Chapter 3
Measurement of Sedentary Behaviour in Population Studies

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

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What Is New?

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

3.1 Relevance of Accurate Exposure Assessment

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

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

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

3.1.1 Psychometric Properties

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

Validity

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

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

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

3.1.2 Conforming to a Consensus Taxonomy of Sedentary Behaviours

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

3.2 Subjective Methods of Sedentary Behaviour Measurement

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

3.2.1 Types of Questionnaires

Global Questionnaires

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

Quantitative Recall Questionnaires

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

3.2.2 Characteristics of Sedentary Behaviour Questionnaires

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

Mode of Administration

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

Content of Sedentary Behaviour Questionnaires

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

Table 3.1 Characteristics of a sample of sedentary behaviour questionnaires

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

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

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

Table 3.2 Measurement qualities of a sample of sedentary behaviour questionnaires

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

(continued)

Table 3.2 (continued)

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

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

Characteristics or Domains of Sedentary Behaviours

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

Recall Frame

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

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

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

(continued)

Table 3.3 (continued)

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

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

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

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

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

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

3.3 Objective Methods of Sedentary Behaviour Measurement

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

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

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

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

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

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

3.3.1 Pedometers

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

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

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

3.3.2 Accelerometers/Inclinometers

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

Table 3.5 Accelerometer cut-points for sedentary behaviours in adults

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

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

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

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

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

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

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

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

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

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

3.4 New Horizons in Measurement Technology

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

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

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

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

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

3.5 Summary

The measurement of sedentary behaviours in surveillance and in population studies is a relatively new practice. The definition of sedentary behaviours has matured from merely being the opposite of physical activity to a combination of energy expenditure $\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. The use of a consistent definition and measurement methodologies to assess sedentary behaviours enhances the opportunities to compare data from surveillance systems across demographic groups and to conduct population studies designed to establish relationships between sedentary behaviour exposures and health-related outcomes.

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