ASSESSING SEDENTARY BEHAVIOUR AT WORK WITH TECHNICAL ASSESSMENT SYSTEMS

PEROSH Joint Research Project

Recommendations for procedures to measure occupational physical activity and workload

PEROSH (Partnership for European Research in Occupational Safety and Health) is a Network of European Occupational Safety and Health research institutes.

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Institutions collaborating on the report:

[1] Austrian Workers Compensation Board (AUVA), Wien, Austria.

[2] Central Institute for Labour Protection - National Research Institute (CIOP-PIB), Warszawa, Poland.

[3] Finnish Institute of Occupational Health (FIOH), Helsinki, Finland.

[4] University of Gävle, Gävle, Sweden

[5] Health and Safety Executive, Harpur Hill, Buxton, SK17 9JN, United Kingdom.

[6] Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA), Sankt Augustin, Germany.

[7] National Institute for Insurance against Accidents at Work (INAIL), Rome, Italy.

[8] French National Research and Safety Institute for the prevention of occupational accidents and diseases (INRS), Vandoeuvre Les Nancy, France

[9] Spanish National Institute for Safety and Hygiene at Work (INSHT), Madrid, Spain.

[10] Karolinska Institutet (KI), Stockholm, Sweden.

[11] Lund University (LU), Lund, Sweden.

[12] National Research Institute for the Working Environment (NRCWE), Copenhagen, Denmark.

[13] National Institute of Occupational Health (STAMI), Oslo, Norway.

Authors:

Andreas Holtermann[12], Svend Erik Mathiassen[4], Andrew Pinder[5], Anne Punakallio[3], Bo Veiersted[13], Britta Weber[6], Dirk Ditchen[6], Esa-Pekka Takala[3], Francesco Draicchio[7], Henrik Enquist[11], Kevin Desbrosses[8], Maria Peñahora García Sanz[9], María Villar[9], Marzena Malińska[2], Michael Wichtl[1], Michaela Strebl[1], Mikael Forsman[10], Nidhi Gupta[12], Peter Hendriksen[12], Sirpa Lusa[3], Tomasz Tokarski[2], Vera Schellewald[6], Rolf Ellegast[6].

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List of abbreviations:

ACSM	= American College of Sports Medicine
AHA	= American Heart Association
ANOVA	= Analysis Of Variance
ANSES	= French Agency for Food, Environmental and Occupational Health & Safety[a]
BMI	= Body Mass Index
BVP	= Blood Volume Pulse
CDC	= American Center for Disease Control and Prevention
CSEP	= Canadian Society for Exercise Physiology
ECG	= Electrocardiography
EE	= Energy Expenditure
EMG	= Electromyography
ESC	= European Society of Cardiology
EU-OSHA	= European Agency for Safety and Health at Work
GPS	= Global Positioning System
HRV	= Heart Rate Variability
IMU	= Inertial Measurement Units
LED	= Light-Emitting Diode
METs	= Metabolic Equivalents
NCCDPHP	= National Center for Chronic Disease Prevention and Health Promotion
NHANES	= The American National Health and Nutrition Examination Survey
NNBG	= Dutch healthy exercise norm[b]
PAI	= Physical Activity Intensity
PEROSH	= Partnership for European Research in Occupational Safety and Health
PPG	= Photoplethysmography
REML	= Restricted (or residual, or reduced) Maximum Likelihood
SD	= Standard Deviation
USB	= Universal Serial Bus
VO_{2max}	= Maximum rate of oxygen consumption
WHO	= World Health Organization

[a] Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail
[b] Nederlandse Norm Gezond Bewegen

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Introductory summary

It is well documented that spending large amounts of time each day in sedentary behaviour is associated with increased risks of a variety of health impairments. The time engaged in sedentary behaviours is generally high in Europe, and has increased over recent decades during both work and leisure. This has resulted in considerable research and societal attention over the last decade.

Sedentary behaviour in the workplace varies between occupations. It is high among office workers, and is likely to be high for job groups with lower education with constrained sitting-based working tasks like long-haul drivers and surveillance work in manufacturing. However, the question of whether spending large amounts of time in occupational sedentary behaviour is a causal risk factor for health impairments remains to be settled.

An important reason for this could be the poor validity and reliability of many of the methods used to assess sedentary behaviour such as self-report and interviews. Another reason might be that the sedentary behaviour is often not measured in accordance with its proposed definition "*any waking behaviour characterised by a low energy expenditure (≤1.5 METs) while in a sitting or reclining posture*". Measurements of sedentary behaviour should therefore capture its two main components, namely posture and energy expenditure.

Observational methods are also used to assess sedentary behaviour, but they are costly, time-consuming, and may lead to observational-bias. Measurements using wearable devices ("wearables") are thus recommended due to their objective nature, and their ability to be relatively low cost and to have little impact on the daily life of the participant.

Numerous suitable small wearables, with long battery life and high data storage capacity, have become commercially available in recent years. However, none of the commercially available wearables can independently assess occupational sedentary behaviour in accordance with its definition (i.e. a sitting or lying posture with low energy expenditure). Therefore, deciding on how to assess sedentary behaviour is currently not easy.

The wide variety of devices with the potential to assess sedentary behaviour is likely to leave practitioners and researchers wondering - "How can I choose the measurement system best-suited to my aim, preferences, funding, and skills?" However, no practically useful guidance for researchers and practitioners exists on how to assess occupational sedentary behaviour.

This report provides an overview of relevant technical systems and their general capabilities and gives examples of their appropriate use when assessing occupational sedentary behaviour. The report emphasises factors such as the target population, the need for accuracy, data accessibility, wearing comfort, expert knowledge for analyses, assessment duration, the number of participants needed, budget available, and the need for information on time patterns of sedentary and non-sedentary behaviour, including moderate and vigorous physical activity. Importantly, the need for assessing body posture, energy expenditure, or both, should be critically evaluated based on the work tasks undertaken by the target population and the aim of the project.

The report highlights needs for developing of cheap, feasible wearables combining precise posture and energy assessments for a valid and reliable assessment of sedentary behaviour at work, which fulfils the current needs of both researchers and practitioners alike.

1 Sedentary behaviour – health effects

The literature highlighting a variety of health risks associated with spending large amounts of time each day in sedentary behaviour is rapidly growing. The rationale for assessing sedentary behaviour is mainly based on observational studies finding associations between sedentary behaviour and negative health effects. This chapter aims to briefly introduce the scientific literature on the associations between sedentary behaviour and health. It focuses primarily literature published from 2010 onwards.

1.1 Do large amounts of sedentary time lead to health impairments?

Accumulating evidence exists linking time spent in sedentary behaviour with health impairments[1]. Prospective observational studies have demonstrated harmful associations between increasing time spent sitting and increasing all-cause mortality[2,3], cardiovascular diseases[4,5], some forms of cancers[6,7], metabolic diseases such as Type 2 diabetes[8], obesity indicators[9], and mental health[10].

Importantly, several studies have found these associations even after adjusting for physical activity, which indicates that increasing time in sedentary behaviours increases the risk of a variety of health impairments except in very active individuals. A meta-analysis including just over 1000000 individuals reported increasing Hazard Ratios for all-cause mortality as sitting time/TV-viewing time increased but the risk was attenuated among individuals engaged in at least 60-75 minutes of moderate physical activity per day[3].

This highlights sedentary behaviour as an important target for interventions in the modern world, especially among individuals not engaged in relatively high amounts of physical activity.

1.2 When does time spent in sedentary behaviours become “too much”?

A meta-analysis including nearly 600000 adults reported a non-linear dose-response relationship between total daily sitting time and all-cause mortality risk. For individuals sitting for up to 7 h/day, the all-cause mortality risk increased by 2% per hour sitting; each additional hour spent sitting beyond 7 h/day led to a 5% increase to the all-cause mortality risk. The meta-analysis estimated that adults sitting for 10 h/day have a 34% increased risk of all-cause mortality compared to sitting for 1 hour/day, even when accounting for physical activity[11]. The American National Health and Nutrition Examination Survey (NHANES) reported that inactivity in excess of ≥8.6 hours/day objectively assessed by count accelerometry was significantly associated with increased all-cause mortality[12]. These findings show promise towards determining threshold values and dose-response relationships for total daily sedentary behaviour and health outcomes, but these values are still to be firmly established using valid measurements of sedentary time.

1.3 Occupational sedentary behaviours and risk of health impairment

A systematic review devoted to detrimental health effects of occupational sitting found limited evidence for an independent association with musculoskeletal pain, some forms of cancers, cardiovascular diseases, obesity indicators, diabetes and mortality[13]. One systematic review of predictors for neck and shoulder pain reported limited evidence for a positive association between occupational sitting and non-specific neck pain[14], while insufficient evidence was found by two other systematic reviews[15,16]. One systematic review found strong evidence for no causal association between low back pain and occupational sitting[17]. A meta-analysis found a significant association between colon cancer and self-reported occupational sitting time, but none for breast and endometrial cancers[6], while another meta-analysis reported a slightly increased risk of breast cancer associated with self-reported occupational sitting time[7]. Prospective studies on self-reported occupational sitting and obesity also present mixed evidence. One found that Body Mass Index (BMI) decreased with less occupational sitting for women, but not for men[18], while no association between occupational sitting and BMI was found in two other studies[19,20]. Studies have also found conflicting results concerning the association between self-reported occupational sitting and mortality risk, with a protective effect for women and no association for men when compared to standing occupations[21], no association[22,23], and a higher mortality risk relative to more active jobs[24].

Therefore, it is currently not clear if a high amount of occupational time spent in sedentary behaviour is a causal risk factor for health impairments. A potential explanation for this overall finding is the different methodologies used, with most studies being cross-sectional, with only a few using instrumentation (primarily count based accelerometry) to assess sedentary behaviour. Furthermore, the use of categorical classifications of jobs as either sedentary or active has been widespread, leading to a low degree of precision in the exposure assessments[13,25]. As a consequence, definite conclusions on the association and causality of occupational sedentary behaviour with detrimental health effects cannot yet be drawn. High-quality longitudinal studies based on valid and precise measurements of occupational sedentary behaviour are needed to establish conclusive evidence for the health consequences of high amounts of occupational sedentary time, as well as the dose-response and threshold values for occupational sedentary behaviour and health.

1.4 Is the temporal pattern of importance for the health effects of sedentary behaviour?

Besides the total duration of sedentary time, the pattern of the sedentary behaviour is reported to be of importance for the resulting health effects. More frequent breaks during periods of sedentary time have been found to be associated with beneficial health effects[26,27]. Similarly, in blue-collar workers, more prolonged periods of objectively assessed sitting time have been shown to be positively associated with obesity[28].

1.5 What are the underlying mechanisms linking sedentary behaviour and health?

Sedentary behaviour requires a very low degree of muscle activation, much lower than in activities requiring carrying the body weight around, such as standing, walking and running in which muscles need to actively keep the body upright and moving against the forces of gravity. Hence, being sedentary imposes a very low metabolic energy cost and if not compensated for by reduced energy intake it can lead to a positive energy balance and, in time, obesity[29]. Furthermore, low muscular activity has been shown to result in reduced muscular strength[30,31], as well as a decrease in the muscles' ability to take up and metabolise fat (lipids) which can contribute to increased insulin resistance and diabetes biomarkers in the bloodstream[32]. Prolonged sitting also leads to dilation of the blood vessels and pooling of blood in the lower limbs due to the hydrostatic pressure imposed by gravity, as the low muscular activity hampers the venous return and disturbs proper blood circulation. The disturbed blood circulation in the lower limbs is compensated for by increased blood pressure[33]. Disturbed blood circulation in the lower limbs might ultimately lead to varicose veins and thrombosis[34]. It has been suggested that prolonged sitting in static positions can cause lumbar stiffness[35], increased intradiscal pressure, and prolonged stress on ligaments in the lumbar part of the spine, which have been hypothesised as potential factors in the development of low back pain[36,37]. However, as investigations on biological mechanisms behind health impairments from exposures occurring during normal daily living (and not space flights or long term bed rest) are still relatively new, the role of sedentary behaviour in the (potentially complex) aetiology of health impairments is not yet well understood.

1.6 Key messages

- Extensive time sedentary per day can increase the risk for a variety of health impairments.
- The dose-response and threshold values for sedentary time per day and health outcomes remain to be established using valid measurements of sedentary behaviour.
- The question of whether spending large amounts of time in occupational sedentary behaviour is a causal risk factor for health impairments remains to be settled.
- Potential aetiological mechanisms of sedentary behaviour relate to low metabolic requirements, low muscular activity and prolonged static sitting posture.

2 Sedentary behaviour – occurrence

It is generally acknowledged that we spend large amounts of time in sedentary behaviour in our main domains of living, for example, while working (e.g. using computers or doing desk work) when traveling (e.g. by car or train) and during leisure (e.g. watching television). Accordingly, time spent in sedentary behaviour is high in western society and seems to have increased over the last decades, both in the domains of leisure and work[38,39].

2.1 How much time do we spend in sedentary behaviour?

A common way to estimate sedentary behaviour in large populations has been self-reported daily sitting time. In a study encompassing 32 European countries (the EuroBarometer study), the average self-reported sitting was 5-6 h/day[40]. Thus, Europeans roughly report one-third of their waking hours spent sitting. This matches self-reported sitting time from 20 countries (including 7 European countries) assessed by the same questionnaire[41].

When comparing the 32 European countries participating in the EuroBarometer study, the self-reported daily sitting time has been shown to vary extensively. The lowest amounts of self-reported daily sitting time occurred in the Southern (Malta and Portugal means 3–4 h/day) and Eastern (Romania and Hungary means 3–4.5 h/day) European countries, whereas the highest amounts of self-reported daily sitting time occurred in the northern European countries (Germany, Benelux and Scandinavian countries; means 5.5–6.5 h/day)[40].

For the overall European population, high-risk groups for large volumes of self-reported sitting time were identified as males, those with bad health, younger age groups, non-active adults, and those with higher levels of education[40].

Another common way to estimate sedentary behaviour is by assessing inactivity[c] via instrumentation, commonly by hip-worn accelerometers. The assessed time spent inactive during the day, has been shown to be as high as 55-70% of the daily time awake, corresponding to 8-10 h/day, in a variety of western countries[42-44]. This duration is somewhat longer than generally found by self-reports, supporting the need for using instrumentation to make valid measurements of sedentary behaviour.

2.2 How much time do we spend in sedentary behaviour during working hours?

Sitting nowadays is not only common during leisure time, but also during work. In the Danish national survey of a representative sample of the Danish workforce, 57% spent at least half of their working time sitting in 2012, which is a rise from 49% in 1990. In a representative sample of Dutch workers, the self-reported average was 2 h/day of sitting at work[45]. Similarly in a cross-sectional sample of German adults from the working population, the median self-reported sitting time at work was 2 h/days[46]. Similar to the data for the overall European population, higher educated men and women were defined as high-risk groups for prolonged self-reported occupational sitting time, although in contrast to the findings for total sitting time only young women were identified as a high-risk group[47].

[c] Includes both sitting and standing in the assessment.

2.3 Which occupational groups spend large amounts of time in sedentary behaviour?

Major differences in sedentary time between occupations and sectors have been reported[45]. In a study using hip-worn accelerometers among Australian office workers showed that 82% of the measured work hours were spent sedentarily[48]. A study on office workers from the United Kingdom, observed using posture monitors found that 66% of work time was spent sitting[49]. In another study, Dutch legislators and senior managers had 3 h/day of self-reported sitting work, while service workers only had 1 h/day of self-reported sitting during work[45]. For Danish blue collar workers engaged in cleaning, manufacturing, and transport; objectively measured sitting time at work was on average 2.4 h/day[50] or 30% of the average workday[51]. Amongst these groups, workers within transport had the highest sitting time at 4.5 h/day, manufacturers sat for 2.3 h/day and cleaners sat for 1.6 h/day[50]. However, even though some existing occupational groups spend large amounts of time sitting at work, it is important to highlight the fact that within an occupation there can be considerable inter- and intra-individual variability in the sitting duration and time pattern[52].

2.4 Key messages

- Time spent in sedentary behaviours is generally high in Europe and has increased over the recent decades during both work and leisure.
- In Europe, the total duration of sedentary behaviour is generally higher among males, younger age groups, those with higher levels of education, individuals with less influence at work and individuals with poor health.
- Occupational sedentary behaviour varies between occupations, and between individuals within an occupation.
- Occupational sedentary behaviour is high among office workers and is likely to be high for job groups with constrained sitting based work tasks such as long-haul drivers and surveillance work in manufacturing.
- Occupational sedentary behaviour has primarily been investigated in Northern Europe, thus more research is needed in Southern and Eastern Europe to investigate incidence and impact of sedentary behaviour.

3 Sedentary behaviour – definition and rationale for how to measure it

In common usage, the phrase "sedentary behaviour" can be ambiguous. As an example, one of the major dictionaries defines the adjective "sedentary" as both "doing or requiring much sitting" and "not physically activity"[53]. These different uses can easily be confused. This chapter therefore adopts an agreed definition of sedentary behaviour in order to describe how it can be characterised.

3.1 How is sedentary behaviour defined?

A consensus definition for sedentary behaviour proposed in 2012 is; "*any waking behaviour characterised by an energy expenditure ≤1.5 METs while in a sitting or reclining posture*"[25,54].

Therefore, sedentary behaviour involves performing tasks or movements with low energy requirements in postures such as lying down as well as sitting.

3.2 How should sedentary behaviour be assessed?

According to the proposed definition, an optimal assessment of sedentary behaviour requires assessment of its two main characteristics:

I. Energy expenditure, and
II. Body posture.

Assessments of energy expenditure have mainly addressed physical activities, but have also been performed to obtain information about sedentary behaviour. Energy expenditure can be described by the relative energy requirements of human motion over time assessed in metabolic equivalents (METs). METs are defined as the ratio of the work metabolic rate relative to the resting metabolic rate[55]. Thus, a MET value of 1 is equal to the energy expenditure of a person at rest, and a MET value of 3 corresponds to energy expenditure 3 times larger than being at rest. In short, METs can be described as a measure of the level of physical activity and movements compared to when at rest.

Generally, physical activities have been differentiated into four categories: minimal[d], light, moderate and vigorous respectively. In this categorization, minimal physical activity[d] is defined as activities ranging from 1.0 to 1.5 METs, light physical activity as between 1.5 and 3.0 METs, moderate physical activity as 3 to 6 METs, and vigorous physical activities are defined as above 6 METs[25,55-57]. See Table 1 for examples of activities belonging to the different MET based categories.

However, as shown by Table 1, the absolute difference in energy expenditure between sitting and standing can be relatively small[58,59], so assessment of energy expenditure alone does not provide reliable information on whether the person is sitting or standing. Therefore, assessment of body posture is required for identifying sedentary behaviour.

[d] "Minimal physical activity" is termed "sedentary" in Ainsworth et al., (2011). However, this usage of sedentary does not match the proposed definition of sedentary behaviour; therefore we use "minimal" to describe the lowest category of energy expenditure to avoid confusion.

Table 1 - Examples of activities included in the different MET categories of physical activity, based on assessed energy expenditure (definition of physical activity categories and examples of activities from Ainsworth et al., 2011[55]).

Physical activity category	Minimal Physical Activity[e]	Light Physical Activity	Moderate Physical Activity	Vigorous Physical Activity
Definition	1.0≤ to ≤1.5 METs	1.5< to <3.0 METs	3.0≤ to <6 METs	6≤ METs
Examples	Lying	Slow walking (*<4 km/h*)	Moderate and fast walking (*4≤ km/h*)	Very fast walking (*7≤ km/h*)
	Sitting, quietly or light effort (*e.g. office work, computer work or attending meetings*)	Sitting tasks with moderate effort (*e.g. operating heavy machinery or truck driving*)	Most manual labour (*e.g. garbage collecting, carpentry, bricklaying or masonry*)	Running Bicycling
	Standing, quietly (*e.g. in a queue or very light work*)	Standing tasks with light effort (*e.g. active workstations, store clerks or light nursing tasks*)	Standing tasks which include lifting.	Carrying heavy loads or carrying moderate loads up a flight of stairs (*e.g. construction materials or bricks*) Firefighting

On the other hand, assessment of gross posture is not sufficient by itself for detecting sedentary behaviour as movements while sitting or lying can require considerable energy expenditure, so such behaviour would not fulfil the definition of being a sedentary behaviour. For example, crane operators and forklift drivers may perform upper body work during sitting requiring as much as 2.5 METs[55]. Other examples are hand and machine sewing while sitting, requiring 1.8 and 2.5 METs respectively[55], using an under desk bike[60] or using a semi-recumbent elliptical workstation (e.g. LifeBalance Station), which can lead to an energy expenditure between 2.4 METs and 3.1 METs[61].

In summary, we consider that valid and reliable assessments of sedentary behaviour require simultaneous assessment of both energy expenditure and body posture.

3.3 How should sedentary behaviour be characterised?

Accumulated total duration of sedentary behaviour during the day is the metric normally used for evaluating its health effects and need for interventions[62-64]. Moreover, information about the domain in which the sedentary behaviour takes place, such as work and transportation, can also be useful for considering where and how to intervene upon the sedentary behaviour[63,65].

Also, it can be important to capture the time pattern of sedentary behaviour to evaluate its health consequences[25,66]. For example, time spent in long periods sedentary behaviour may be more detrimental to health than the same total time spent in short bouts of sedentary behaviour[26,28,67,68]. Therefore, investigations of sedentary behaviour should address not only the total daily duration of sedentary behaviour but also the pattern and durations of periods of sedentary and physically active behaviour. Methods have been proposed for describing the timelines of variables describing sedentary and physically active behaviour[69-71].

[e] "Minimal physical activity" is termed "sedentary" in Ainsworth et al., 2011. However, this usage of sedentary does not match the proposed definition of sedentary behaviour; therefore we use "minimal" to describe the lowest category of energy expenditure to avoid confusion.

Furthermore, the body posture (e.g. standing), behaviour (e.g. standing still or walking), and energy expenditure during physically active periods can be important for describing and evaluating the overall health consequences of the sedentary behaviour pattern. Moreover, this information can be useful for tailoring and evaluation of interventions targeting sedentary behaviour during work, leisure or transportation[25,72].

Thus, using wearables capable of capturing the total duration and the time pattern of both sedentary and physically active behaviours should be considered when assessing the need for an intervention aimed at reducing sedentary behaviour, the later evaluation of such an intervention and for studies on the effects of sedentary behaviour.

3.4 Should moderate and vigorous physical activity also be assessed?

It is well documented that moderate and vigorous physical activities have a wide range of positive health effects. Therefore public health guidelines have generally advised spending approximately 150-300 minutes per week (30-60 min, 5 days a week) on moderate or vigorous activities[73]. A person meeting the recommendations can be described as being adequately physically active, while a person not meeting the recommendations can be described as being physically inactive[54]. As described in Chapter 1, adequate or inadequate physical activity is an important health determinant, especially when individuals are spending large amounts of time in sedentary behaviour. Thus, assessing if participants engage in moderate to vigorous activity ought to be strongly considered depending on the particular aim of the project.

3.5 Key messages

- Sedentary behaviour is defined as “any waking behaviour characterised by an energy expenditure ≤1.5 METs while in a sitting or reclining posture”.
- Assessments of sedentary behaviour should capture its two main components, namely posture and energy expenditure.
- Sedentary behaviour can be described by three main aspects; total amount (e.g. hours, hours/day), time pattern (e.g. average bout length, frequency, total duration of bouts over 30 minutes) and domain of occurrence (e.g. work, leisure, transport).
- Capturing energy expenditure and posture during breaks from sedentary behaviour, as well as assessment of time spent in moderate and vigorous activities should be considered depending on the particular aim of the project.

4 How to assess sedentary behaviour?

Assessing sedentary behaviour has been done by various means, including self-reports, observations, and measurements with instruments. This chapter briefly introduces the various methods and their strengths and weaknesses.

4.1 Self-reports

Assessments of sedentary time have most commonly been performed till now using indirect measures based on self-report, such as questionnaires and surveys. For example, the existing public health recommendations are mainly based on self-reported measures of sitting time and time spent doing moderate or vigorous physical activity. The strength of these indirect measures is that they have relatively low cost and low burden, both for the respondent and for analysis. This makes it a very convenient method for collecting information from large populations. However, self-reports by workers systematically under-/over-estimate sitting time[74-76] and overestimate activity[77] intensity when compared to objective measurements, and thus are biased[78,79]. Therefore, assessments of sedentary time using these indirect measurements are generally considered to have moderate to poor validity and reliability for quantification of sedentary behaviour.

4.2 Observations

Sedentary work is also frequently assessed using direct observational methods, which involve a trained observer witnessing or videotaping the sedentary behaviours at work. Observational methods are still commonly used for assessing body postures in the field[80] and have shown to be valid, reliable and with moderate-to-good inter-rater repeatability for large-scale body postures using trained observers[81]. Direct observational methods can be calibrated and validated to judge the intensity of free-living activities in METs[82,83]. Thus, observations can potentially provide both aspects needed to assess sedentary behaviour. Observation also allows detection of the contextual information about the sedentary behaviour[84]. However, it is generally very time consuming and expensive per unit of working time observed[85-87], and is therefore often only feasible with relatively short assessment periods or on a limited population size. Observation-based methods are also associated with considerable uncertainty due to observers differing in ratings[88,89]. Direct observation at the workplace can also be challenging due to the logistic burden associated with data collection and the ethical aspects (e.g. observing work with patients). Observations may also modify the behaviour of the observed worker (observational bias).

4.3 Technical measurement systems

Technical instruments can be used to assess occupational sedentary behaviour directly by measuring energy expenditure and/or body position during daily living. Technical instruments are believed to be both valid and associated with minor error in use[90]. A wide variety of direct technical assessment systems are available, such as accelerometry, pedometry, heart rate monitoring and indirect calorimetry[62]. All of these can be attached to a person who remains able to move freely. Therefore, from now on we refer to them as "wearable equipment" or simply "wearables". This report will focus on wearables, and excludes fixed (e.g. optoelectronic) systems or tethered systems, which are less feasible for data collection in dynamic real-life work environments.

The on-going development of wearables has led to miniaturization and diminishing costs. This continues to increase the feasibility of assessing sedentary behaviour and physical activity with wearables on larger populations in real-life settings with minimal disturbance for the participants. Because of the potential bias and imprecision of self-reports, the costliness of observations, and the decreased burden and low disturbance for the participants from wearables, instrumentation has generally been recommended as the preferred method for obtaining valid measures of sedentary behaviour[91,92]. However, despite the growing literature on sedentary behaviour, there are no current standard procedures and recommendations available for assessing occupational sedentary behaviour using wearables. When deciding which wearable and protocol to use for assessing sedentary behaviour in a reliable and valid way, researchers or practitioners encounter the following methodological issues:

- What information does the wearable need to measure?
- How detailed and accurate should the measurements be?
- Where should the wearable be attached on the body?
- How long should the wearable be worn for?
- How should the measurements collected by the wearable be processed?
- How should the processed data be interpreted?

Therefore, the Partnership for European Research in Occupational Safety and Health (PEROSH, http://www.perosh.eu/) gathered a group of scientists from several European research institutions with the aim of developing a practically useful guide for researchers and practitioners on how to assess occupational sedentary behaviour. Specifically, we provide recommendations for measuring and interpreting sedentary behaviour at work using current wearable devices, as well as a framework of important criteria for the use of potential future equipment.

4.4 Key messages

- Indirect methods, such as questionnaires and interviews, are generally considered not to be valid or reliable for assessing sedentary behaviour.
- Observational methods are a potential valid and reliable way to assess sedentary behaviour, but are costly and time-consuming, and may lead to observational bias.
- Measurements with wearable instrumentation are recommended due to their objective nature, precision, relatively low cost and the fact they don't interfere with work tasks or the daily life of the participant.
- There are many factors to consider when choosing a wearable system suitable for assessing sedentary behaviour.
- No current standard procedures or recommendations exist, thus a guide for assessing sedentary behaviour is required.

5 What principal wearable technologies exist?

The advances in modern wearables, such as the developments in posture-based assessment technology, help to provide more accurate assessments of sedentary time and to deal with any limitations of previous methods. An important point is that interest in collecting data on sedentary behaviour and physical activities is no longer limited to health researchers and elite athletes carrying out studies in the sporting field or in the lab, but is becoming increasingly important to private users and practitioners in the occupational world.

In response to the increasing demand for accurate measurement systems and techniques to analyse sedentary behaviour and physical activity, wearables are rapidly being developed and introduced to the market. The devices range from very basic accelerometers used as pedometers to a huge variety of activity trackers. Typically, they are worn as a wristband, or less commonly on the hip. They offer features from just capturing physical activity up to the full functions of a smart watch. Many current smartphones include integrated functions to track physical activity and many free fitness-apps are available. A further development of wearable technology is “smart textiles” which are worn like functional sportswear and measure physiological parameters. Mobile systems are being developed to measure movement and physical activity of patients in daily life for medical purposes. Additionally complex wearable motion capturing systems are used in field studies to record body positions and joint angles and to assess the mechanical load of specific tasks.

This wide variety of devices with the potential to assess sedentary behaviour is likely to leave most practitioners and researchers wondering - “How can I choose the measurement system best suited to my aim, preferences, funding and skills?”

The following sections of this chapter describe the different sensor technologies available, and their characteristics and applications.

5.1 Accelerometers - postural and kinematic assessment

One of the most important sensors to capture human movement is the accelerometer, which is used by the majority of activity trackers.

5.1.1 Operating principle

An accelerometer responds to forces and to changes in velocity that result from movement of the body of the wearer. They normally measure accelerations in three spatial axes [x,y,z]. It uses gravity to identify the vertical vector and hence its own static spatial orientation.

5.1.2 Outputs from accelerometer systems

Two basic applications for accelerometers are finding the orientation of a body segment and using activity counts to log repeated activities such as gait cycles. The acceleration signal can be used with activity count thresholds to measure overall levels of physical activity. It can also be used to convert activity counts into energy expenditure via algorithms based on calibration of counts obtained by indirect calorimetry or doubly labelled water[84,93]. The number of steps taken can be calculated using an algorithm based on the periodic signal of dynamic change of the acceleration signal. By adding anatomical height and further signals (form, frequency of detected periodicities etc.), it can be used to also estimate the step length. The distance travelled is then calculated based on the length and number of steps.

5.1.3 Strengths and weaknesses of accelerometers

Accelerometers are quite small, can easily be integrated into other systems and have low power consumption. Therefore they are unobtrusive to wear and very practical for field measurements. They are less suitable for accurately measuring spatial orientation during rapid movements. Furthermore, the estimated energy expenditure derived from the simple counts per minute measure lacks the ability to differentiate between tasks such as walking, stair climbing and lawn mowing, making it a very rough estimation.

For accurate 3-dimensional kinematic field measurements inertial measurement units (IMUs) consisting of 3-axis accelerometers, 3-axis gyroscopes and 3-axis magnetic field sensors are required. The three different sensor types complement each other, so that negative characteristics of each sensor type (e.g. drift of gyroscopes or dynamic errors of accelerometers) can be minimised.

5.2 Heart rate measurements – cardiorespiratory and metabolic assessments

Another important type of sensors in wearables is used to assess parameters like heart rate and respiratory values to apply methods of indirect calorimetry.

5.2.1 Operating principle of optical heart rate sensors – photoplethysmography (PPG)

Optical heart rate sensors use integrated photodiodes which radiate light on the skin and captures its reflection. When the heart muscle contracts, blood is pushed through the arteries which therefore dilate. Relaxation of the heart muscle decreases the blood pressure in the arteries and they become narrower again. These changes alter the way that light is reflected from the skin in a predictable way, making it possible to count pulses and therefore to assess the heart rate.

5.2.2 Strengths and weaknesses of optical heart rate sensors

In principle these sensors can be applied anywhere on the skin, giving great flexibility in application. When used in wearables they are typically attached at the wrist, but the ear lobes or fingertips are commonly used in clinical applications. A main limitation for usage in the field is that the technique is prone to movement artefacts since movement can rapidly change the volume of the tissue underlying the sensor.

5.2.3 Operating principle of electrical heart rate sensors – electrocardiography (ECG)

Electrical heart rate sensors use skin electrodes to detect the electrical signals generated by the heart muscle each time it contracts. The unique structure of this signal allows the precise measurement of each individual heartbeat and therefore the calculation of the heart rate. As the ECG signal is strongest near the heart, the electrodes are usually attached to the thorax.

5.2.4 Strengths and weaknesses of electrical heart rate sensors

When the electrodes are placed correctly, they provide a quite precise measurement of the heart rate. They can be integrated into chest straps or fabrics in direct contact with the skin. But as they measure electric signals, the technique is susceptible to artefacts due to movement of tissues near the electrodes as well as interference from nearby electrical equipment.

5.2.5 Output parameters of heart rate sensors

It has long been established that there is a linear relationship between cardiorespiratory stress and energy expenditure, and thus with activity intensity[94]. However, this only holds true within a given activity type (e.g. sitting, walking, running) and not between them. Heart rate can therefore be used to estimate energy expenditure, which complements the data from accelerometers, leading to an increased accuracy for assessing physical activity and sedentary behaviour. However, since heart rate can be altered by sympathetic nervous system activity due to factors such as emotional state, stress or caffeine, it is a challenge to assess sedentary behaviour based on low heart rate measurements. Heart rate variability (HRV), the variation in beat-to-beat time intervals, can be measured to detect several conditions that affect the autonomous nervous system[95].

5.2.6 Operating principle of ambulatory metabolic measurements

One of the most precise ambulatory methods for assessing energy expenditure is open-circuit spirometry. By measuring and comparing the consumption of oxygen and the production of carbon dioxide during rest and steady-state exercise, the oxidation of macronutrients is estimated indirectly and serves as an assessment of energy consumption[96]. In addition, pulmonary values such as vital capacity, expiratory and inspiratory volume and breathing flow parameters can be assessed.

5.2.7 Strengths and weaknesses of mobile spirometry

Spirometry is the most precise way to capture the lung function and to analyse the intensity of physical activities based on the method of indirect calorimetry[96]. An ambulatory breath analyser can also be used in field studies. However, they are often quite bulky and uncomfortable due to the mask and tubing making them less practical for long term measurements as the equipment might interfere with job tasks and normal interactions at the work place.

5.3 Additional sensor technologies

Accelerometers and heart rate sensors can be found in nearly every wearable on the consumer market today, but some wearables use an even wider range of sensors that provide possible parameters for even more detailed analyses of physical activity and sedentary behaviour.

Measuring the skin temperature can help to determine the kind of physical activity. Skin resistance measurements can be used to describe emotional arousal, and an atmospheric pressure sensor can detect changes in height, making the counting of climbed stairs possible, while GPS sensors can track the user's global position to provide information on where activity occurs. Techniques being used with complex measurement systems include field measurements of surface electromyography (EMG), assessing the muscle activity level and corresponding time pattern.

5.4 What are the typical characteristics of wearables?

Although wearables show differences in their specific features, they do have some principal characteristics in common.

5.4.1 Output parameter(s)

The complexity of the output parameter(s) is roughly proportional to the number of sensors used to capture data. The use of different sensor types also increases output complexity. Based on the type of sensors, wearables provide a wide range of measurement techniques from very basic to measuring a multitude of physical activity types, tracking sleep and capturing physiological responses.

All devices can count the steps taken; many calculate the number of stairs/floors climbed. Some ankle-worn devices can interpret the movement of the legs as cycling or rowing. Using standardised calorie consumption data and/or given information about calorie intake by the user, many wearables estimate energy expenditure. Additional features include heart rate data and pulmonary information. Most commercial wearables summarise and display the assessed output parameters to improve usability.

5.4.2 Attachment

Nearly all of the current commercially available wearables are small and unobtrusive and can be attached by the wearer. As they are designed for wear throughout the day - some even at night - the sensors are covered by skin-friendly, synthetic materials and integrated into synthetic or textile bands. Advanced scientific systems often have stricter attachment requirements and are often less practical for wearing for extended periods.

5.4.3 Time resolution and data storage

Possible time resolutions to record the physiological and/or kinematic outcome(s) are seconds, minutes or hours depending on the data logger used. The data storage capabilities on the devices themselves differ due to the features available. Nearly all wearables offer either real-time streaming to a connected smartphone or can store data for at least one week on the device itself. When used in conjunction with an online dashboard or installed software, data collected over weeks or months can be stored and displayed.

5.4.4 Battery life

Like the capacity to store the recorded data, the battery life depends on the features of the device. Normally a capacity of at least eight hours is available; most devices have to be charged twice a week when being worn every day.

5.4.5 Accessibility

Most of the commercially available products provide an app or online dashboard that displays the processed data, which is often also displayed on the device itself. Access to raw data (e.g. as spreadsheets or text files) and to data processing options is more likely to be available in systems designed for scientific use (such as multiple-sensor measurement systems).

5.4.6 Cost

The extensive range of low-cost measurement systems allows for application in numerous fields. However, cost also depends on the desired outcomes of the measurement, the required precision, and their complexity.

5.5 General categories of wearables

This section categorises wearables according to their sensor technologies and characteristics (see Figure 1). It serves as a practical guideline for their use in different field applications. It gives a brief overview of the differences of wearables according to their function, the outputs available and the accuracy of data.

5.5.1 Category 1 wearables – Single integrated motion and physiological sensor

When considering the number and type of sensors being used in a wearable, the devices using only one motion sensor placed on one body part can be described as a Category 1 measurement system of physical activity. These sensors are limited by the fact that placement on only one part of the body provides spatial orientation of that specific part, but not other parts of the body. Most of these wearables are worn as a wristband and interpret recorded data as a movement of the whole body, even if just the arm is moving (shaking and clapping could cause false positive readings). By placing the wearable on one part of the upper body, a distinction between an upright or lying position is possible, but the movement of the lower body cannot be assessed. Therefore, such a wearable cannot differentiate well between body postures such as sitting, standing still, walking or cycling.

Most Category 1 wearables calculate energy expenditure of the user by transforming the accelerometer raw data into counts, and then transforming the counts into kilocalories or METs[84]. With just one accelerometer worn on the wrist or hip, the accuracy of the transformation can be poor, due to the effect of physical activity and movements performed by body segments not being included in the assessment[97]. Instead, placing the sensor on the leg, (e.g. on the thigh or ankle), makes it possible to differentiate between body postures and makes it possible to estimate the energy expenditure of the user based on predefined average intensities of the identified postures. But the accuracy of the output of activity trackers can be improved using more accelerometers and physiological sensors. The addition of heart rate data to accelerometer data can lead to more precise assessments because an increased heart rate can often indicates a rise in the intensity of physical activity.

A great advantage of devices combining accelerometer and heart rate monitoring is their small appearance and their unobtrusiveness during work or leisure and when sleeping. But Category 1 wristbands are currently showing limitations in measuring heart rate because the sensors are limited to optical methods and the options for data accessibility and processing are highly limited. Moreover, the measurements can often be incorrect when overhead movements of the arms occur.

5.5.2 Category 2 wearables – Multiple individual motion and physiological sensors

A further step into assessing sedentary behaviour and physical activity is provided by using integrated sensor systems measuring from multiple motion and physiological sensors, attached directly to the skin or via clip-on attachments or Integrated into “smart textiles”. Smart textiles can simplify the attachment, positioning and wearing of multiple sensors. They generally require a very tight fit, and function as an additional layer of clothing which might not be practical or appropriate for recording all kinds of occupational sedentary behaviour and physical activity, potentially for several days in a row.

Category 2 wearables capture kinematic and physiological data like Category 1 wearables, but provide more accurate information on body postures and movement, physical activity and energy expenditure. For example, placement of multiple accelerometers on a specific body segment or on two connected body segments provide a more accurate assessment of body posture than using a single accelerometer only. The accuracy of the heart rate measurement increases from Category 1 to 2 wearables, especially when using electrical instead of optical sensors, and placing them on the thorax instead of at the wrist. A limitation of Category 2 wristbands designed as recreational sportswear is that they are highly unlikely to provide good access to raw data. Parameters of ventilation such as the breathing rate and minute ventilation can be assessed with electrical sensors placed on the rib cage.

5.5.3 Category 3 wearables – Complex multi-sensor systems

If high data precision and a large number of different output parameters such as kinematic, cardiological and pulmonary data are required, validated methods with multiple sensors are needed. Accurate measurements of the movements of multiple body parts and their relative spatial orientations can be provided by multi-sensor systems using IMUs. When measuring the activity of the heart in the field the most precise way is a mobile ECG system and a mobile spirometer is used to calculate the energy expenditure of movements by analysing the respired gases. However, these devices require most effort to attach and are the least comfortable for the wearer. They have to be calibrated, and the raw data has to be processed with expert software. They are normally used for scientific purposes and are sometimes not commercially available.

Figure 1 – Categorization of wearables based on type and number of sensors used.

As wearable technology is developing rapidly, it is important to keep in mind that this report is describing the currently available commercial sensor systems. In the future, there will be more advanced sensor technology available which might lead to the categorisation system of wearables being modified.

5.6 Key messages

- Commercially available devices today offer a wide variety of sensor technologies, functions, and output parameters
- The most common sensor technologies for capturing physical activity are accelerometers and physiological sensors such as heart rate sensors
- Wearables show differences regarding principal characteristics, which are:
    - output parameters concerning physical activity
    - ease of attachment
    - time resolution
    - battery capacity and autonomous recharging
    - display of data
    - costs
- Development of wearables is on-going; at the moment three categories can be defined based on the general characteristics of all wearables:
    - Category 1 systems: A single integrated motion and/or physiological sensor
    - Category 2 systems: A limited number of motion and physiological sensors with individual attachment locations
    - Category 3 systems: Complex, multiple sensor systems

6 Selection of the appropriate wearables

Due to the different characteristics and pros and cons of commercially available wearables, no general recommendation can be given for which wearable to use, which must be chosen considering the purpose of the project, the intended output parameters and their application. This chapter provides detailed information about the characteristics of devices in the three categories. It summarises the advantages and disadvantages of each category at the end of its description.

6.1 Category 1 systems

6.1.1 Attachment

Portable accelerometers or physiological sensors can be housed in small synthetic cases that can be fixed to the skin by tape or textile bands worn on locations such as the wrist or ankle. Clip-on sensors can be attached easily to clothing. In general, they are comfortable to wear. Manufacturers provide instructions on how to wear them. Most can be worn day and night and also during sports. Waterproof ones allow completely uninterrupted wear.

6.1.2 Output parameters

Activity: An accelerometer can detect whether the person is active or not by recording movement. With a built-in timer, it can also save the duration of the movement and the amount of activity.

Postures / tasks / movement patterns: Recording movement in three axes allows the generation of data such as steps, cadence, speed and elevation. A device worn on the ankle can differentiate between walking and cycling by interpreting velocity and acceleration data.

Cardiovascular: The most common measured physiological parameter is heart rate. Heart rate monitors can commonly record and identify resting heart rate, average heart rate throughout the day and maximum and minimum heart rates within a session.

Energy expenditure: Energy expenditure can be estimated using simple algorithms based on defined intensities of activities based on standard measurements of METs for walking and cycling. Use of heart-rate sensors improves the accuracy of the estimates.

6.1.3 Time resolution and duration

The time resolution of a device can be very precise (milliseconds) and long duration datasets (for example, measurements over days or weeks) can be recorded and processed. Activity tracker and fitness watches show measurements for periods ranging from one week to a month. Where data are being measured at short intervals, such as every second, the display graphs typically have resolutions of minutes and hours. Most devices can provide a summary of daily activities that can be compared across several weeks.

6.1.4 Battery life

The battery lives of Category 1 wearables range from a day to about a month and depend on the kind of use and the technical and additional features of the devices. It reduces as more parameters are recorded and processed by the device. Recharging via USB generally takes around 2 hours.

6.1.5 Data accessibility

Nearly all Category 1 wearables display output data on the device itself; some just indicate physical activity with LED lights on their displays. The majority can be connected to a computer or a mobile phone via Bluetooth and/or USB to store the processed data and display it in connecting apps or online dashboards. Sometimes the export of data is limited to just a few parameters. Category 1 devices often do not make raw data available to the user.

An exception is the stand-alone use of an accelerometer that is not integrated into a wrist or ankle band. In this situation, the raw data are analysed with external software which can require specialised knowledge.

6.1.6 Cost

Purchasing an accelerometer as a measurement tool is cheaper than buying a device with additional features. Devices for just recording steps can be very low cost. The price depends on the kind of attachment (wrist band/ankle band/chest strap) and increases with the complexity of recorded outcomes (additional physiological data). Characteristics such as the ability to connect to the internet and/or a smartphone can result in a price of hundreds of Euros.

Info box: Category 1 systems - single motion and / or physiological sensors

+ Wrist and ankle bands represent possible measurement systems for very large populations and long-term measurements in several settings.

+ These systems are very well suited to private users who want to monitor their daily activity.

+ Single accelerometers may be suitable for longitudinal measurement of physical activity of large groups of participants in their working hours and leisure time.

+ Displaying processed data in apps and dashboards can act as a motivational tool to increase the personal amount of physical activity.

- The accuracy of motion sensors is limited and optical heart rate sensors have not yet proven to be reliable.

- Each device has its own algorithm underlying the calculation of the output parameters. These algorithms are usually not accessible to the user.

- Cloud storage of data can conflict with the ethical requirement to protect personal data collected as part of a scientific study.

- Export of data can be restricted to just a few parameters at low time resolutions such as daily summaries and raw data may not be accessible.

- Scientific analysis of recorded data of commercially available activity trackers is difficult due to limited access to unprocessed data.

6.2 Category 2 systems

6.2.1 Attachment

Category 2 wearables consist of small numbers of independently positioned accelerometers and physiological sensors. These sensors can be attached directly to the skin or to individual body parts with straps. Accelerometers can be combined with measurement technology assessing heart rate like chest straps or additional sensors to capture physiological values.

Integration of sensors into “smart textiles” can make it easy to attach and wear multiple sensors. These garments provide built-in sensors on textile bands, placed inside of the textile at the chest, the back and the hip. To ensure that the sensors are measuring correctly, the fit of the garments has to be quite tight to get the sensors in close contact with the underlying skin. Smart textiles are comparable to functional sportswear which keeps the user warm and is comfortable to wear. However, this might enhance sweating while wearing and may limit their feasibility in long term assessments.

6.2.2 Output parameters

Activity: Systems that include accelerometers can record movement in general and the total volume of movement in the same way as Category 1 systems.

Postures / tasks / movement patterns: Measurement of steps, cadence, speed and elevation of segments are obtained by analysing the acceleration data. When the system includes a GPS function, it is possible to record the distance being walked/ run/cycled etc.

Cardiovascular: Category 2 wearables that use electrical sensors detect heart activity are more accurate than compared to optical heart rate sensors. The average heart rate values like resting and maximum heart rate can be displayed. Some systems even calculate HRV as an indicator for stress (reactions) of the individual while being physically inactive.

Pulmonary: Wearables using sensors to record the breathing rate are able to determine the tidal volume and the minute ventilation, too.

Energy expenditure: The intensity of the movement is being indicated by displaying the energy expenditure which is calculated with basic algorithms using the parameters heart rate and breathing rate.

6.2.3 Time resolution and duration

Using accelerometers as well as skin electrodes to measure heart and breathing rate, the time resolution of outcomes is theoretically up to seconds. Like previously described, it depends on whether the data is being displayed in seconds, minutes or hours and summaries of days or weeks.

6.2.4 Battery life

An accelerometer with a built-in battery can record measurements over weeks without needing recharging. But the combination of recording cardiologic and even pulmonary data can result in higher energy consumption of the system. Furthermore, the ability to connect to the internet or wirelessly transferring data is additional indicators for a lower battery life just lasting for a few days. Normally, the systems can be charged by using the USB connection.

6.2.5 Data accessibility

Category 2 systems don´t have displays on the sensors or textiles but connect through Bluetooth or USB to mobile phones, tablets or computers. The data can be displayed in an app or software. Raw data can sometimes be exported for later analysis with suitable software.

6.2.6 Cost

Depending on the availability of the product on the commercial market and the features prices rang4 from 200 to 500 Euros.

Info box: Category 2 systems – small numbers of motion sensors and one physiological sensor

+ Direct attachment of sensors ensures their correct placement.

+ Integrating of sensors into textiles simplifies attaching and wearing multiple sensors.

+ The use of multiple sensors on different body parts allows measurements that are more precise.

+ The use of electronic or infra-red heart rate sensors in close proximity to the heart can improve the accurate measurements of heart rate.

+ Additional measurements, such as parameters of pulmonary function are possible.

- These systems have limited suitability for measurements over longer periods and on large populations.

- Although wearing smart textiles is more comfortable than direct attachment of sensors, their use in the workplace may make the user too warm and result in increased sweating.

6.3 Category 3 systems – complex multiple-sensor-systems

6.3.1 Attachment

Category 3 systems are the most accurate type of system and consist of multiple high quality sensors attached to the torso using special portable systems and/or fixed them to the extremities with tape or textile bands. An external data logger may also be attached to the body. There may be cables or wires connecting the sensors to the logger.

These systems need to be set up specifically and calibrated, usually using specific software. They usually need another person to fit them correctly to the wearer and the precise and correct placement of the system with the help of another person. Fitting them can be extremely time-consuming.

The wearing comfort of these systems can be affected by the placement and size of the attached devices. The systems are often quite complex and can be heavy to wear due to the number of components or sub-systems.

6.3.2 Output parameters

Activity: Category 3 systems can be designed to provide information for nearly every aspect of the analysis of physical activity including the amount, the intensity and the specific components of activity.

Postures / tasks / movement pattern: With multiple accelerometers fixed on various body segments as part of a multi-sensor system, it is possible to record body and joint angles and identify limb orientation in relation to external axes. The data can be used to identify postures and activities such as standing, walking, sitting, lying, rowing and cycling. The duration of each posture or activity and the frequency of changes between them can also be obtained.

Cardiovascular: ECG sensors can be used to assess the electrical activity of the heart.

Muscular: EMG sensors can be used to assess the muscular activity of relevant skeletal muscles. Non-invasive surface electrodes will detect activity of muscles near to the surface of the skin. Invasive methods such as needle electrodes are needed to detect activity of deeper muscles.

Pulmonary: Spirometry can be combined with other systems to provide information on pulmonary parameters such as breathing rate, tidal volume, and rate of oxygen consumption.

Energy expenditure: The systems are able to differentiate motion intensities by quantifying the energy expenditure from the exact cardiovascular and pulmonary parameters or by calculating the Physical Activity Intensity (PAI) for either the whole body or individual body segments.

6.3.3 Time resolution and duration

Measurements can be performed at resolutions of milliseconds for durations lasting as long as several weeks.

6.3.4 Battery life

The complexity of Category 3 systems means they often need to be connected to an external power supply.

6.3.5 Data accessibility

Extraction of detailed information from a multi-sensor system requires software that can process and synchronise raw data from multiple sensors. Analysis usually requires specialist software; correct interpretation of the outputs requires expert knowledge. The use of these systems is likely to be limited to experts with specific knowledge, such as scientists, health care professionals and medical personnel.

6.3.6 Cost

As they are highly specialised, Category 3 wearables are the most expensive systems with costs varying from hundreds to thousands of Euros.

Info box: Category 3 systems – multiple-sensor-systems

+ Assessment of body position, movements, physical activity and physiological parameters under controlled conditions using the highest standard for accuracy.

+ They generally give good access to raw and processed data.

+ Highest time resolution possible.

+ Complex analysis with high quality data is possible.

- Expert knowledge is usually needed to use the system and analyse data.

- High equipment costs.

- The equipment is complex and needs to be fitted carefully: attachment on several body parts, sensors connected with cables, weight of equipment, etc.

- Checks have to be made to ensure the equipment does not interference with work tasks.

- Often only practical for use with by one person at a time in standardised settings.

- Measurements over longer durations are difficult.

6.4 Key messages

- Category 1 wearables
  - Generally allow only rather basic assessment of relatively simple kinematic or physiological parameters.
  - Cheap, primarily with private consumers as the target audience.
  - No current system can assess sedentary behaviour in accordance with its definition.
  - Feasible to wear for long-term field measurements.
  - Specialised systems have been developed for certain scientific assessments.

- Category 2 wearables
  - The more detailed assessments of movement and physiological parameters can permit measurement of sedentary behaviour.
  - Integration into “smart textiles” can ease attachment.
  - Intermediate feasibility for measurements over longer durations.

- Category 3 wearables
  - Allow precise temporal assessments of movement and physiological parameters, and thus precise temporal assessment of sedentary behaviour.
  - Often requires specialist knowledge to collect and analyse data.
  - Wearing them for long durations is often not practical
  - May not be easy to use in field settings.
  - Expensive.

7 Data collection strategy

7.1 Need for a data collection strategy

Even with optimal instrumentation for assessing sedentary behaviour that avoids problems such as observational bias[88,89,98], the quality of the findings is determined by the data collection strategy. Subject selection needs to avoid systematic error or bias due to subjects or data collection days not representing the population they are intended to typify. Data sampling needs to consider the number of subjects needed and the number of days needed per subject. When data collection does not cover full working days, the number of measurements per day must be considered[99-101]. Statistical power analysis is the established method of determining the number of measurements needed to detect differences between groups, tasks or working conditions[102].

7.2 Effect of variability

The variability in sedentary behaviour between and within subjects depends on the occupational context. Therefore, it is inappropriate to issue numeric guidelines on sample sizes, intended to be generally applicable to all studies of sedentary behaviour.

The uncertainty of a result, typically expressed as a standard deviation or a confidence interval, is a key issue when designing a data collection strategy. As not all subjects behave in the same way and not all working days are the same[103,104], results based on samples will inevitably be associated with uncertainty, or “random” error. Wearables are usually regarded as being associated with negligible random error in use[90,105], even though some technologies, for instance accelerometers in smart clothes, may show errors deserving consideration.

The statistical performance of a data collection strategy, in terms of the precision of the eventual mean exposure value across all subjects and days, is directly related to the variability in exposure between and within subjects, and to the number of sampled subjects, measurement days and measurements per day[106]. Smaller variability and more samples lead to better precision, i.e. a result that has a larger probability of being close to the truth.

Variability between subjects and days can be expressed in terms of variance components, which are individual sources of variability contributing to the overall uncertainty in the data[107]. Variance components can be extracted using standard statistical techniques such as ANOVA[99] and REML-procedures[108]. Variance components are more useful for study design purposes than relative metrics of statistical performance such as Intra-Class Correlations[109,110].

7.3 Pilot studies

Some occupational studies have reported basic descriptive statistics on the variability between subjects in sitting time per day, if not separated into between- and within-subject sources of variability[40,45,49,51,69,111]. These data may give an idea about approximate sizes of overall variance in settings similar to those addressed by the studies. However, as variability is strongly influenced by the study population and occupational setting, it will often be advisable to conduct a pilot study to obtain study-specific estimates of variance components prior to designing the full study.

7.4 Compositional data

Well-established equations express the relationship between variance components and sample sizes, and the precision of the eventual result[106]. Based on these theoretical equations[99,112,113], or on computer-intensive empirical simulation techniques[100,101,114,115], considerable research has been devoted to determine sufficient sample sizes for different purposes, different occupational exposure variables, and different occupational settings. To our knowledge, only one study has specifically addressed sampling needs in studies of sedentary behaviour and physical activity for data obtained using accelerometry[116]. Calculations in that study was based on conventional assumptions of data being normally distributed. However, the occurrence of sitting, standing and physical activity is usually expressed as percentages of time, explicitly or implicitly adding up to 100%. Data of this nature are "compositional"[117], and behave differently from data that are not constrained to add up to a fixed total. This has consequences for sample size calculations and statistical testing. Work has been done on equivalent problems in other scientific areas[118-120] but only sporadic attention has been paid to the compositional nature of many variables addressing physical load[121,122]. It is likely that future research will address this issue in sedentary behaviour studies.

7.5 Precision and sample size

The generic equations expressing statistical precision as a function of variance components and sample sizes predict that a particular total sample size will always yield a more precise estimate of the mean value if the samples are distributed "widely" among subjects[106]. Thus, collecting data for 1 day each from 50 subjects gives a better estimate of the mean than collecting data from 10 subjects for 5 days each.

The marginal effect on precision of collecting data from another worker or on another day decreases with the size of the data set. Thus, adding 5 workers to a data set that already contains 5 will decrease the variance of the mean by half, while adding 5 workers to a set of 15 workers will reduce variance by only 25%.

The theoretical equations are valid under a number of assumptions, including that data for different workers, days and measurements within days are independent. This may not be true, one example being that exposures close in time during a working day are likely to be correlated to a larger extent than exposures further apart[101,123]. In case of correlation, more data are needed to arrive at a particular precision of the mean than predicted by the theoretical equations[101].

7.6 Cost and efficiency of data collection

Assessments of cost and efficiency of measurement strategies are necessary to answer questions such as "what is the cheapest possible strategy that can still produce information of a specified quality" and "which one of a number of alternative data collection strategies that entail the same cost leads to the better precision of the eventual result". However, there has been little research on measurement strategies in the context of both cost of sampling and precision[80,86,124], let alone studies of specific relevance to the cost-efficiency of sedentary behaviour and physical activity studies.

However, equations are available for assessing the trade-off between cost and statistical performance in some study designs, including collecting data for a particular number of days in a population of subjects[125]. These show that spreading a fixed number of measurements among as many subjects as possible to improve statistical precision may increase costs. Thus, if additional measurement days are cheap while additional subjects are expensive, and exposure variability between days is large compared to exposure variability between subjects then the most cost-efficient strategy is likely to be to collect data for many days per subject rather than from many subjects over a few days.

The cost-efficiency trade-offs between questionnaires, observation and instrumentation will change as with the costs of using these approaches change[86]. The likely trend for wearables to continue to get cheaper will probably favour their use, even from a cost-efficiency point of view.

7.7 Key messages

- Projects require a well-designed data collection strategy to ensure representative high quality data for the project target population.
- The data collection strategy can vary the number of subjects, number of days per subject and number of measurements per day.
- Variance in the data measurements may stem from within or between subject differences. The source of variance should be evaluated or pilot-tested prior to deciding on the data collection strategy.
- Statistical theory generally suggests that, when sampling for a fixed total time, measuring more subjects for shorter durations is generally superior to measuring fewer subjects for longer durations.
- Care should be taken that occurrences of high loading, which might occur on specific days or at specific times during the day, should not be over or underrepresented in the sampling.
- On a constrained budget, cost-efficiency might make longer measurement durations per subject more attractive than adding more subjects.

8 How to interpret the measured output parameters

This chapter gives an overview of how the outputs of wearables are converted into a meaningful quantitative outcome.

8.1 Output parameters and corresponding quantitative assessment

The sensor technologies implemented in the three categories of wearables provide various output parameters describing body posture, energy expenditure and physical activity. Table 2 gives an overview of the output parameters related to assessing sedentary behaviour and the level of recommendation for assessing sedentary behaviour from the different wearable categories. For detailed information on possible output parameters from wearable sensor technology, see the matrix in Appendix A. Overall, the complexity of the output variables, as well as the accuracy of measurement, increases from Category 1 to Category 3 wearables.

The Category 1 wearables are limited by the fact that placement on only one body segment provides spatial orientation of that specific segment, and no information on other segments of the body. For example, a wearable placed on the wrist or thorax cannot assess movements of the legs, and cannot differentiate between sitting and standing still. A Category 1 wearable placed on the upper body can distinguish between an upright or lying position, but cannot assess movement of the lower body.

Category 2 and 3 wearables permit the placement of two or more sensors on a body segment or on different body segments so can make more accurate assessment of the orientation and movements of the body and body segments. If complex postures and movements of several body parts (e.g. twisting the upper body while kneeling) are of interest, sensors need to be attached to several body segments and to be connected to each other (i.e. Category 3 wearables). Therefore, the accuracy in assessment of temporal patterns, including frequency of changes and variation of body postures and movements, increases with the number of sensors, the number of body segments with sensors attached, and the types of sensors used.

The most common output parameters from wearables are values describing the amount and intensity of physical activity. These are mainly estimated by interpreting kinematic or physiological parameters. A general kinematic output variable from all systems is the number and frequency of steps. Placing sensors on the hip, trunk or thigh leads to a more precise measurement of steps than with sensors placed on the arm or wrist. However, brands of wearables differ in accuracy of step quantification[126], and the number or frequency of steps cannot be used alone to assess physical activity intensity or energy expenditure accurately[127]. Other measures of the general level of physical activity are the PAI and "activity counts"[97]. PAI is calculated by high pass filtering of the acceleration signal and then averaging over time[128]. An activity count is the number of samples that exceed a threshold over a measurement period. Calculations are possible for any body part instrumented with an accelerometer. By combining several accelerometers and weighting the accelerometer signals, PAI or count values can be calculated for body segments, body regions and the whole body[128].

Additional assessments of physiological data, such as heart rate and ventilation makes the estimation of activity intensity more accurate than just interpreting data derived from accelerometers[129]. The accuracy of heart rate measurements increases from Category 1 to 2 wearables, because of better placement of the sensors and time distribution of recordings. Output parameters of ventilation like the breathing rate and minute ventilation can be assessed with electrical sensors placed on the rib cage (Category 2 wearables). Otherwise, using a mobile spirometer and conducting breath gas analysis (Category 3 wearables) offers the whole range of parameters for assessing pulmonary function[130].

Table 2 – Overview of the output parameters and recommendations for using the different categories of wearables to assess sedentary behaviour: "-" = not recommended, "0" = partially recommended; "+" = recommended

	Category 1 wearable					Category 2 wearable		Category 3 wearable
Sensor types	Accelerometer + PPG or ECG					Accelerometer or IMU + ECG		IMU + ECG + indirect calorimetry
Attachment location	Single attachment on one body part					Attachments in one body region		Attachment on the whole body
Attachment(s)	Wrist/ Upper arm	Chest/ Back	Hip	Ankle	Thigh	Smart textiles	Few single sensors	Multi-sensor-systems
Output parameters								
Spatial orientation	Orientation of one individual body part					Orientation of one body region and few body parts		Orientation of several body parts, body regions and whole body
Activity type								
Sitting or standing	-	-	-	-	+	-	+	+
Upright or lying	-	+	0	0	+	+	+	+
Complex postures or activities	-	-	-	-	-	-	0	+
Activity intensity								
Steps	0	+	+	+	+	0	+	+
PAI calculation	PAI calculation for the instrumented body part					PAI calculation for one body region, few body parts		PAI calculation for body parts, body regions, whole body
Heart rate	0	+	-	-	-	+	+	+
Breathing	-	-	-	-	-	0	0	+
Energy expenditure estimation								
Low accuracy	+	+	+	+	+	+	0	-
Moderate accuracy	-	-	-	-	-	0	+	0
High accuracy	-	-	-	-	-	-	-	+

PPG = Photoplethysmography; ECG = Electrocardiography; IMU = Inertial Measurement Unit; PAI = Physical Activity Intensity

The intensity of physical activity is measured as energy expenditure[131], which is challenging to assess accurately because it depends on a variety of interacting factors. Therefore, heart rate and activity counts from accelerometer data have commonly been used to assess it. Estimates of energy expenditure from heart rate and activity counts are predominantly based on the linear relationships between activity intensity, heart rate, and energy expenditure as assessed by indirect calorimetry. However, this linearity only holds true within a particular activity type[93], making energy expenditure assessments more accurate when activity type also is assessed[128]. None of these parameters can be assessed with Category 1 wearables, so accurate estimation of energy expenditure requires Category 2 or Category 3 wearables. The most precise manner to assess energy expenditure in the field is indirect calorimetry[96], which inherently requires a Category 3 wearable because of its low feasibility for field measurements and high requirements for calibration, data analyses and interpretation of output variables.

An important and inherent limitation of Category 1 wearables is that they are currently unable to assess both components of sedentary behaviour simultaneously. A Category 1 wearable placed on the thigh can assess sitting or standing posture, but is unable to assess activity intensity of the upper body or energy expenditure while sitting or reclined. When placed on the wrist or arm, a Category 1 wearable can assess physical activity intensity and/or energy expenditure while sitting or reclined, but is unable to assess postural information. An integrated accelerometer and optical heart rate monitor attached to the thigh could theoretically solve this problem, but to our knowledge, such a wearable is yet to be developed and validated.

8.2 Overview of the main characteristics of the categories of wearables

Table 3 provides decision support for choosing the wearable best suited to a particular project regarding sedentary behaviour. It deals with several factors, including accuracy, duration of measurements, and available budgets. It allows users of wearables to check the particular requirements of their project and the feasibility of each wearable category before selecting a particular system.

The left side of the matrix lists factors that have to be considered before conducting a sedentary behaviour assessment. Three levels are given for each factor, ranging from low requirements to high requirements. A user first has to decide which main factors need to be measured to answer the aim of the project. The next step is to decide which level of each factor is needed. The row for that level gives the ratings of the different categories of wearables: “+” = recommended, “0” = partially recommended and “-” = not recommended“. The selected system should be rated at least “partially recommended” or “recommended” for all of the main factors to be measured. If that is not the case, the user ought to consider to modify the requirements of the system, changing the aim of the project or to use another wearable system which better meet the requirements.

Table 3 – Overview of the main characteristics of the categories of wearables and recommendations for choosing a category of wearables depending on its characteristics; “-" = not recommended; “0” = partially recommended; “+” = recommended

		Category 1	Category 2		Category 3
		Single attachment	Smart textile	Several sensors	Multiple sensor system
Output accuracy	Low	+	+	-	-
	Moderate	-	0	+	-
	High	-	-	-	+
Need for access to raw data	Very limited or none	+	0	-	-
	Limited	-	+	+	-
	Essential	-	-	0	+
Expertise in data analysis	Not available	+	0	-	-
	Partially available	+	+	0	-
	Fully available	+	+	+	+
Measurement duration, battery economy	≤1 workday	+	+	+	+
	2-3 work days	+	0	0	-
	4≤ work days	+	0	-	-
Number of subjects to be monitored	Few	+	+	+	+
	Several	+	+	0	0
	Many	+	0	-	-
Cost per subject	Low	+	-	-	-
	Moderate	+	+	0	-
	High	+	+	+	+
Expertise required to attach the wearable	Low	+	0	-	-
	Moderate	-	+	0	-
	High	-	-	+	+

8.3 Overview of recommendations related to physical activity and sedentary behaviour

Chapter 3 briefly touched upon the WHO global recommendations on physical activity [73]. However, to interpret and give advice based on the output parameters from the wearables, we need an established consensus of guidelines or recommendations based on threshold or dose-response values. Table 4 gives an overview of the current national guidelines for the collaborators on this report, as well as for WHO, USA, Canada and Australia.

Table 4 – Overview of selected National and International physical activity and sedentary behaviour recommendations.

Region	Source	Physical activity	Pub year	Sedentary behaviour	Pub year
USA	CDC/NCCDPHP[132]	1, 2, 3, 4*	2008		
Global	WHO Global [73]	1, 2, 3, 4	2010	*	
USA	ACSM[133]	1, 2, 3, 6*	2011	*	
United Kingdom	Department of Health, Chief Medical Office[134]	1, 2, 4	2010	7	2010
Spain	Ministerio de Sanidad, Servicios Sociales e Igualdad[135]	1, 2, 3, 4, 5, 6	2015		
Germany	WHO EU fact sheet[136]	Adopts WHO Global	2012		
Italy	WHO EU fact sheet[137]	Based on CDC/ACSM	2012		
France	Ministry of Health and ANSES	Based on ACSM (1995)*	2002	7, 8	2016
Austria	Ministerium Frauen Gesundheit	1, 2, 3, 4	2014		
Netherlands	Rijksinstituut voor Volksgezondheid en Milieu.	1, 2*	1998 & 2007	*	
Denmark	Department of Health[138]	1, 2, 3*	2016		
Norway	Helsedirektoratet	1, 2, 3, 4	2014	7, 8	2014
Finland	UKK-instituutti[139]	1, 2, 4	2009	7, 8	2015
Poland	WHO EU fact sheet	Adopts WHO Global*	2012		
Sweden	Folkhalsomyndigheten[140]	1, 2, 3, 4	2011	7, 8	2011
Australia	Department of Health[141]	1, 3, 4*	2014	7, 8	2014
Canada	The Canadian Society for Exercise Physiology (CSEP)[142]	1, 2, 3, 4	2011		

1) *Adults aged 18–64 should do at least 150 minutes of moderate-intensity aerobic physical activity throughout the week or do at least 75 minutes of vigorous-intensity aerobic physical activity throughout the week or an equivalent combination of moderate- and vigorous-intensity activity.*
2) *Aerobic activity should be performed in bouts of at least 10 minutes duration.*
3) *For additional health benefits, adults should increase their moderate-intensity aerobic physical activity to 300 minutes per week, or engage in 150 minutes of vigorous-intensity aerobic physical activity per week, or an equivalent combination of moderate- and vigorous-intensity activity.*
4) *Muscle-strengthening activities should be done involving major muscle groups on 2 or more days a week.*
5) *8-12 repetitions for muscle training up to 8-10 different movements.*
6) *Adults should do flexibility exercises at least two or three days each week to improve range of motion.*
7) *Minimise the amount of time spent in prolonged sitting.*
8) *Break up long periods of sitting as often as possible.*
*) *Further recommendations explained in text.*

Overall, there seems to be a consensus in Western countries regarding the physical activity guidelines based largely upon the 2008 guidelines of the National Center for Chronic Disease Prevention and Health Promotion (NCCDPHP) of the Center for Disease Control (CDC). These were adopted by the WHO in 2010. In short, the guidelines are: be moderately active 150-300 minutes or vigorously active 75-150 minutes a week, in bouts of 10 minutes or more and do muscle-strengthening activities on two or more days per week.

Beyond the eight generalizable statements used in Table 4, regarding physical activity and sedentary behaviour recommendations, a few recommendations exist that didn't make sense to be systematised. The French recommendation is to practice at least 30min/day of rapid walking. The American College of Sports Medicine (ACSM) guidelines state that adults should train each major muscle group two or three days each week using a variety of exercises and equipment, which is a bit stricter when compared to the statement of engaging major muscle groups in general. The US and Australian recommendations emphasise that doing any physical activity is better than doing nothing and that you can start to slowly ramp up into the recommended values, while most other recommendations state that activities should be undertaken for 10 minutes or more. The recommendation in Denmark is that that intense exercise of 20 minutes duration should be undertaken on at least two days a week to increase aerobic capacity or muscle strength. This is very similar to the Dutch recommendation called Fitnorm which recommends intense exercise of 20 minutes duration on 3 days a week. In total, the Netherlands has three official sets of recommendations: Dutch healthy exercise norm (NNBG), Fitnorm and Combinorm, where Combinorm is adhering to at least one of either NNBG or Fitnorm. The Polish Society of Sports Medicine adds further recommendations for adults based on the recommendations from the European Society of Cardiology (ESC), ACSM and American Heart Association (AHA), to the officially adopted WHO global recommendations in Poland.

Table 4 shows that there is a lack of quantitative guidelines regarding overall sedentary behaviour during the day1. Five of the collaborating nationalities (France, Finland, United Kingdom, Norway and Sweden) for this report have guidelines for sedentary behaviour, all of which are very recent and recommends adults to minimise time spent in sedentary behaviour and break up prolonged sitting as often as possible. The Dutch recommendations specify that it is possible to be very sedentary despite adhering to the physical activity recommendations. The WHO has issued a mission statement regarding lowering or limiting the amount of time spent sedentary, and it was mentioned in the 2016 WHO European strategy that “recent evidence suggest to limit prolonged sitting”. The ACSM recommends generally reducing sedentary behaviour by replacing it with light intensity physical activities. However, no specific national quantifiable recommendations targeting sedentary behaviour seem to be available1. Owen et al. 201165 suggested a limit for discretionary sitting time of 2 hours and to stand up and move after 30 minutes of uninterrupted sitting, which corresponds to the later laboratory studies finding metabolic and cardiovascular benefits from interrupting prolonged sitting every 30 minutes57,143,144. However, more research is obviously needed to establish strong coherent guidelines and thresholds.

Quantifiable guidelines or thresholds for work exposure to sedentary behaviour, for sitting and for replacing sitting with standing appear not to exist despite sedentary behaviour being recognised as a growing risk by the European Agency for Safety and Health at Work145 and despite prolonged sitting being directly addressed in the European Union Checklist for Preventing Bad Working Postures146. The suggestion of moving every 30 minutes or having at most 2 hours discretionary sitting time, could practically limit this advice to leisure time sedentary behaviour or workers with relatively high influence over their own work tasks. Thus, it is important to investigate the importance and effect of occupational sedentary behaviour and how interventions to reduce prolonged periods of sedentary behaviour can be efficiently implemented in the workplace. It is important to note that replacing sitting with other activities should be undertaken in such a way that the activity replacing sitting is not also a detrimental health exposure (e.g. too long periods of standing).

8.4 Key messages

- Assessing sedentary behaviour requires a minimum of an accelerometer on the thigh combined with either (in order of increasing potential accuracy); heart rate measurements, one or more additional accelerometers on the upper body or indirect calorimetry.
- Recommendations regarding sedentary behaviour and especially occupational sedentary behaviour are currently highly limited and non-quantifiable, despite strong consensus on guidelines and recommendations regarding physical activity.
- The recommendation is to limit sedentary behaviour and interrupt periods of it as much as possible. It has also been suggested that prolonged sitting should be interrupted every 30 minutes and self-controlled sitting should be limited to a maximum of 2 hours per day.

9 Example scenarios for using different categories of wearables

In the following, we present example scenarios for measuring sedentary work. The solutions describe the minimum requirements for the wearable to assess sedentary behaviour. Wearables that use more sensors to make more precise assessments or to add additional output parameters should be considered if the scope of the project requires it.

9.1 Scenario a)

To inform a decision about whether to acquire sit to stand tables, a practitioner needs to estimate the total amount of sedentary behaviour of individual workers in a medium to small sized office workplace.

In this scenario, the practitioner needs to use a wearable that gives relatively precise measures of the exposure of individuals over whole work days. Questionnaires would not be sufficiently precise to provide valid information and are likely to be biased towards underreporting the exposure. A very precise assessment could be gained by visual observation, but this would be very costly. Due to the current lack of sit to stand tables, it can be assumed that all work is done in a sitting posture. Moreover, it can also be assumed that such office jobs (e.g. computer work) are performed at a low energy expenditure (not performing upper body work). These two assumptions allow the practitioner to use commercially available Category 1 wearables to assess total work time in sedentary behaviour. Due to the widespread availability of smartphones, having the employees download a smartphone app for measuring sedentary behaviour would be a cheap and very feasible solution. Another possibility would be to use a relatively cheap activity tracker.

The practitioner would normally need to measure for 5 days for a typical work-week assessment. However as all work is assumed to be done sitting and with little variance between job tasks, the potential day to day variance can be assumed to be low, allowing the practitioner to use measurements from 1 full workday to estimate the total sedentary behaviour for each individual.

9.2 Scenario b)

After finding the troubling result that these office workers spend 80-90% of their working time engaged in sedentary behaviours, the practitioner is asked by the company to introduce sit to stand tables into the office and evaluate the effect on posture.

For this project, the practitioner needs a wearable that can differentiate between sitting and standing to measure the total times spent sitting and standing. We can assume that the energy requirements are rather low for office work regardless of sitting or standing, so there is no need to assess energy expenditure or to detect other postures. The simplest and least disruptive solution would be a single specialised Category 1 posture analysis accelerometer worn on the thigh either attached directly to the skin or integrated into a smart garment.

To give a good assessment of the total amount of time spent sitting and standing during a typical working week after introducing the sit to stand tables, the wearable should be able to assess 5 workdays for at least 8 hours at a time.

9.3 Scenario c)

After 6 months, the practitioner visits the office again to check if the office workers are still using the sit to stand tables. During this time, the company has encouraged the employees to move more during working hours by relocating the waste bins and printers to a common area and by putting up signs encouraging worker to use the stairs instead of the lift. They ask the practitioner to evaluate the effects of this initiative by assessing the time employees spend in bouts of prolonged sitting, how many steps are taken and how many stairs the employees are climbing.

For this project, the practitioner needs a wearable that can identify and differentiate between sitting, standing and walking, as well as assess the numbers of steps taken and stairs climbed. We can still assume that the energy requirements are rather low for office work regardless of sitting or standing, so although it would be preferable we will not absolutely need to assess energy expenditure. To identify and differentiate standing, sitting, walking and stair climbing, the simplest and least disruptive solution would be a single specialised Category 1 posture and step analysis accelerometer worn on the thigh either attached directly to the skin or integrated into a smart garment.

The posture and step analysis accelerometer must at export “minute-by-minute data” (data summed or averaged over the previous minute) to allow relatively precise temporal detection of prolonged periods of sitting, as well as standing, steps and stair climbing.

To give a good assessment of the number and durations of the bouts of sitting, as well as standing, walking and stair climbing during a typical working week, the wearable should be able to assess 5 workdays for at least 8 hours at a time.

9.4 Scenario d)

In an effort to curb the developing sedentary lifestyle in an office workplace, a group of scientists wants to test if sedentary behaviour could be lessened by providing under-desk bicycles.

For this project, the scientists need a wearable that can assess sitting posture and energy expenditure while sitting. It also needs to record how often and for how long the under-desk bicycle increases energy expenditure outside the range of sedentary behaviour. To allow precise measurement of the changes in posture and energy expenditure of the employees over time, a Category 2 or 3 wearable simultaneously assessing posture by a single accelerometer on the thigh and energy expenditure by a heart rate detector or indirect calorimetry will be needed. This will allow the scientists to gain information about the total duration and temporal pattern of sedentary behaviour and sitting behaviours with higher energy expenditure than during sedentary behaviour.

The device should gather minute-by-minute data to allow relatively precise assessment of sedentary behaviour assessment before and after implementing the under-desk bicycle.

To give a good assessment of the effects of the under desk bicycle over a typical working week, the wearable should be able to assess 5 workdays for at least 8 hours at a time.

9.5 Scenario e)

A researcher is worried that an initiative to introduce sit-to-stand tables in the office to reduce sedentary behaviour at work might increase sedentary behaviour or reduce physical activity during leisure. To test this hypothesis, the scientist needs a wearable that can assess precisely the patterns of sedentary behaviour and physical activity intensity during both work and leisure time. Therefore, the wearable needs to assess sitting and standing posture, while simultaneously assessing energy expenditure. Since leisure time includes periods of sleep, sleep ought to be assessed or recorded by the participant.

At least three synchronised sensors are needed, limiting this scenario to Category 2 and more likely Category 3 wearables. Two setups are feasible: 1) Assessing posture with two accelerometers, one on the thigh to assess posture and one on the trunk/calf to assess lying postures with energy expenditure assessed simultaneously by a heart rate monitor; or 2) assessing both posture and physical activity index or physical activity energy expenditure by using (as a minimum) three accelerometers simultaneously on the thigh, trunk and upper arm.

Data for posture and assessed energy expenditure should at least have a resolution of minutes, but a resolution of seconds would be preferable for precise detection of short breaks from prolonged sedentary behaviour. If possible, sleep should be measured by the wearable or at least recorded in a diary by the participant.

To detect the potential changes in sedentary behaviour and physical activity during work and leisure time, the wearable should be able to assess a full 7 day week before and after the intervention.

9.6 Scenario f)

Many employees at a manufacturing plant have developed musculoskeletal complaints, and the company wants to know if introducing job rotation would be beneficial. The workers at one workstation primarily stand, while three other workstations primarily require sitting. The tasks at the three sitting workstations are surveillance of a manufacturing line, fast-paced assembly work of small pieces, and heavy lifting of the assembled parts.

For this project, a wearable is needed that can assess the differences in kinematic and physiological effect of the different workstations which will include differences in posture, bending, work with the arms, work speeds, muscle activity and energy expenditure. Precise assessments are needed of almost every aspect of work behaviour, including sedentary behaviour, standing, walking, static positions, repeated movements, the speed of movements, muscle activity.

A Category 3 system with multiple accelerometers positioned on respectively the trunk and extremities on both sides of the body allows assessment of individual body part orientation (including bending of the back, arm elevation, postures and more), static movements and repeated movements. The accelerometers combined with heart rate or indirect calorimetry can be used to determine sedentary behaviour as well as whole body activity intensity, while the individual accelerometers can be used to detect differences in upper body vs lower body activity, as well as activity and angles of individual body parts. EMG could potentially be used to detect relevant muscle activation.

The output parameters should be processed to a resolution of seconds to allow precise assessment of subtle differences in kinematic and physiological effects. Measuring each subject at each workstation will control for individual differences. A decision is needed on the cost-efficiency of measuring each individual for several sessions at each workstation versus measuring more individuals for one session at each workstation. Five days assessment would in most cases be optimal, but this is not likely to be feasible wearing these systems. Potentially, measurements over 1-3 workdays of 4-8 hours per workstation could be feasible.

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Appendix A

Appendix A: Output parameters from the different categories of wearables, ✓: available (✓p): partly available

	Output parameter	Category 1	Category 2	Category 3
Kinematic	Total number of steps	✓	✓	✓
	Walking cadence	✓	✓	✓
	Walking speed	✓	✓	✓
	Elevation (number of floors/stairs climbed)	✓	✓	✓
	Distance (via GPS)	✓	✓	✓
	Position and orientation of body segments within a reference frame			✓
	Joint angles		(✓p)	✓
	Ranges of motion of joints			✓
	Reach envelope			✓
	Linear and angular velocities			✓
	Linear and angular accelerations			✓
	Activity specific			
	• Activity type	✓	✓	✓
	• Activity intensity	✓	✓	✓
	• Activity duration calculations based on manufacturer-specific algorithms using accelerometer and physiological sensor data	✓	✓	✓
	• Integration of more than one kinematic sensor allows separate analysis of intensity and duration of different activity types		(✓p)	✓
	• Detection and analysis of postures of separate body parts (e.g. position of trunk)		✓	✓
	• Physical Activity Intensities (whole body and body segments) expressed as PAI or %g			✓
	• Detection of posture and activity patterns: lying; kneeling; sitting; standing still; moving; walking; running; stair climbing; cycling; rowing, etc.			✓
	• Number of transitions between sitting and standing postures		(✓p)	✓
	• Total duration of each activity type			✓
	• Duration of bouts of each activity type			✓
	• Intervals between bouts of each activity type			✓
	• Frequency distributions of each activity type			✓
	• Exposure Variation Analysis (EVA) of awkward postures			✓
Cardiovascular	Heart Rate (HR)	✓	✓	✓
	Resting HR	✓	✓	✓
	Maximum HR	✓	✓	✓
	Average HR	✓	✓	✓
	HR Variability		✓	✓
	Electrocardiography			
	• Rhythm			✓
	• RR intervals			✓
	• Axis			✓
	• Amplitudes			✓
	• Heart rate reserve (%HRR)			✓

	Output parameter	Category 1	Category 2	Category 3
Pulmonary	Respiratory rate		✓	✓
	Tidal volume		✓	✓
	Minute ventilation		✓	✓
	Spirometry			
	• Vital capacity			✓
	• Expiratory volume			✓
	• Expiratory flow/inspiratory flow			✓
	• Total lung capacity			✓
	• Maximum voluntary ventilation			✓
Energy Expenditure	Rough estimates of:			
	• Activity calories	✓	✓	✓
	• Calories per day	✓	✓	✓
	• Basal metabolic rate	✓	✓	✓
	• Exercise metabolic rate	✓	✓	✓
	• Metabolic Equivalent of Task (MET)	✓	✓	✓
	Exact calculation of:			
	• EE of specific time intervals/activities in METs			✓
Muscle activity	**Electromyography**			
	• Muscle function			✓
	• Muscular activity (%MVC)		(✓p)	✓
	• EMG frequency and power analysis (JASA: Joint Analysis of Spectrum and Amplitude)			✓