (4) are sensitive to initial pre-change conditions (small differences in initial conditions can lead to large differences in the future); (5) are self-organizing, as people adjust their behaviour to meet different demands; and (6) are open, with crossover between systems as individuals move between them. In trying to understand or change systems, it is necessary to consider the structure (e.g. people, their activities, and their relationships), the meaning people assign to an issue/behaviour, the resources within a system and/or individual, and the 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 interrelationships that could underpin both sedentary behaviour and sedentary behaviour change.

24.5 A Different Perspective: Social Marketing Approaches to Health Behaviour Change

Social marketing is a framework that draws on knowledge from other fields including sociology, psychology, anthropology, and communications theory and applies learning from the commercial sector in order to understand and influence people's behaviour [44]. Social marketing has been described as "the application of commercial marketing technologies to the analysis, planning, execution, and evaluation of programmes designed to influence the voluntary behaviour of target audiences in order to improve their personal welfare and that of society" (p. 7) [45]. Social marketing offers a complementary approach to sit alongside conventional health promotion [46].

Social marketing approaches utilize eight key aspects highlighted by Griffiths et al. [46]: customer orientation, focus on behaviour, theory, insight, exchange (what do customers gain and lose), competition, segmentation (targeting a specific group), and the marketing mix (the 4-Ps: product, price, place, promotion). Social marketing is fundamentally focused on people's behaviour and aims to improve health and society over merely benefiting an organization or making money [47].

Although there are similarities between social marketing and conventional health promotion, social marketing uses some distinctly different strategies in its approach to changing behaviour [46]. Both social marketing and conventional health promotion are focused on behaviour change and understanding people's lives, engage individuals in the process, extensively use health education approaches, and utilize 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 emphasizes 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.

There are not thought to be many studies that have used social marketing approaches with the aim of reducing sedentary behaviour. A review by Stead et al. [48] addressed the effectiveness of social marketing interventions on influencing health behaviours which included some physical activity interventions but not specifically sedentary behaviour. Sedentary behaviour was mentioned in reference to four studies but on further investigation, only one study actually measured changes in sedentary behaviour. Despite the limited research in this area to date, there is potential in employing a social marketing framework or approaches to the development of interventions to reduce sedentary behaviour. 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 [49].

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 Young People

Schmidt et al. [50] and Steeves et al. [51] conducted systematic reviews examining intervention strategies to reduce screen time in children. While most studies employed individual behaviour modification techniques such as goal setting, self-monitoring, problem-solving and positive reinforcement, a number of interventions also included electronic monitoring devices (which turn off the TV after a self-prescribed amount of viewing) or contingent TV devices. Contingent devices can be either closed loop (TV viewing is contingent on a concurrent behaviour such as stationary cycling) or open loop (TV is contingent on physical activity accumulated at other times). Steeves et al. [51] 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 [50, 51]. 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).

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. In a systematic review of randomized controlled trials, inconsistent results for family-based sedentary interventions were found [52]. However, the effectiveness may have been influenced by 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.

The introduction of standing desks has become a popular approach to reduce sitting time during the school day. Minges et al. [27] conducted a systematic review of the impact of school-based standing desk interventions. The authors identified eight studies that met their inclusion criteria; however, most of the studies were pilot or feasibility studies, and 50% employed non-randomized designs. After the introduction of standing desks, standing time was shown to increase across the eight studies identified with moderate to large effect sizes (effect sizes: 0.38–0.71). Sitting time was also shown to decrease by 59–64 min (effect sizes: 0.27–0.49). Similar results were reported in an overview by Hinckson et al. [53] focusing on interventions that changed the classroom environment with the aim of decreasing sitting time while at school. In this overview, 13 studies were identified with the majority providing some sort of standing desk/workstation. In addition, some classrooms also provided Swiss balls, bean bags, stools, or adjustable chairs. Hinckson et al. [53] reported that post-implementation sitting time was reduced and standing time was increased during classroom time. This result held regardless of type of desk; the provision or not of Swiss balls, bean bags, stools, or chairs; and whether it was a primary or secondary school. In many of these 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 even more effective. Both Minges et al. [27] and Hinckson et al. [53] concluded that while the evidence base is small and has some methodological limitations, standing desks have the potential to reduce sitting time and increase standing time among schoolchildren.

24.6.2 Adults

In a systematic review and meta-analysis in adults, consistent evidence was found for reductions in sedentary time following interventions focused on reducing sedentary behaviours [54]. Smaller and less consistent reductions in sedentary behaviours were observed in studies that focused on physical activity or included both a physical activity and a sedentary behaviour component. The majority of the studies in this review were worksite studies and the evidence for worksite interventions is discussed in more depth below. Evidence for environmental strategies beyond the worksite was not articulated within this review.

In a review of behaviour change strategies employed within sedentary behaviour interventions in adults, it was reported that behavioural interventions to reduce sedentary behaviour in adults show promise [55]. After reviewing both intervention function [56] and behaviour change techniques [57], Gardner et al. [55] concluded that incorporating environmental modifications into sedentary behaviour interventions was likely to be fruitful. Much of this evidence comes from worksite studies focused primarily on physical environmental changes (e.g. provision of sit-stand desks), and there is a need to explore the impact of environmental modifications in other contexts.

It is not surprising that the majority of physical environmental interventions to influence sedentary behaviour in adults to date have focused largely on the workplace. In recent times, there has been a significant shift towards computer- and desk-orientated offices, and research suggests that almost 6 h per workday can be spent sitting at a desk [58].

One of the most frequently reported physical environment interventions to 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 positon 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 while 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. [59] conducted a Cochrane review on interventions for reducing sitting at work and reported three studies that had made changes to the physical environment. Two of these studies looked at the effect of sit-stand desks alone on sitting time after a 3-month follow-up. In one group from a public health research institute, who were likely to have previous knowledge on the topic of sedentary behaviour, a decrease in sitting time of 2 h 17 min per 8 h workday was reported [60]. In a more representative sample of office employees, a non-significant reduction in sitting time of 33 min per 8 h workday was reported [61]. When looking at interventions incorporating sit-stand desks alongside additional social ecological strategies (organizational and individual components), Shrestha et al. reported a pooled effect in the reduction of sitting time of 1 h 53 min per 8 h workday. Straker et al. [62] suggested that sit-stand desks on their own only have a modest effect and that more radical, system-wide interventions were necessary in order to effect sedentary behaviour at work. In fact, when adding in such additional strategies, Neuhaus et al. [61] showed that the reduction in sedentary time increased from 33 min to 1 h 39 per 8 h workday. However, Shrestha et al. [59] concluded that there was low-quality evidence that sit-stand desks with or without additional counselling reduced sitting time at work.

Other reviews have reported more positive findings. A systematic review and meta-analysis by Neuhaus et al. [63] reported on 38 interventions that used activity permissive workstations (sit-stand desks, treadmill desks, portable pedal devices) to reduce occupational sedentary time. The authors reported a pooled intervention effect in the reduction of sedentary time of 1 h 17 min per 8 h workday. It was concluded that the installation of activity permissive workstations can lead to substantial reductions in sedentary time. Commissaris et al. [64] reviewed the impact of alternative workstations as part of a wider review of workplace sedentary behaviour and physical activity and found strong evidence for a reduction in overall daily sedentary behaviour and conflicting evidence for sedentary behaviour at work. However, when they performed subgroup analyses for sit-stand desks and treadmill desks (removing pedal machines, etc.), they found that changes to overall daily sedentary behaviour were mainly attributed to the use of treadmill desks. In addition, when looking only at sit-stand desks, they found a moderate positive effect on sedentary behaviour at work. Although largely positive, effects for sit-stand desks have varied widely between reviews in part due to significant differences in methodology. For example, whether reviewers focused on changes in sitting time or sedentary time or included lab- and field-based studies makes a significant difference to the findings. More large-scale, longer-term evaluations in real workplace settings are required to assess the true effect of sit-stand desks and activity permissive workstations on sedentary behaviour. In addition, some additional points should be considered in relation to sit-stand and activity permissive workstations. These include implementation issues and uptake (retrofit versus whole desk sit-stand or practicality of treadmills at work), negative effect of standing (blood pooling, varicose veins), and novelty and compensation effects (sitting more outside of work).

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 breakout spaces, centralized resources (printer, kitchen, and toilets) and attractive central staircases. Jancey et al. [65] 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 min) and an increase in light activity (22 min). 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.

There is also limited evidence on the effect of physical changes to the work environment on other outcomes (physiological, psychological, workplace). There is some research to suggest that activity permissive workstation don't have a negative effect on productivity but mixed evidence on whether productivity increases [59, 66, 67]. For example, treadmill or cycle desks lead to some reductions in productivity, possibly related to typing impairment or mouse usage, but little is known about whether these may improve with repeated use [66]. A review by MacEwan et al. [67] assessed the physiological (chronic disease prevention and management) and psychological (worker productivity, well-being) outcomes in 23 studies looking at standing and treadmill desks. They found that treadmill desks had the greatest impact on physiological outcomes and that standing desks were associated with few changes in physiological outcomes, with mixed findings for both interventions on psychological outcomes [67]. Others have reported inconsistent evidence on the effect of sit-stand desks on musculoskeletal symptoms [59].

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 multicomponent interventions. However, there is very little evidence on the effect of social changes in the workplace alone on sedentary behaviour.

Stand Up Australia is a multicomponent intervention including organizational, environmental and individual approaches that aims to reduce sedentary time in employees in Australia. Many of the interventions discussed in this chapter relating to physical changes to the workplace and sit-stand desks are part of the iterative development of this larger-scale intervention [60, 61, 68, 69]. From a social perspective, they included aspects such as team champions who advocate and promote standing at work. Their role is to actively promote sit-stand desks by using their own sit-stand desk frequently, to initiate standing in meetings, and to send supportive emails to colleagues. The champions are also encouraged to walk around chatting to employees about the sit-stand desks and the intervention to increase visibility of the intervention and potentially the acceptability of such desks within the office culture. Although the results of the large-scale Stand Up Australia with more comprehensive social components are yet to be published, the studies used to inform this intervention have shown promise in reducing sedentary behaviour [61, 69]. However, how much of this reduction in sedentary time is attributable to changes within the social environment alone is not known.

24.6.3 Older Adults

Very few interventions have explicitly targeted sedentary behaviour in older adults (e.g. [70–72]), and none were identified that included a specific focus on environmental factors. Published protocol papers (e.g. [73]) suggest that further interventions are being developed for this group. For example, the protocol paper by Gardner et al. [73] describes a pragmatic trial, based on habit formation, to explore the feasibility of the "On your feet to earn your seat" intervention in older adults. Sedentary behaviour intervention work with older adults is still in its infancy, and without further work, it is not possible to draw conclusions about effective strategies.

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 behaviour can be used to help design more effective interventions. While some social and physical environmental correlates have been identified, many have been studied too few times or within weak designs or have focused on only one sedentary behaviour. This means that there remains a need for more evidence on specific environmental determinants, in specific contexts, and for specific sedentary behaviours. More work is also needed to explore the interaction between individual, social and physical environmental determinants. There is evidence that the introduction of standing desks can lead to changes in sitting and standing times both within schools and worksites. But there is little evidence for other physical environmental 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. That is to say, we need to both create supportive environments and provide individuals with the tools to change and regulate their behaviour.

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Chapter 25
Targeting Sedentary Behaviour at the Policy Level

Anthony D. Okely, Mark S. Tremblay, 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 summarised. 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.

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

A.D. Okely (✉) • M. Hammersley
Faculty of Social Sciences, Early Start Research Institute, University of Wollongong, Wollongong, NSW, Australia
e-mail: tokely@uow.edu.au; megan.hammersley1@uowmail.edu.au

M.S. Tremblay • S. Aubert
Children's Hospital of Eastern Ontario Research Institute, Ottawa, Canada
e-mail: mtremblay@cheo.on.ca

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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 to 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 will first describe major models for targeting sedentary behaviour that incorporate policy level initiatives. It will then examine 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 will then be described. Finally, recommendations for future research targeting policy level change will be 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 emphasised 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. 12.

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 change in behaviour, include 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 with these strategies is the increased motivation that may come from reducing greenhouse gases and through 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. Please refer to Sect. 1.3 for more details on existing recommendations targeting sedentary behaviour.

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 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

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 of 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 are provided, followed by tips on how to reduce sitting and breaking 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 interventions to reduce sitting time such as breaking up sitting every 30 min, providing height-adjustable desks, and utilising 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 to replace sedentary time with light physical activity, such as standing while making telephone calls, breaks during long meetings, or reorganising 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 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 recommendation to minimize and break up long periods of sitting. It also advises to educate students on limiting 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 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 encouraging 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 dose-response relationships become available

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
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
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, 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 which 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: Sitting Less and Moving More"[u]	2011	Health professional organization	Provides practical suggestions for reducing sedentary behaviour in the workplace and at 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

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Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
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 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
USA	Institute of Medicine "Early Childhood Obesity Prevention Policies"[x]	2011	Health professional organization	It is recommended that child care 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 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 3rd–4th grade students and "Media-Smart Youth" is aimed at 11–13 year olds
USA	Society of Behavioral 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 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	US 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 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 to limit 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				
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 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 example of good practices in Europe in various context (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 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

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Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
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 time among 3–17 children and teenagers
Greenland, Iceland, Norway, Sweden, Finland, and 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 Equality "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 provides 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 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 5s, 5–18, 19–64 and 65+ 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 5s), children and young people (5–18 years), adults and older adults (65+ 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 wellbeing 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	British Heart Foundation "Physical activity for children and young people"[aq]	2014	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), present exergames as an alternative to sedentary behaviours, and gives some recommendations for designing interventions that incorporate exergaming

(continued)

Table 25.1 (continued)

Country	Title/organization	Year	Sector	Description
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 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 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

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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 maximising 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 nontraditional 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 (for example 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 sport 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 through 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 wellbeing. From a public health perspective, it is hypothesised 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 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 minimising 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 = −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 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 synthesised 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 (Göteborg/Malmö) 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. Please refer to Table 25.1 of this chapter and to Sect. 1.3 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 organisations “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 sport 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, don't 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.

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Chapter 26
Dynamics of Sedentary Behaviours and Systems-Based Approach: Future Challenges and Opportunities in the Life Course Epidemiology of Sedentary Behaviours

Sebastien F.M. Chastin, Marieke DeCraemer, Jean-Michel Oppert, and Greet Cardon

Abstract This chapter challenges our current thinking about sedentary behaviours 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, 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 complexity science are needed. Systems-based approach and adaptive dynamical systems modelling will help model the interaction between factors and feedback loops. A systems-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

S.F.M. Chastin (✉)
Institute for Applied Health Research, Glasgow Caledonian University, Glasgow, Scotland, UK

Department of Movement and Sport Sciences, Ghent University, Ghent, Belgium
e-mail: sebastien.chastin@gcu.ac.uk

M. DeCraemer • G. Cardon
Department of Movement and Sport Sciences, Ghent University, Ghent, Belgium
e-mail: marieke.decraemer@ugent.be; greet.cardon@ugent.be

J.-M. Oppert
Department of Nutrition, Pitie-Salpêtrière Hospital (AP-HP), Institute of Cardiometabolism and Nutrition (ICAN), University Pierre et Marie Curie, Paris, France
e-mail: jean-michel.oppert@psl.aphp.fr

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context and type of sedentary behaviours. Finally, future opportunities for innovative data collection and analysis (big data) and innovative interventions (natural experiments, 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.

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 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, change in our thinking, and updating the paradigms we use.

In the past 20 years, the epidemiology of sedentary behaviours has evolved very rapidly since its first definition [1] (see also Chap. 4 of this book). Chapters 6–14 provide a summary of the current evidence base on the relationship between sedentary behaviours and a variety of health outcomes including 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]. Chapters 4 and 16–25 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 the current chapter, we examine how the complex nature of sedentary behaviour defies our current thinking and paradigms in moving forward. To date we have often either considered sedentary behaviours in a global way/as a whole or considered sedentary behaviours to be equal. We studied them in isolation of 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, 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 how future opportunities for innovative data collection and analysis (big data) and innovative interventions (natural experiments, 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 crosswords 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 risks [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 shows more promise 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 and 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 video cassette recorder (VCR) technology becoming more widely available and used [20]. Advances in media and information technology (IT) 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 television 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 television for a long time span, usually watching between two and six episodes of the same TV show in one sitting [22]. Furthermore, media multi-tasking 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 is 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 the use of the PC, tablets, or smart phones to watch TV or to chat, be on the Internet and 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 the assumption of linear associations. 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 follows power law distributions [5, 27], which is the hallmark of complex systems dynamics present in numerous aspects 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, because during the day one can theoretical fit many short 1 min bouts of sitting but only eight 4 h long bouts. Yet a single 4 h bout contributes much more time to the total sitting time compared to numerous 1 min bouts. It would actually take 480 one minute bouts to accumulate as much sedentary time as a 4 h 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 epidemiologic modelling and for measurement and assessing behaviour change in interventions [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 daily physical 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 tried 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 behaviour needs to be studied in conjunction with the rest of the 24 h 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 is necessarily co-dependent [35, 38]. Finally, there is also evidence that nutrition and sedentary behaviours interact and that this might be one 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 socioecological model of sedentary behaviour [3]. However, this neglects how determinants change over the life course. In addition, research has focused largely on proximal factors and studied them as independent variables, neglecting 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 very 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. 26.1.1 we discussed how technological advances are changing the nature of sedentary behaviours, but this is also accompanied by non-linear change in sitting time. However, the technology is not enough to explain these changes. Actually, the combination of technological advances (digital video disc (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 viewing experience. In turn, this has led to an explosion and social normalization of binge-watching which several years ago would not have been technically possible or socially acceptable.

To date there are no anthropological or historical studies that could help us understand these trends and identify key macro-level drivers. We often blame technology, industrialization, urbanization, and automation but without solid evidence or understanding 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 powerful 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 us 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 non-linear dynamics resulting from the interactions of multiple heterogeneous factors [50].

In the past decade, an exciting, interdisciplinary field called “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 provides a collection of important concepts and tools for responding to these challenges. Among those, systems-based approaches and adaptive dynamical systems modelling are increasingly used to address particularly persistent and complex issues in healthcare 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 systems or problem must be distinguished from a complicated problem and is characterized by the features in Table 26.1.

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

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 Systems-Based Approach to the Determinants of Sedentary Behaviours, Intervention, and Policy

Dealing with sedentary behaviours as a complex adaptive system, as has been done with other public health problems [54–56], might provide the next step change and address some of the limitations of current socioecological models that inform sedentary behaviours research [56]. While these models acknowledge 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 interaction between factors and feedback loops. A systems-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 systems-based framework (Fig. 26.1) for the study of sedentary behaviours called SOS (Systems of Sedentary behaviours) [58]. This framework was developed by emerging evidence and eminence in an international consensus process with the most multidisciplinary panel ever

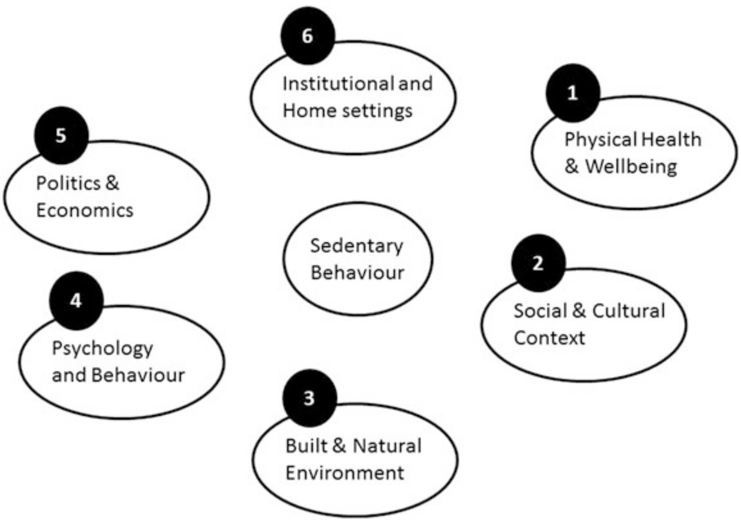

Fig. 26.1 SOS framework. Systems of sedentary behaviour with six cluster of determinant influencing sedentary behaviour

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 provision of healthcare or health-enhancing facilities.
- Social and Cultural Context: Cluster referring to the social environment individuals/groups live in and 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 natural environmental factors such as weather or the 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 is currently used to guide secondary analyses of European cohort studies and to set research priorities. The framework also forms the base for modelling and simulations 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. 3 of this book, there is a host of novel methodologies 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, compositional data analysis which considers the distribution of time throughout the day as a single mathematical object that can be used in statistical modelling has been advocated [35] because it is congruent with reality and provides a solid mathematical formalism with a long history [59]. Integrating sedentary behaviours into multiple behavioural healthy lifestyle profiles as an integrated approach also looks promising [60]. In terms of epidemiologic 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 effects on sedentary behaviours. This is a combined approach that is being used in obesity research [54, 55, 61].

26.2.4 Solutionist Approach 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 multicentre trials, it will take a very long time and a lot of resources to locate in this very vast parameter space of possible interventions which one is optimal or even identify those that work. Adopting a solutionist approach might be better suited to this type of complex problem [62]. Enabling local actors to define localized and tailored solutions in very specific contexts (work, education, transport) and for different populations and life stages might allow us to sample this large parameter space more efficiently and arrive at feasible solutions quicker. This process could be complemented with careful analyses of societal changes and natural experiments, which might be facilitated by advances in "big data" and "Internet of things" as discussed below. This however requires us to let go in part of 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 [63]. 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 description of sedentary behaviour measurement, please refer to Chap. 2 of this book.

Self-report tools such as questionnaires are flexible tools to explore the 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 [64]. Generally, those questionnaires ask about the time spent sedentary for different activities such as watching TV or context such as 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. Until 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 their potential associated variables: one for adolescents, one for adults, and one for older adults [65]. The reliability and validity against 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 results among older adults were superior compared to those among adolescents and adults. Participants over-reported total sedentary time (except for weekend days in older adults) compared to the activPAL™ for weekdays, weekend days, and average days, respectively, by +57%, +46%, and +53% in adolescents; +40%, +19%, and +33% in adults; and +10%, −6%, and +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 multi-tasking 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 multi-tasking may be less prevalent in older adults. The newly developed age-specific questionnaires may enhance the knowledge on 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.

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 [66]. SenseCam (developed by Microsoft) was one of the first devices to be used to record context of sedentary behaviours [9, 67]. 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 [68]. Currently there are no convincing algorithms to extract and classify sedentary behaviours from lifelogs, and most of the analyses need to be done by hand. Second, the technology presents some ethical issues [69] that make it difficult to fund studies, despite the fact that users report that they find the technology not necessarily intrusive [70].

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 advance signal processing techniques to detect more specific sedentary behaviours [71]. 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 [72].

Loveday et al. [73] recently conducted 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 [73].

Self-report location instruments are unable to provide detailed and temporally patterned location information. Objective monitoring could provide a more robust means to measure the location of sedentary behaviours. Based on their review, Loveday et al. [73] 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 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-storey buildings with a wooden roof or high-storey 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. [73] 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 [73].

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 that is readily purchasable for location tracking. According to Loveday et al. [73], 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.

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 a 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 [74]. 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. 2 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 [75, 76]. The importance of time in the study of sedentary behaviours is explained by the fact that consequences of exposure to sedentary behaviours [77–79] and their determinants [18, 44, 45, 80] 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 change through the life course.
- Understand how biological, social, environmental, and societal processes integrate to drive individuals to be become more or less sedentary.
- Identify critical periods of the life course and societal changes which 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, 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 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 them 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 EU-wide Eurobarometer survey). In the USA, surveys like the National Health and Nutrition Examination Survey (NHANES) have included assessments of sedentary behaviours quite early on and have used objective measures such as accelerometry but not longitudinally. The UK is very rich in cohort studies, but information on sedentary behaviours is only available in very recent waves, and historical data are lacking [81].

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 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 in the perspective of the life course, and real needs to improve standardization in data collection, facilitate data access and data sharing supported by robust data modelling and taxonomy [74]. 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 among the public about data privacy. Recent attempts to start new cohort studies that took place in the UK and USA were discontinued because of low recruitment rate [82]. 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, please refer to Sect. 9.2 of this book. Chapter 12 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" [37].

"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" [83]. 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 [84]. 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 and become cheaper and more easily connected with other mobile technologies and the Internet (the so-called Internet of things). As population age and healthcare 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 healthcare 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 "spillover" effects [85]. 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 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. 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 this kind of initiatives can be used outside the private sector.

The term "Internet of things" was originally used in the context of supply chain management [86]. However, in the past decade, the definition has been more inclusive, covering a wide range of applications like healthcare, utilities, transport, etc. [87]. 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. Fueled 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 9 billion interconnected devices, and it is expected to reach 24 billion devices by 2020. 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 individuals could be used to send behavioural feedback or goal settings.

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 and 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/or 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 which can be widely accessed on different platforms and which can be designed for different applications and for strong underpinning behaviour taxonomies and classification [74].
- Another classic big data science problem is extracting signal 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" [88].
- 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, commercial tracking companies, and 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* [89] 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 allocation of resources to studies proposing to use big data.

26.4 Summary

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 frameworks for classification, measurement, and analysis. Combining life course with systems-based approaches in a solutionist mindset while making the most of the opportunity given by new advance in technologies (e.g. big data) appears the most exciting and promising avenue to address the challenge of the health burden of an increasingly sedentary lifestyle.

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Chapter 27
Genetics of Sedentariness

Charlotte Huppertz, Eco J.C. de Geus, and Hidde P. van der Ploeg

Abstract The genetic investigation of sedentary behaviour is only recent and greatly lags behind that of other health behaviours. This section will review the available literature on the genetics of sedentary behaviour. First, the classical twin design will be outlined, and twin studies will be summarized that decompose the variance of sedentary behaviour into genetic and environmental variance. Second, it will be shown how twin studies can contribute to a better understanding of the consequences of sedentary behaviour by explicitly testing causality between this behaviour and health outcomes. Finally, molecular genetic studies will be outlined that aim to find the actual genetic variants that affect sedentary behaviour. We conclude that sedentary behaviour is partly heritable (~30%) but can also be affected by the environment that is shared between siblings. Paucity of studies and heterogeneity in the age ranges studied and measures used make it challenging to provide stable estimates for heritability and environmental influences. To date, no genetic markers have been reliably associated with sedentary behaviour.

C. Huppertz (✉)
Department of Public and Occupational Health, VU University Medical Center Amsterdam, Amsterdam, the Netherlands

Department of Psychiatry, Psychotherapy and Psychosomatics, RWTH Aachen, Aachen, Germany
e-mail: chhuppertz@ukaachen.de

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: jcn.de.geus@vu.nl

H.P. van der Ploeg
Department of Public and Occupational Health, VU University Medical Center Amsterdam, Amsterdam, the Netherlands

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

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27.1 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 [1–3]. Sedentary behaviours are defined as activities incurring no more than 1.5 metabolic equivalents in sitting or reclining position during waking time [4]. This is distinctly different from inactivity, which is the lack of moderate to vigorous physical activity and is poorly correlated with sedentary behaviour [5].

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. 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 [6], 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.

27.2 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 [7–9] and a three-generation study [10] have shown familial aggregation of total sedentary time as assessed by survey [9] and with accelerometers [7, 8], as well as self-reported computer use [9], television viewing and sitting time [9, 10]. 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 family studies, twin studies allow the disentanglement of familial resemblance into genetic ("nature") and shared environmental ("nurture") effects [11]. To this end, the resemblance of monozygotic (MZ) twin pairs is compared 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 fertilized egg, meaning that they are (nearly) genetically identical, whereas DZ twins share on average 50% of their segregating genes. 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. If the DZ correlation is larger than half the MZ 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

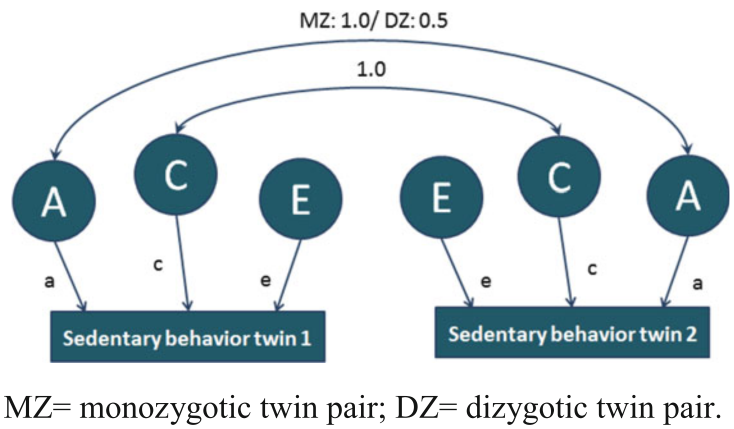

Fig. 27.1 Path diagram of a basic twin model depicting additive genetic factors ("*A*"), shared environmental factors ("*C*") and non-shared environmental factors ("*E*"). *MZ* monozygotic twin pair; *DZ* dizygotic twin pair

both their genetic material and (by definition) of their shared environment. These 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, as long as two twins of a pair do not systematically differ, 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 on a range of human phenotypes was recently published in Nature Genetics [12].

Figure 27.1 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), "*C*" (shared, or common, environmental effects) and "*E*" (non-shared environmental effects). The latent *A* components have a correlation of one for MZ twins (meaning that they share 100% of their genetic material), whereas the correlation is 0.5 for DZ twins (meaning that they share 50% of their genetic material). By definition, the shared environmental factors have a correlation of one, and the non-shared environmental factors are not correlated for both types of twins. Based on maximum likelihood estimation, structural equation software aims to find the path coefficients (a, c, e) that, given the imposed model, fit the data best. The *absolute* variance that is explained by *A*, *C* and *E* is obtained by squaring the path coefficients (a^2, c^2, e^2). Their *relative* contribution is obtained by dividing the result by the total variance [e.g. $a^2/(a^2 + c^2 + e^2)$]. The relative contribution of genes is called heritability.

27.2.1 Heritability of Sedentary Behaviour

Table 27.1 depicts an overview of twin studies on the heritability of sedentary behaviour. The available studies have assessed a wide variation of sedentary

Table 27.1 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	Sedentary behaviour phenotype	ACE (%) or twin correlations for sedentary behaviour
Kujala et al., 2002 [13]	The older Finnish twin cohort; $N = 15577$ twins (5133 complete pairs); 49% male; age range: 24–60 years	Self-reported sedentary work, dichotomized as "mainly sedentary work, which requires very little physical activity" versus more active categories	$A = 50$ (derived from twin correlations)
Nelson et al., 2006 [14]	National Longitudinal Study of Adolescent Health (Add Health); $N = 4782$ siblings that shared households in youth at baseline; 50% male; mean age (SD) at baseline/follow-up: 16.5 years (1.7)/22.4 (1.8); the sample included 1440 twin pairs of which some *live together* in adulthood and others *live apart*	Leisure screen time based on survey items assessing hours per week watching television/videos and/or playing video/computer games	Adolescence, cross-sectional rMZ = 0.32, rDZ = 0.40 Adulthood, cross-sectional *Live together:* rMZ = 0.16, rDZ = 0.16 *Live apart:* rMZ = 0.40, rDZ = 0.09 Change baseline to follow-up *Live together:* rMZ = −0.06, rDZ = 0.31 *Live apart:* rMZ = 0.31, rDZ = 0.18
Fisher et al., 2010 [15]	Twins Early Development Study (TEDS); $N = 234$ twins (117 complete pairs); 46% male; age range: 9–12 years	Total sedentary time measured with Actigraph accelerometers (<100 counts per minute)	Full model: $A = 24$, $C = 37$, $E = 39$ Best-fitting model: $A = 0$, $C = 55$, $E = 45$
van der Aa et al., 2012 [16]	Netherlands Twin Register (NTR); $N = 5090$ twins (2367 complete pairs) and 980 siblings; 44% male; age range: 12–20 years	Leisure screen time, based on survey items assessing weekly frequency of television viewing, playing electronic games, and personal computer/internet use	Age moderation Males: age 12 ($A = 35$, $C = 29$, $E = 36$) vs. age 20 ($A = 48$, $C = 0$, $E = 52$) Females: age 12 ($A = 19$, $C = 48$, $E = 34$) vs. age 20 ($A = 34$, $C = 0$, $E = 66$)
den Hoed et al., 2013 [17]	TwinsUK registry; $N = 1654$ twins (772 complete pairs); 2% male; age range: 17–82 years	Total sedentary time (≤1.5 metabolic equivalents of task) as derived from a combined heart rate and movement sensor (Actiheart)	Full model: $A = 31$, $C = 15$, $E = 55$ Best-fitting model: $A = 47$, $C = 0$, $E = 53$

(continued)

Table 27.1 (continued)

Reference	Sample	Sedentary behaviour phenotype	ACE (%) or twin correlations for sedentary behaviour
Piirtola et al., 2014 [18]	The older Finnish twin cohort; $N = 6713$ twins (1940 complete pairs); 46% male; age range: 53–67 years	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)
Haberstick et al., 2014 [19]	MacArthur Longitudinal Twin Study (MALTS) and the Colorado Twin Registry (CTR); $N = 2847$ twins (1418 complete pairs); 48% male; mean age (SD): 15.1 years (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: full model ($A = 3, C = 21, E = 76$), best-fitting model ($A = 0, C = 23, E = 77$) Females: full model ($A = 30, C = 23, E = 46$), best-fitting model ($A = 35, C = 19, E = 46$)

A additive genetic effects; *C* shared environmental effects; *E* non-shared environmental effects; *rMZ* monozygotic twin correlation; *rDZ* dizygotic twin correlation

behaviour outcomes based on self-report, namely, leisure screen time [14, 16], "passive activities" during leisure time [19], sedentary work [13] and total sitting time [18], whereas two studies have objectively assessed total sedentary time with accelerometry [15] and a combined heart rate and movement sensor [17]. It is usually tested whether the structural equation model that includes all possible parameters can be reduced to a model that includes fewer parameters without a significant deterioration of the model fit. If available, both the results of the full model and the results of the best-fitting model are reported. Two studies [13, 18] 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 [14] report (1) twin correlations on leisure screen time for adolescents, as well as (2) separate twin correlations 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, favouring a genetic cause of twin resemblance. Across all studies, the relative role of the shared environment seems to decrease from childhood to adulthood, whereas heritability remains fairly stable.

The estimates in Table 27.1 differ widely, however, 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 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. A 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 are probably highly complex, as this is a time of free choice, while sedentary time at work is often predetermined by job type and specific tasks.

27.3 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. Twin 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. Causality can be supported (but not proven) or falsified by using (1) bivariate models that decompose genetic and environmental effects on the covariance between two phenotypes [20, 21] and (2) the MZ twin intra-pair differences design [20].

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 27.2 depicts the path diagram of such a model. 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 (a22, c22, e22) and (3) effects that overlap between the two

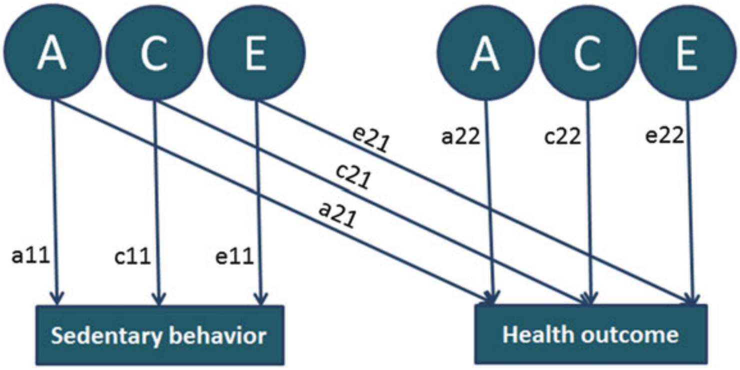

Fig. 27.2 Path diagram of a bivariate twin model with only one of the twins depicted, for clarity

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.

The outlined designs have been frequently applied to regular exercise behaviour. For instance, de Moor and colleagues [20] have shown that the negative association between regular exercise behaviour and symptoms of anxiety and depression that is seen on a population level can most likely be explained by underlying genes that affect both phenotypes in the absence of causality. Unfortunately, applications to sedentary behaviour are scarce. Kujala and colleagues [13] 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 pair served as sedentary control and the other performed exercises to counteract bed rest-induced bone loss [22, 23]. 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 for prolonged periods of time. Future studies on phenotypes that are relevant to the population at large should fully exploit the power of causality testing based on twin data.

27.4 Molecular Genetics

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. There are, roughly, two approaches to study the effects of allelic variation on a phenotype such as sedentary behaviour: *linkage studies* and *association studies*.

27.4.1 Linkage Studies

The method underlying linkage studies is outlined by Ferreira [24]. Briefly put, if individuals that share a greater proportion of alleles identical by descent (IBD) on a given genetic variant (a marker) are also more similar to each other on a given phenotype, it is concluded that there is linkage between the marker and the phenotype. One genome-wide linkage study has been conducted with sedentary behaviour as the outcome variable. Cai and colleagues [7] assessed awake time spent in sedentary activities with Actiwatch accelerometers in 1030 Hispanic children and 631 parents of the Viva La Familia Study and found significant linkage ($p < 0.0001$) with markers on chromosome 18q. Simonen and colleagues [25] combined sedentary behaviour and inactivity as assessed by 3-day activity diaries in 767 subjects of the Québec Family Study. Participants indicated their dominant activity for each 15-min period of a day. The activities were categorized into one of nine classes according to their energy expenditure level, and the scores of the first four classes were summed to reflect resting or very light activities. The authors found promising linkage with two markers on chromosome 2p22-p16 ($p < 0.0023$). The main limitation of linkage studies is that they do not identify actual DNA variation related to a phenotype. Instead, they identify chromosomal regions that harbour these variants, and subsequent fine mapping by association testing is needed to identify the allelic variants causing the linkage signal.

27.4.2 Association Studies

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).

Klimentidis and colleagues [26] have recently published a candidate gene study on sedentary behaviour. They found a significant association between a variant in the FTO[1] 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. Two additional studies were, again [25], based on a combined measure of sedentary behaviour and physical inactivity as assessed from a 3-day activity diary in French Canadian parents and their offspring from the Québec Family Study. Simonen and colleagues [27] investigated a polymorphism in the DRD2[2] gene ($N = 712$) and found no association with the phenotype. Based on the same measure, 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 a variant of the MC4R[3] 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 utmost importance with these kinds of studies as significant associations are often found by mere chance or due to confounding [29].

The current state-of-the-art 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 [30]. 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 very small effects, however, meaning that large samples are needed to identify associations and significant effects need to be confirmed in independent samples to make sure they do not represent chance findings. Unfortunately, collecting, genotyping and processing DNA data of hundreds of thousands of individuals is still an expensive undertaking. Therefore, the Genetic Investigation of ANthropometric Traits (GIANT) consortium has recently pooled data of cohorts that have measured both

[1]FTO gene: fat mass and obesity-associated gene

[2]DRD2 gene: dopamine receptor D2 gene

[3]MC4R gene: melanocortin 4 receptor gene

genome-wide DNA and sedentary behaviour, and the first GWAS for sedentary behaviour is underway.

Once specific genetic variants are clearly associated with sedentary behaviour, it becomes feasible to identify their function and to understand how they could affect sedentariness [31]. Furthermore, the test of causality based on bivariate genetic twin models that was outlined before can then be performed with measured genetic variants instead of latent genetic variance components, using Mendelian randomization [32].

27.5 Summary

Although behaviour genetics has tackled many behavioural and health phenotypes [12], 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 objective data, that sedentary behaviour is partly heritable (~30%), but no genetic markers have been reliably associated with this phenotype. 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 section, we have outlined genetic methods that could be applied to test the causal effects of sedentary behaviour on health. Bigger twin- and family-based datasets, the use of better measurement instruments for sedentary behaviour as well as enrichment of datasets with molecular genetic marker data will further help to advance this field of research.

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Chapter 28
Limitations in Sedentary Behaviour Research and Future Research Needs

Daniela Schmid, Carmen Jochem, and Michael F. Leitzmann

Abstract This section 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 to determine how long people should maximal 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, the elderly, socially disadvantaged individuals, and ethnic/racial minorities. In addition, additional future mechanistic and experimental work is required to identify the aetiologic pathways through which sedentary behaviour impacts upon the aetiology of chronic diseases.

Mounting epidemiologic evidence suggests that sitting for long periods of time poses risk for developing chronic diseases and preterm death [1–3]. 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

D. Schmid • C. Jochem • M.F. Leitzmann (✉)
Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany
e-mail: daniela.schmid@ukr.de; carmen.jochem@ukr.de; michael.leitzmann@ukr.de

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relationships. 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.

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 organizations 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 Chap. 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. [4], which specifies a sequence of five research phases regarding health-related behaviours. These five phases are (1) establishing relationships between the behaviour and health outcomes, (2) developing behaviour measures, (3) identifying influences on the behaviour, (4) evaluating interventions to impact the behaviour, and (5) translating findings into practice [4]. This framework was recently adapted to sedentary behaviour epidemiology [5]. For further detail on the behavioural epidemiology framework, please refer to Chap. 15.

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 [2]. 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 on mortality risk [6–12] presented inconsistent findings. A recent meta-analysis [13] revealed that 1 h of moderate physical activity spread over the day was sufficient to oppose the adverse effect of sitting for more than 8 h. In contrast, the detrimental association of sitting with mortality persisted for TV viewing, regardless of the physical activity level [13].

Future studies are needed to resolve whether and to what extent physical activity can alleviate the deleterious health consequences associated with prolonged sitting time. 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 the findings from previous reports.

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. Recent 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 optimizing their daily activity behaviour aimed at replacing sedentary time with ambulatory movement [14]. For example, using data from the National Health and Nutrition Examination Survey (NHANES) 2003–2006, we found that replacing 30 min per day of objectively measured sedentary time with an equal amount of light activity or moderate-to-vigorous activity 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 reallocations of sedentary time to moderate-to-vigorous physical activity were associated with improved 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 a comprehensive investigation of the proportional distributions of daily time spent in sedentary behaviour and other activities in relation to health outcomes [18].

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/racial 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 personalized disease prevention interventions.

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 aetiologic 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 [19, 20], who found that reduced contractile activity localized to the two hindlimbs of mice led to the 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 [21, 22]. Discrepancies between study results may have arisen from variation 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 of 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 [23].

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).

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. 2). Inconsistencies in study findings may stem from misconception and misclassification of the term “sedentary behaviour” in the individual studies. In our understanding, sedentary behaviour is defined as “any waking behaviour characterized by an energy expenditure $\leq$1.5 METs while in a sitting or reclining posture” [24]. 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 [25]. High levels of sedentary time may coincide with high levels of physical activity [25]. 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 referent would neglect the coexistence of high amounts of both sedentary behaviour and physical activity [25]. In addition, inferring occupational sitting from job titles represents a potential source of exposure misclassification [25]. To obtain comparable and valid results, future studies of sedentary behaviour should be consistent in their terminology and measurement structure.

Most studies to date evaluated sitting time based on self-report measurements. Self-reported methods are widely used because they 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 [26–28]. Advances in measurement technology now deliver affordable objective methods such as accelerometers and inclinometers that help overcome the limitations of self-report assessments [26]. To date, only a small number of studies have used objective activity monitors to measure sedentary time accumulated throughout the day. Device-based measurements have been demonstrated to more accurately assess total sedentary behaviour than self-report measurements [26–28]. Moreover, they enable assessment of total sedentary time across the day and provide important information about patterns of sedentary behaviour accumulation, e.g. durations of sedentary bouts and interruptions in sedentary time [28]. Advanced activity monitoring using the activPAL allows different postures such as sitting/lying and standing to be distinguished [29]. 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 [26, 28]. A recent study utilizing data of around 10,000 adults aged $\geq$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 [28]. The descriptive epidemiology of sedentary time determined by self-reported measures and accelerometer-derived measures was compared [28]. The major 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 race/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 [28]. Stratifying sedentary behaviour by both race/ethnicity and life span, self-reported measures detected significant differences in women, while important differences in men were noted using accelerometer-based measures [28]. 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.

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 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 [30]. 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 [30]. Moreover, the above-mentioned study [30] was able to discover important findings related to change 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 [30]. Another study found that hourly increments of change in TV viewing over a 5-year period were associated with increases in biologic markers (body mass index, waist circumference, fasting insulin, and insulin resistance) of postmenopausal breast cancer risk [31]. 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 [28]. Likewise, hormonal and metabolic changes occur over the life span [32, 33] 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 aetiology.

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, and environmental factors. Identifying correlates and determinants of sedentary behaviour at a multilevel represents an important step in designing appropriate interventions programmes aiming to reduce sedentary behaviour. Ecologic approaches in correlates research may help navigate through the numerous possible influences of sedentary behaviour and identify important interactions across levels that are 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 urbanization, passive entertainment, and motorized commuting [34].

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. 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 several hours sitting in the office [35]. Findings of numerous studies showing prolonged sedentary behaviour to harmfully affect health-related outcomes 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 includes computer-based prompts and personal motion assessment devices, placement of toilets and kitchens on different floors, promotion of stair use, and standing meetings [35]. However, there is a need for future prospective studies and randomized controlled trials to evaluate standing and light activity interventions in real office environments [35] 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.

The efficiency 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 USA, Australia, and Belgium [36] revealed that adults spent on average 326.7–478.6 min per week in motorized transportation. People would meet the physical activity recommendations of 150 min per week of moderate-intensity activity [37] if they replaced half of the time spent in a car or bus for commuting by moderate-intensity pursuits of walking or bicycling.

The majority of intervention studies published to date involved only healthy adults, and thus studies of understudied population groups such as individuals with chronic disease or disabilities, ethnicity/race minorities, elderly, or overweight/obese individuals are a research priority. Such groups are at an increased risk for high levels of sedentary time and subsequent negative 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 personalized disease prevention strategies.

5. How can research findings be effectively translated into practice?

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 efficiency in the study scenario may be unwise if it cannot be effectively applied to a real-life setting. 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, organizational, and political factors. The last phase deals with questions about how we can properly disseminate, implement, and maintain effective interventions. Clearly, more research is needed to ensure successful translation of evidence-based intervention programmes into real-life settings. This important area of future research will require mobilizing transdisciplinary collaboration.

28.1 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 aiming to reduce long periods of sitting. Future prospective studies using objective measures (e.g. accelerometers) are needed to confirm the 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. 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. Enhanced research efforts are suggested for population subgroups to allow personalized disease prevention strategies. Moreover, future mechanistic and experimental studies are needed to identify the biologic pathways through which sedentary behaviour affects the aetiology of various disease outcomes. Equally important are studies to explore for how long people should maximal 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 into real-life settings.

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Index

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