SEDENTARY BEHAVIOUR AND PHYSICAL ACTIVITY IN ADULTS: MEASUREMENT AND BEHAVIOUR CHANGE

by

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Doctoral Thesis

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Abstract:

The increasing evidence of associations between sedentary behaviour and low levels of physical activity in adults and both immediate and long term health implications is of public health concern. There is a need to further our understanding of adult's health behaviours, to facilitate the development of behaviour change strategies promoting healthy behaviours. This thesis provides four independent but interlinked studies focusing on adult's sedentary behaviour and physical activity in the context of measurement and behaviour change.

Chapter 1 provides an introduction to the thesis where the scene is set for the placement of the studies in this thesis in the field of sedentary behaviour, physical activity, and measurement methods. Chapter 2 describes a systematic review of the relationship between sedentary behaviour and physical activity in adults. This systematic review is of primary importance as it was instrumental in shaping and informing the direction of the research described in later chapters. Chapter 3 describes a laboratory study investigating the measurement of energy expenditure during common sitting and standing tasks and also examines the 1.5 MET definition of sedentary behaviour. This study provides evidence that the 1.5 MET threshold for sedentary behaviours seems reasonable however some sitting-based activities may be classified as non-sedentary in people of differing weight status. This study raised some important questions on the validity of objective measurement devices for differentiating between sitting and standing postures. Thus, Chapter 4 of this thesis describes a laboratory study investigating the validity of the ActiGraph inclinometer algorithms for differentiating between sitting and standing postures. Chapter 5 is an intervention investigating sedentary behavior and physical activity compensation outside working hours in a sample of office workers exposed to sit-to-stand desks in the workplace.

This thesis found that light physical activity, especially standing, could be one of the most efficient and feasible behaviours to replace sedentary behaviour. Such findings add considerably to the existing literature. Targeting such facets of adults behaviour and specially office workers holds great potential for behaviour change strategies.

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Chapter 1

INTRODUCTION

1.1. Sedentary behaviour

Technological advances, societal influences and environmental attributes have significantly influenced the way we socialize, travel, work and shop resulting in substantial proportions of the day spent in sedentary pursuits, or sitting (Church et al, 2011; Clemes et al, 2014). Sedentary behaviour is defined as "any waking behaviour characterized by an energy expenditure of <1.5 METs while in a sitting or reclining posture" (Sedentary Behaviour Research Network, 2012, p. 540).This definition includes activities such as sitting, lying down, watching television, reading, screen-based entertainment and driving a vehicle (Pate et al, 2008). Many researchers use the term 'sedentary' to represent people who are physically inactive but being physically inactive is different to having high levels of sedentary behaviour, or sitting for long periods during the day. Being inactive is defined as not meeting the recommended levels of physical activity (Sedentary Behaviour Research Network, 2012, p.540), and people can be sufficiently active and sedentary, or inactive and sedentary as represented in Figure 1.1.There is evidence which has shown that being sedentary and being inactive are different constructs and have a differential effect on health factors such as cardiovascular disease (CVD), some types of cancer, diabetes and all-cause mortality (Wilmot et al, 2012; Tremblay et al, 2010; Hamilton et al, 2008; Lynch, 2010) This work suggests that we must study sedentary behaviour as a unique behaviour that is distinct from physical activity.

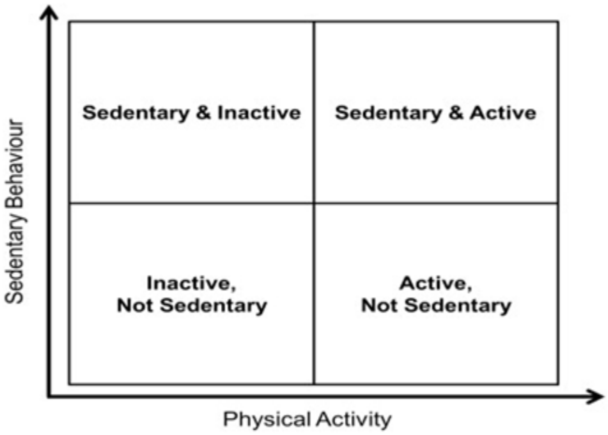

Figure 1.1 Sedentary behaviour and physical activity as distinct constructs. This figure categorises individuals into one of 4 groups: 1) those who are not sedentary (i.e. do not spend long periods of time sitting) but also not sufficiently active to meet physical activity guideline (inactive, non sedentary); 2) those who do sufficient physical activity to meet guidelines and also spend limited amounts of time sitting (active, not sedentary); 3) those who spend long periods of time sitting and also do insufficient amounts of physical activity to meet guidelines (sedentary and inactive); and 4) those who spend long periods of time sitting, but do sufficient levels of activity to meet guidelines (sedentary and active). (Saunders et al, 2014)

The prevalence of sedentary time has been reported in a number of international studies and the findings of these confirm that in most of the evaluated countries a large amount of adult's daily life is engaged in sedentary time (Bauman et al, 2011; Bennie et al, 2013; Milton et al, 2015). For example Milton et al. (2015) examined the prevalence of sedentary time in 27 European countries and the results showed that the average daily time reported sitting was 316 minutes per day in 2002, 312 minutes per day in 2005, and 292 minutes per day in 2013 (Milton et al, 2015). Another study by Bennie et al. (2013) across 32 European countries showed that average weekday time spent sitting in evaluated countries was 309 minutes per day (Bennie et al, 2013). Also a study by Bauman et al. (2011) across 20 countries showed that average sitting time was 300 minutes per day (Bauman et al, 2011). These studies measured sedentary time from predominantly developed countries, the findings therefore cannot be generalised to lower-income nations. Furthermore, whilst these papers report data from multiple countries, limited data have been presented in the papers to describe between country differences and data are reported without taking into consideration different ethnicities, cultural groups, and social, economic and demographic groups. In all studies, data were collected via self-report questionnaires which can be prone to recall errors and/or bias. The IPAQ questionnaire was predominately used in all studies, which has been shown to underestimate sedentary behaviour and has poor validity (Atkin et al, 2012).

Over the past five decades there has been a significant reduction in the percent of people who are employed in physically active occupations but there has been a growth in the percent of employees in more sedentary jobs (Church et al, 2011) (Figure 1.2). These 'sedentary' occupations typically involve sitting for long periods of time at an office desk or driving a vehicle, and evidence suggests that adults in these occupations spend the majority of their working day sitting. For example, a recent study in office workers showed that adults had higher levels of sedentary behaviour (68% vs 60%) and lower levels of light-physical activity (28% vs 36%) on working days compared to non-working days, and that these adults spent 71% of their working days sedentary (Clemes et al, 2014a). In comparison to the international epidemiological studies mentioned above, research specifically targeting office workers has indicated that office workers are sedentary for approximately 10 hours/day (Clemes et al., 2014a, b, 2015). This shift towards sedentary occupations may have serious implications for health and well-being.

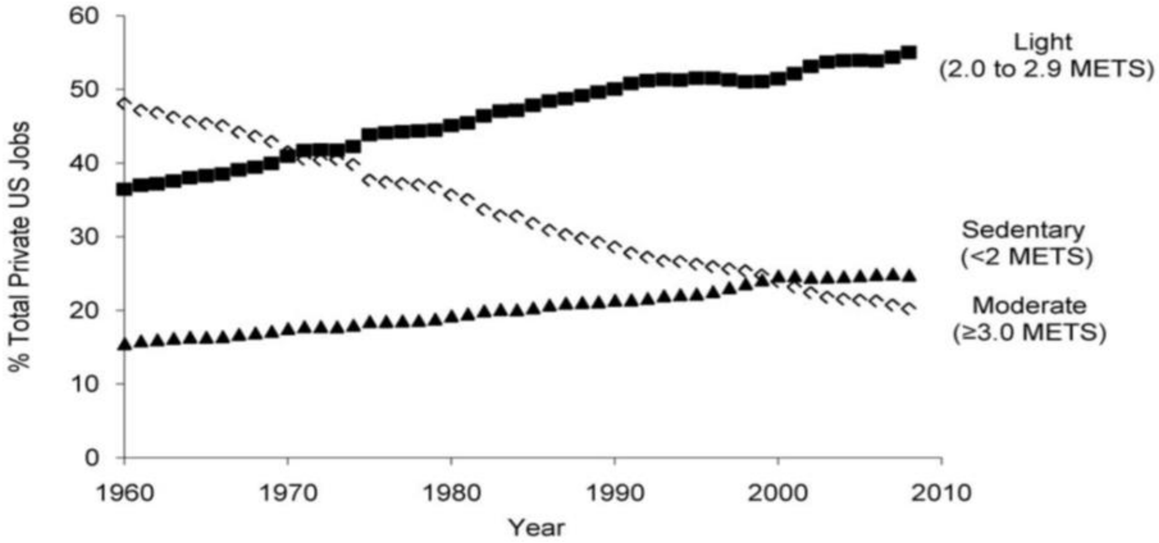

Figure1.2 Trends in the prevalence of sedentary, light and moderate intensity occupations from 1960 to 2008 (Church et al, 2011).

1.2. Sedentary behaviour and health

The case for promoting reductions in sedentary behaviour in adults is underpinned by the growing body of evidence suggesting that sedentary behaviour is associated with immediate and long term negative health effects. A growing body of epidemiological evidence has linked sedentary behavior to health risks including an increased risk of type 2 diabetes (Proper et al,2011; van Uffelen et al,2010; Yancey et al, 2004), the metabolic syndrome (Edwardson et al, 2012; Florez et al; Ford et al, 2005), cancer (Dallal et al, 2012; Lynch et al, 2010; Matthews et al, 2002), obesity (Thorp et al, 2005; Chau et al, 2012), cardiometabolic dysfunction (Chau et al, 2013; Craig et al, 2003; Tomaz et al, 2014), and all-cause and CVD mortality (Dunstan et al, 2010; Proper et al,2011; van Uffelen et al,2010).

The associations between sedentary behaviour and health highlighted above have been shown to be at least partially independent of moderate-to-vigorous physical activity (MVPA). For example, a meta-analysis performed on 18 studies by Wilmot et al. (2012) revealed that compared to those with the lowest time spent sedentary, those with the highest sedentary times had a 112% increased risk of diabetes, a 147% increased risk of a cardiovascular event, a 90% increased risk of cardiovascular mortality and a 49% increased risk of all-cause mortality. Physical activity was included as a controlling variable in the majority of studies included in this review, and the authors therefore concluded that the deleterious effects of sedentary behaviour on health appear to be independent of physical activity. In a recent meta-analyses on 47 studies performed by Biswas et al. (2015) it was observed that, compared to those with the lowest amount of sedentary time, those with the highest amount of time spent sedentary had a 24% increased risk of all-cause mortality, a 18% increased risk of cardiovascular disease mortality, a 14% increased risk of cardiovascular disease incidence, a 17% increased risk of cancer mortality, a 13% increased risk of cancer incidence and a 81% increased risk of type 2 diabetes incidence. Like the Wilmot et al. (2012) review, this updated meta-analysis also concluded that the detrimental effects of sedentary behaviour on health appear to be independent of physical activity.

Furthermore, recent reviews have noted that there is an inverse association between some sedentary behaviors (mostly TV viewing or screen time) and leisure-time physical activity in adults (Mansoubi et al, 2014; Rhodes et al, 2012), providing evidence for time displacement. Conversely the amount of light-intensity physical activity accumulated, for example during non-exercise related standing activities, has been linked to improved metabolic health (Alkhajah et al, 2012). Importantly these observations are often independent of MVPA and BMI (Thompson et al, 2011). Moreover, breaking long periods of sitting could be a promising avenue for interventions given evidence that increasing the number of breaks in sitting time per day (e.g. going from sitting to standing) is associated with health benefits such as preventing diabetes and other chronic diseases (Gilson et al, 2012; Swartz et al, 2011).

Whilst the evidence linking sedentary behaviour to adverse health outcomes is increasing (Wilmot et al., 2012; Biswas et al., 2015), our knowledge of the precise mechanisms which relate sedentary behaviour to poor health are currently poorly understood. Research has begun to explore potential mechanisms, with early research in this area focusing on the activity of the enzyme lipoprotein lipase (LPL). It has been suggested by Hamilton et al.

(2007) that the absence of activity happening within the large skeletal muscles in the legs, back, and trunk during sitting affects cellular processes within these muscles responsible for metabolic risk factors for disease (this concept has been termed ‘inactivity physiology’) (Hamilton et al. 2007). Evidence to support this suggestion has been provided from studies examining the specific role of local contractile activity in postural skeletal muscles on LPL activity in rats. LPL is a protein important in the control of plasma triglyceride catabolism, high-density lipoprotein (HDL) cholesterol, and other metabolic risk factors (Hamilton et al. 2007). In response to inactivity (immobilisation of the hind limbs of rats), a profound reduction in LPL activity (≥10-fold) was observed, accompanied by significant decreases in the clearance of plasma triglycerides by skeletal muscle and reductions in plasma HDL cholesterol concentration. This initial research has led to the hypothesis that signals harming the human body during prolonged sitting are not always the same signals which boost health during bouts of structured exercise (Hamilton et al. 2007). However, further research is required to ascertain whether similar changes in LPL activity are observed in studies with humans.

Lynch et al., (2010) have evaluated potential mechanisms that link sedentary behaviour to cancer risk and reported that prolonged time spent sedentary can increase the levels of adipose tissue which in turn can have an effect on the levels of circulating sex hormones, lead to insulin resistance, and chronic inflammation. It was suggested that these biological changes can increase the risk of some cancers such as colon, breast, endometrial, kidney, and esophageal cancers (Lynch et al, 2010).

Based on the links between sedentary behaviour and health, it has been suggested that the physical activity paradigm should incorporate sedentary behaviour (Katzmarzyk, 2010), and physical activity initiatives and recommendations should adapt accordingly (Hamilton et al, 2008; Yates et al, 2011). To further support this effort, a new conceptual framework has emerged, redefining physical activity and demonstrating the complex, multi-dimensional aspects of physical activity and sedentary behaviour as mechanisms of human movement (Petee Gabriel et al, 2010; 2012) (Figure 1.3). The research conducted within this thesis addresses a number of topics highlighted in the conceptual framework displayed in Figure 1.3. In the current thesis the relationship between physical activity and sedentary behaviour has been evaluated through a systematic review in Chapter 2. Energy expenditure and metabolic rate have been measured during 13 different lifestyle activities involving seated and standing postures in Chapter 3. The validity of a sedentary behaviour and physical activity measurement device (the ActiGraph) has been checked in Chapter 4 and Chapter 5 presents a study examining an intervention designed to reduce sedentary behaviour in the workplace environment. Physical fitness is not evaluated in the current thesis.

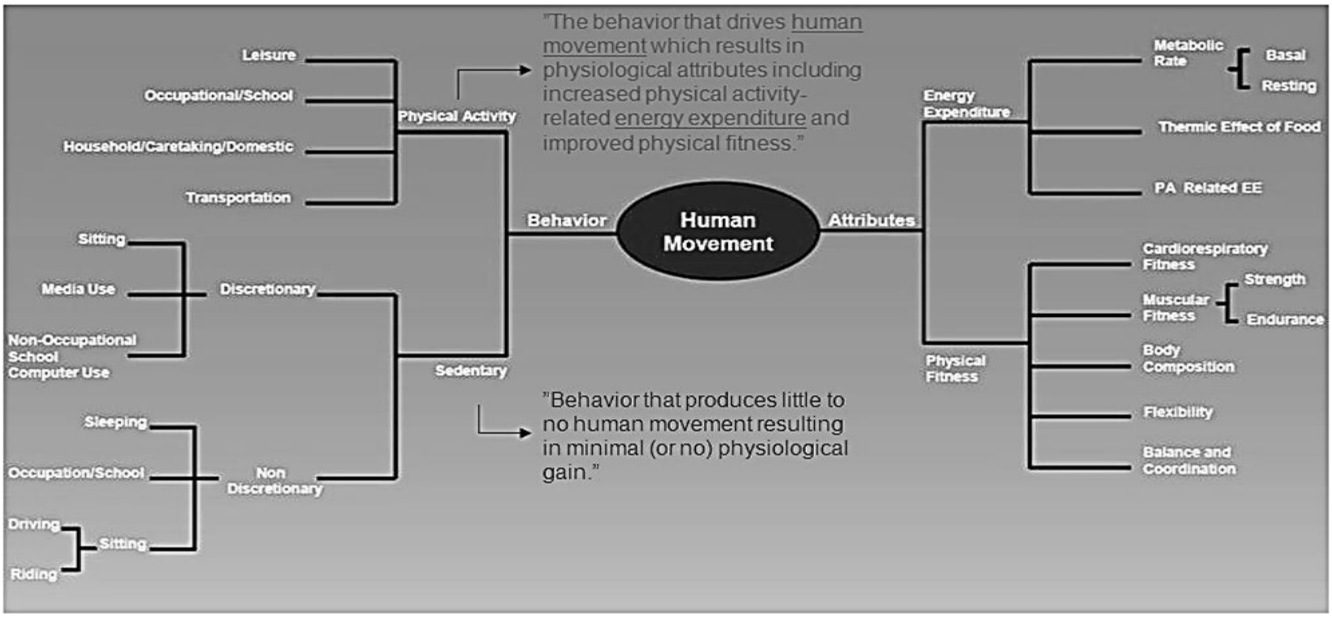

Figure 1.3: A novel conceptual framework for physical activity and sedentary behaviour as 'a complex, multidimensional behaviour' (Figure from Pettee-Gabriel and Morrow 2010)

1.3. Physical Activity and Health in Adults

According to the national physical activity guidelines and World Health Organisation, adults (19-64 years) should accumulate at least 150 minutes (2 hours and 30 minutes) of moderate-intensity aerobic activity such as cycling or fast walking every week, and muscle-strengthening activities on 2 or more days a week that work all major muscle groups (legs, hips, back, abdomen, chest, shoulders and arms). Or 75 minutes (1 hour and 15 minutes) of vigorous-intensity aerobic activity such as running or a game of singles tennis every week, and muscle-strengthening activities on 2 or more days a week that work all major muscle groups. Or instead an equivalent mix of moderate- and vigorous-intensity aerobic activity every week (for example; 30-minute runs plus 30 minutes of fast walking), and muscle-strengthening activities on 2 or more days a week that work all major muscle groups (Chief Medical Officers of England, Scotland, Wales & Northern Ireland, 2011). At present these guidelines are generic and apply to all adults, regardless of ethnicity, culture, sex, and socio-demographic background.

Over the past few decades, urbanisation and mechanisation has led to changes in daily lifestyles and behaviour to the extent that physical activity has been engineered and socialised out of the norm, and it is almost easier to choose to be inactive. Indeed, many people are not accruing the recommended amount of physical activity to benefit health. According to a recently released statistic by the British Heart Foundation (BHF), in 2013, 37% of men and only 23% of women were physically active on five or more days in a week (Townsend et al, 2015). Also a statement from the World Health Organisation (WHO) showed that only around a third of adults aged 15 years or older were physically active in 2008 (male 28% and female 34%) and that physical inactivity is a significant contributor to the 3.2 million deaths each year globally (WHO, 2015).

A recent meta-analysis including data from 71 cohort studies showed that meeting current WHO physical activity guidelines had the potential to decrease cancer mortality in general populations and cancer survivors (Li et al, 2015). Also another meta-analysis showed that physical activity is associated with reduced risk of meningioma (Niedermaier et al, 2015). Evidence has shown that MVPA is associated with reducing a number of metabolic and cardiometabolic risk factors. For example, Hamer et al, (2014) showed that time in MVPA was associated with reduced levels of cholesterol, triglycerides, HbA1c, and BMI. Another study by Henson et al, (2013) showed that total levels of physical activity and MVPA have an inverse association with adiposity. Also a study by Herrmann et al, (2013) demonstrated that total physical activity and MVPA were inversely associated with baseline waist circumference, systolic blood pressure, serum levels of fasting insulin and also triglycerides.

A review by Warburton et al. (2006) has summarised the possible mechanisms underlying the health benefits of physical activity. Biological mechanisms which lead to the prevention of chronic diseases through regular physical activity include improved levels of physical fitness and reduced risk of obesity due to increased levels of energy expenditure. Physical activity has been shown to have positive effects on metabolic heath factors such as reducing triglyceride levels, increasing high density lipoprotein [HDL] cholesterol levels and decreasing the low-density lipoprotein [LDL]-to-HDL ratios (Warburton et al., 2006). It has also been observed that regular physical activity improves glucose homeostasis and insulin sensitivity through increased glucose uptake by working muscles. Physical activity also aids the control of blood pressure levels, improves autonomic tone, reduces systemic inflammation, decreases blood coagulation, improves coronary blood flow, and augments cardiac function and enhances endothelial function (Warburton et al., 2006). It has been shown that chronic inflammation can increase the circulating levels of inflammatory mediators such as C-reactive protein, which is directly related to heart disease morbidity and mortality (Warburton et al., 2006).

Previously researchers believed that only MVPA could have health benefits, but more recent evidence has shown that time spent in light physical activity could be beneficial for health (Healy et al. 2007; 2008; Dunstan et al 2012; Carson et al. 2013). For example, objectively measured light intensity physical activity has been shown to be positively associated with blood glucose levels in adults (Healy et al, 2007). Another study by Carson et al. (2013) showed that light intensity activity was associated with lower diastolic blood pressure and higher HDL-cholesterol in adults. A recent study by Khoja et al. (2015) showed that very light, light and moderate PA were inversely associated with most cardiovascular risk factors. Also this study showed that associations between PA and cardiovascular risk markers were equal or stronger at very light and light intensities of activity rather than at moderate intensity physical activity (Khoja et al, 2015). Research has also shown that breaking up sitting time with 2 minutes of light- or moderate-intensity walking reduces glucose and insulin levels in overweight/obese adult participants (Dunstan et al, 2012).

Evidence has shown that sedentary behaviour is inversely associated with time spent in light physical activity, such as standing and light ambulation (Healy et al, 2008, Mansoubi et al, 2014). Hence, sedentary time seems not to displace MVPA but, it could displace levels of light-intensity physical activity. A recent study which evaluated hourly patterns of sedentary behaviour and light intensity physical activity demonstrated that the two behaviours displayed an inverse pattern during waking hours (Clemes et al, 2014a). Also short bouts of physical activity can be used to break up sedentary time. Furthermore, compared to sitting for five hours, light and moderate intensity walking breaks every 20 min reduces resting blood pressure, though no differences are detected in heart rate (HR) (Larsen et al, 2014).

1.4. Measurement of Sedentary Behaviour and Physical Activity

Due to the increasing evidence highlighting sedentary behaviour as an independent harmful factor for a number of adverse health outcomes (Edwardson et al, 2012; Wilmot et al, 2012; Katzmarzyk et at, 2009), there have been calls for the explicit measurement of sedentary behaviour, in addition to the measurement of physical activity, in surveillance studies (Owen et al, 2000; Rosenberg et al, 2008). Many studies have utilised subjective measurement tools, such as questionnaires, for assessing sedentary time and these have focused on total sitting time (Wilmot et al, 2012; Katzmarzyk et at, 2009) or leisure time sedentary behaviours (Kohl et al, 2012), with less attention given to other aspects of sitting time and sedentary behaviours such as sitting at work or sitting in vehicles during daily transport. Self-report methods, such as diaries, although used less frequently in epidemiological studies to date, have also been used (Atkin et al, 2012). The International Physical Activity Questionnaire (IPAQ) is frequently used to assess total sitting time in epidemiological research (Bauman et al, 2011). However, studies have shown that total daily sitting time is underestimated when using such single-item measures (Atkin et al, 2012), and this tool does not allow for the differentiation between different types of sedentary behaviours and sitting time to achieve an in-depth picture of sitting time (Miller et al, 2004; Marshal et al 2010; Salmon et al, 2003). Recently, researchers have used domain-specific sitting time questionnaires (for example, Marshall et al, 2010) to provide a more detailed understanding of daily sitting times. These questionnaires have the advantage of providing some contextual information on where sedentary behaviours are taking place. Total daily sitting times calculated from these questionnaires have also been reported to provide a more valid estimate of daily sedentary times when compared to objectives measures (Marshal et al, 2010, Clemes et al., 2012). Self-report methods such as diaries, self-administered questionnaires, in-person and telephone interviews also are being used less frequently in epidemiological research (Atkin et al, 2012; Marshall et al, 2011; Clark et al, 2009).

Measuring physical activity and sedentary behaviour has recently become more accessible with the use of accelerometers and inclinometers, small devices that can record activities and body position over extended periods of time in non-laboratory environments (e.g. at home or work) (Healy et al, 2008; Hagstromer, 2007). Accelerometers have increasingly been used to provide objective measurements of physical activity, especially in adults, because these devices are easy to use, provide numerical data and are reasonably priced (Healy et al, 2008; Mathew et al, 2008). Accelerometers are also increasingly being used as an objective measure of sedentary behaviour (Rowlands et al, 2007; Pate et al, 2010; Oliver et al, 2007).

One of the most popular accelerometers for the measurement of physical activity is the ActiGraph, which is worn on the hip and integrates a tri-axial sensor to measure acceleration in three axes from 0.05-2.5 g at sampling rates up to 100 Hz, using cut points with traditionally a cut-point of <100 counts per minute (cpm) applied to estimate sedentary time. Although much progress has been made in the assessment of physical activity with accelerometers, there are several limitations when using accelerometers to assess sedentary time. Accelerometers traditionally do not measure posture and sedentary time is purely estimated through a lack of movement counts. As a result, time spent standing still could be misclassified as sedentary (Atkin et al., 2012). Recently newer models of the ActiGraph contain an inclinometer algorithm which classifies the wearers posture into sitting, lying, standing or device off. However, further research is needed to examine the validity of this additional feature (Carr et al, 2012).

Another popular device for the academic measurement of physical activity and especially sedentary behaviour is the activPAL, which is a small inclinometer worn on the front of the thigh. The activPAL has been validated for use with adults as a measure of physical activity and body posture (Ryan et al,2006; Busse et al, 2009; Dahlgren et al, 2010; Godfrey et al, 2007; Oliver et al, 2011; Harrington, 2011; Grant et al, 2006). With this inclinometer device researchers are able to objectively measure time spent sitting, lying, standing and walking, sit-to-stand transitions and step counts (Ryan et al, 2006; Grant et al, 2006). The activPAL is able to detect time in different postures because of its placement on the thigh.

As described above, sedentary behaviour (and physical activity) have traditionally been assessed using self-report measures. Whilst these measures are inexpensive and feasible for use across large samples, these measures can be limited due to reduced levels of validity. Figure 1.4 presents a range of measurement tools on a continuum according to their levels of ease of use and validity. Generally, the measures (such as self-report) which are the simplest to use have the lowest levels of validity. The most accurate measures of physical activity energy expenditure are found towards the top end of the continuum. Indirect calorimetry is a method that provides a precise assessment of energy expenditure via the assessment of carbon dioxide production and oxygen consumption during rest and steady-state exercise. Indirect calorimetry can be assessed through open- and closed-circuit methods and technology within this area has advanced from the early Douglas bag method to fully-portable, electronic tools such as the Cortex calorimeter which provides continual and instantaneous breath-by-breath values of pulmonary gas exchange (Levin, 2005). Whilst the most accurate tools to assess energy expenditure, like calorimetry and doubly-labelled water provide a valid measure of energy expenditure, they do not directly measure physical activity or sedentary behaviour, only the energy cost of specific activities. Traditionally, the more practical devices for the assessment of free-living physical activity (and more recently sedentary behaviour) such as accelerometers and self-report tools, have been validated against these criterion measures. In the current thesis, indirect calorimetry is used to assess the energy cost of a range of sitting and standing postures in Chapter 3. Direct observation, another highly accurate measure of physical activity and sedentary behaviour (Figure 1. 4), is used in Chapter 4 in this thesis as a tool to validate the ActiGraph inclinometer algorithm for measuring posture. Chapter 5 uses the more practical tools, an accelerometer and inclinometer, to assess physical activity and sedentary behaviour in free-living participants completing an intervention designed to reduce sedentary time in the workplace.

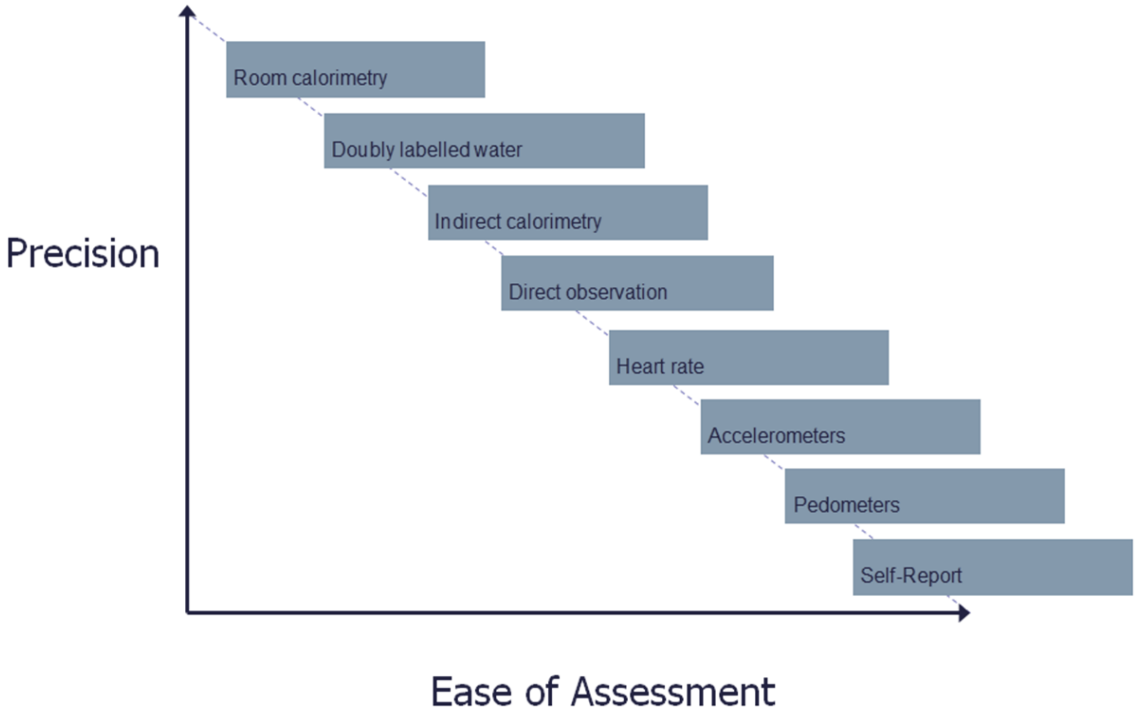

Figure1.4. Different methods of physical activity assessment. This figure shows the range of different methods of physical activity and energy expenditure assessment. According to this

Figure, easier and cheaper measurement methods are less precise than more expensive tools, which are also more complex to use. Methods such as room calorimetry, doubly labelled water, indirect calorimetry and direct observation are often used as criterion measures when validating estimates of energy expenditure derived from more practical physical activity and sedentary behaviour monitoring tools.

1.5. Interventions to reduce sedentary behaviour

Most adults usually spend time sitting in three different domains including: a) sitting in the workplace, b) in their leisure time such as sitting at home or watching television and c) during transportation. Many adults in the UK are employed within sedentary occupations such as office work. For example a UK based study, with 72 participants showed that approximately 65% of participants working hours were spent sedentary (Clemes et al, 2014a). The majority of office workers' time is spent in sitting activities (Gilson et al, 2012). A study by Clemes et al (2015) with 4436 participants showed that participants' total daily sitting times were greater on workdays than non-workdays. Also this study showed that office workers typically sit for >10 hours/day, with over half of their total daily sitting time occurring in the workplace (Clemes et al, 2015). According to a recent consensus statement by experts, office workers should aim to stand or move around for at least 2 hours per day and it preferably should increase to 4 hours per day (Buckley et al, 2015). Therefore, the workplace represents a promising environment in which to undertake interventions to reduce sitting time. A study by De Cocker et al, (2015) has evaluated different intervention strategies, methods and barriers for reducing sitting in the workplace. This study suggested a range of intervention methods for working hours such as; standing during phone calls, standing in meetings, use of standing desks, etc. Also this study introduced several barriers such as productivity concerns, inconvenience, and the routine habit of sitting (De Cocker et al, 2015). Therefore it is important that interventions which target reductions in sitting and increases in physical activity do not affect the office workers' performance and productivity.

Using standing desks to reduce or break up sedentary time could be beneficial for office workers. For example a recent systematic review showed that using standing and/or treadmill desks could be helpful for breaking up sedentary time and lead to improved health (MacEwen et al, 2015). A health intervention study for office workers showed that a health protection/health promotion intervention using an activity permissive workstation was associated with improvements in health variables such as cardiometabolic biomarkers (weight, total fat mass, resting heart rate, body fat percentage) and work productivity outcomes (concentration at work and absent days from work because of health problems) (Carr et all, 2015). A study using sit to stand workstations showed that the Intervention successfully reduced objectively measured time spent sitting at work by 73 minutes per working day and increased standing time at work by 65 minutes per working day (Chau et al, 2014). A recent systematic review by Neuhaus et al, (2015) evaluated the evidence on activity-permissive workstations for reducing occupational sedentary time. This study showed that activity permissive workstations could be an effective solution for reducing occupational sedentary time, without effecting an office workers work performance (Neuhaus et al, 2015). Hence according to the recent evidence, designing interventions such as; using standing desks, treadmill desks or active office planning in the workplace seems to be a feasible way of reducing sitting time and improving office workers health.

1.6 Overview and aims of thesis

This thesis aims to further our understanding of sedentary behaviour and physical activity in adults in the context of measurement and behaviour change. This thesis contains four studies, detailing original research. Chapter 2 presents a systematic review investigating the relationship between sedentary behaviour and physical activity in adults. There is a meta-analysis in children and adolescents which has shown a small but significant inverse relationship between sedentary time and physical activity (Pearson et al, 2014), however, the relationship between sedentary behaviour and different physical activity intensities has received limited attention in adults. Understanding the presence of any association between sedentary behaviour and physical activity would help identify how definite behaviours could displace others and such evidence could help researchers to develop effective interventions to decrease sedentary behaviour in adults. In the context of this thesis, this systematic review was instrumental in shaping and informing the direction of the research described in later chapters.

Building on the findings and conclusions from Chapter 2, Chapter 3 of this thesis broadens the investigation of sedentary behaviour by examining the utility of the current 1.5 MET definition of sedentary behaviour. Chapter 4 broadens the investigation of the measurement of sedentary behaviour by examining the validity of the ActiGraph inclinometer algorithm for detecting sitting and standing postures.

The findings from the systematic review detailed in chapter 2, as well as aspects of the results from chapters 3 and 4, led to the development of a pilot trial examining sedentary behavior and physical activity compensation outside working hours in a sample of office workers exposed to sit-to-stand desks in the workplace. The results of this intervention study are detailed in Chapter 5. Each chapter contributes to the overall structure of the thesis and builds on the chapter before it. However, each chapter could also be read in isolation. The studies presented in this thesis have been widely disseminated through conference presentations and published papers (see appendix 1.1 & 1.2).

Chapter 2

The Relationship between Sedentary Behaviour and Physical Activity in Adults: A Systematic Review

This chapter presents a systematic review of the literature. In this chapter the associations between sedentary behaviour (SB) and physical activity (PA) among adults aged 18-60 years has been evaluated. Key findings and conclusions of this systematic review were a significant influence on the work detailed in later chapters.

The review detailed in this Chapter is published in Preventive Medicine (Mansoubi M, Pearson N, Biddle SJH, Clemes SA. (2014), The Relationship between Sedentary Behaviour and Physical Activity in Adults: A Systematic Review. Preventive Medicine, 69:28-35), and was presented as an oral presentation at the 4th International Congress on Physical Activity and Public Health, in Sydney, Australia in October 2012..

The Relationship between Sedentary Behaviour and Physical Activity in Adults: A Systematic Review

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2.1 Abstract:

The purpose of this study was to ascertain, through a systematic review, the associations between sedentary behaviour (SB) and physical activity (PA) among adults aged 18-60 years. Studies published in English up to and including June 2013 were located from computerized and manual searches. Studies reporting on at least one measure of SB and an association with one measure of PA were included. 26 studies met the inclusion criteria. Six studies examined associations between SB and PA prospectively, and 20 were cross-sectional. The most commonly assessed subtype of sedentary behaviours were television viewing (11 studies), total sedentary time (10), total sitting time (4), General screen time (3) and occupational sedentary time (2). All studied types of SB were associated with lower levels of PA in adults. Findings of this review suggest inverse associations between SB and PA were weak to moderate. Objective monitoring studies reported larger negative associations between SB and light intensity activity. Current evidence, though limited, supports the notion that sedentary behavior displaces light intensity activity.

Key words: Sedentary behaviour, Physical Activity, Adults

2.2 Introduction

Over the past few decades, the way in which we live our daily lives has changed dramatically. Technological advances, societal influences and environmental attributes have significantly influenced the way we spend our leisure, work and travel time, and how we live our lives at home and in our communities, resulting in substantial proportions of the day spent in sedentary pursuits, or sitting. For example, estimates from objective monitoring in the US show that adults spend 7-9 hours of their working day sedentary (Matthews et al, 2008). Sedentary behaviour has been defined as "any waking behaviour characterised by an energy expenditure ≤1.5 METs while in a sitting or reclining posture" (SBRN, 2012, p. 540). This definition includes activities such as sitting, lying down, watching television, reading, screen-based entertainment and driving a vehicle (Pate et al, 2008). A growing body of epidemiological evidence has linked sedentary behaviour to health risks including an increased risk of type 2 diabetes (Proper et al, 2011; Van Uffelen et al, 2010; Wilmot et al 2012), metabolic syndrome (Edwardson et al, 2012), cancer (Lynch 2010, Schmid et al, 2014), and all-cause and CVD mortality (Proper et al, 2011; Van Uffelen et al, 2010; Wilmot et al, 2012; Chau et al, 2013). These associations have been shown to be at least partially independent of levels of moderate-to-vigorous physical activity (MVPA), suggesting that sedentary behaviours have the potential to influence risk of disease, independent of physical activity levels typically recommended for good health.

Traditionally it was believed that only MVPA was beneficial to health, however recent studies employing objective monitoring have shown that time spent in light physical activity may also have health benefits (Healy et al. 2007; 2008; Dunstan et al 2012; Carson et al. 2013). For example, Healy et al. (2007) observed that, after adjustment for confounders, objectively measured light intensity physical activity was beneficially associated with blood glucose levels in a sample of adults. The temporal patterning of behaviours suggests that MVPA and some single sedentary behaviours (e.g. TV viewing and / or computer use) may compete for time at certain periods during the day, but over 24 h there appears to be time for both behaviours to co-exist (Biddle et al, 2009). However, in contrast, population level studies have shown that sedentary behaviour is strongly and inversely associated with time spent in light physical activity, such as standing and light ambulation (Healy et al, 2008). Therefore, on a population level, sedentary time appears not to displace MVPA but, instead, may displace levels of light-intensity physical activity. Given that light physical activity will include standing and light ambulation, and these are the kinds of behaviours likely to be undertaken when not sitting, it is logical to expect a relationship between sedentary behavior and light activity. For example, a recent study examining hourly patterns of sedentary behaviour and light intensity physical activity showed that the two behaviours displayed an inverse pattern throughout waking hours (Clemes et al, 2014).

These arguments may assist researchers in better understanding the nature of the displacement hypothesis – a notion suggesting that time in sedentary behaviour is displacing physical activity (Mutz et al, 1993). A recent meta-analysis conducted in children and adolescents has shown a small but significant inverse association between sedentary time and physical activity (Pearson et al. 2014), however associations between sedentary behaviour and all intensities of physical activity have received limited attention in adults. Understanding the presence of any association between sedentary behaviour and physical activity will provide insight into how certain behaviours may displace others and could aid in the development of effective interventions to reduce sedentary behaviour in adults. It is opportune, therefore, to review whether sedentary behaviours are associated with physical activity in adults. Therefore the aim of this study was to systematically review the literature to determine the nature and strength of the relationship between sedentary behaviour and different types and intensities of physical activity.

2.3 Methods

2.3.1 Search Strategy

Potential studies were located from computerized (PubMed, Science Direct, Cochrane Library and Web of Knowledge) and manual searches of personal files and review articles. Search strategies were built around four groups of key words: sedentary behaviour (e.g. sitting, lying, seated, TV viewing, computers), physical activity (e.g. exercise, light physical activity, MVPA, walking, sports, cycling, active travel, active transport), sample type (e.g. healthy adults, young adults, middle age adults) and study type (e.g. cohort, prospective, cross-sectional).

2.3.2 Inclusion and exclusion criteria

For inclusion, studies were required to (1) include adults aged 18 years and over as participants of the study at baseline; (2) have a point estimate (mean) of at least one aspect of sedentary behaviour (Such as; TV viewing, General screen time, sitting at work, etc..); (3) have a point estimate (mean) of at least one aspect of physical activity (such as; walking, exercise, biking, etc..); (4) be observational and report on the statistical association between at least one aspect of sedentary behaviour and one aspect of physical activity; (5) be published in peer reviewed journals in the English language; (6) be published up to and including June 2013.

2.3.3 Identification of relevant articles

Potentially relevant articles were selected by (1) screening the titles; (2) screening the abstracts; and (3) if abstracts were not available or did not provide sufficient data, the entire article was retrieved and screened to determine whether it met the inclusion criteria.

2.3.4 Data extraction and coding

Data were extracted on standardized forms developed for this review. This information is summarized in Table 2.1. Identified sedentary and physically active behaviours were tabulated to highlight the state of the literature for the associations between sedentary behaviour and physical activity among adults (see Table 2.2). Associations between sedentary behaviours and physical activities in adults are reported as positive (+), inverse (-) or no association (0).

2.3.5 Strength of association

The strength of association was graded as none, small, medium, or large for data using Pearson correlation (r), standardized regression coefficient (β) (Sawyer et al. 2004), multiple regression (R, partial R, R^2, partial R^2), Cohen's *d* effect size, and odds ratio (OR) (Allen et al. 2008) (See Appendix 2.1 for the full details).

2.3.6 Study Quality

Methodological quality of the included articles was assessed using a 13-item scale, adapted from previously reported scales (Craggs et al. 2011; Chin A Paw et al. 2011; Uijtdewilligen et al. 2011), and used in a recent systematic review and meta-analysis (Pearson et al. 2014). The scale focused on quality of reporting (3-items, with an additional item for prospective studies) and study quality (validity/precision: 8-items with one additional item for prospective studies). Items were marked "positive," "negative," or "not sufficiently described." A total score for quality of reporting and for study quality respectively was calculated by adding all positive scores for each assessed study. The scoring system placed an emphasis on positive scores. Negative and not sufficiently described items were treated equally in that no points were scored for either (see Appendix 2.2). For analytical purposes, study quality scores (ranging from 0 to 8 for cross-sectional studies and from 0 to 9 for prospective studies) were converted into a percentage to enable comparisons in quality across the different study types, with higher percentages meaning higher quality. Based on their study quality score, papers were categorised into low and high quality studies using a medium split.

2.4 Results

The literature searches yielded 17,499 titles of potentially relevant articles, 26 of which met the inclusion criteria and were included in this review (see Figure 2.1). The included studies are summarised in Table 2.1. Twenty studies examined associations between sedentary behaviour and physical activity cross-sectionally, and 6 examined associations prospectively. (For ease of reading and space, references for studies in the results are numbered as in Table 2.1).

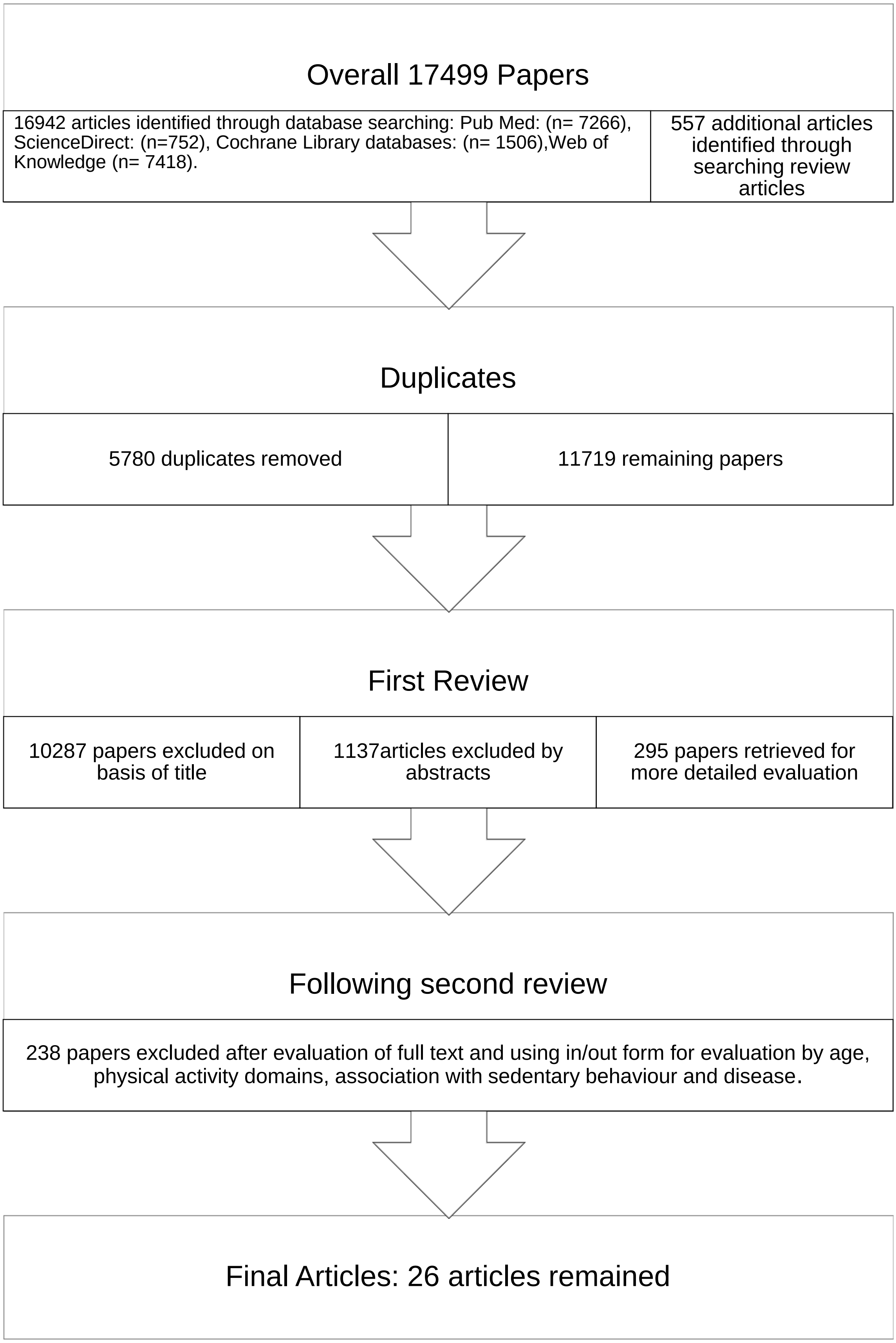

Figure 2.1: Systematic review flow diagram.

2.4.1 Study Quality

All 20 cross-sectional studies were evaluated for study quality and scores ranged from 3/8 to 8/8 (mean score: 68%). Among the 6 prospective studies, study quality scores ranged from 3/9 to 8/9 (mean: 70%) (see Table 2.1). Across all studies, papers with a study quality score equal to or above 75% were classified as high quality (n = 15).

Table 2.1. Characteristics of included studies, along with the results of the study quality assessment for each study

Study	Sample	Measure SB	Measure PA	Association	Study* quality
1- Kronenberg 2000 (USA)	1778 participants, women mean age 49± 13; men mean age 48± 14 years	Self-reported television viewing	Questionnaires on physical activity were based on those used in the CARDIA study with minor modifications.	Weak inverse associations between total LTPA and TV viewing in women (Spearman r =-0.084, p=0.009) and men (r= -0.115, p=0.001).	4 / 8 50%
2- Jacoby 2003 (Peru)	1176 families, men mean age 42.1± 9.0; women mean age 37.5 ± 7.6 years	Self-reported television viewing	Self-reported physical activity using questions adapted from the Health Insurance Plan of New York (HIP) Activity Questionnaire.	Significant positive associations between hours reported sitting, watching TV and physical inactivity in men and women (p <0.001).	3 / 8 37.5%
3- Zhang 2003 (China)	254 females with ovarian cancer and 652 healthy female controls, aged 45 - 65 years.	Self-reported domain-specific sitting time (work, travel, TV meals, other)	Self-reported leisure-time and occupational physical activity	The association with sedentary behaviours was weak and varied across the three intensity levels of physical activity. Total sitting time was significantly associated with strenuous sport (r = 0.31), vigorous work (r = -0.44), and moderate PA (r = -0.41). No associations between TV viewing	6 / 8 75%

				and PA, or sitting at work and strenuous sport.	
4- McCormack 2004 (Australia)	1803 participants, aged 18 - 59 years	Self-reported television viewing via interview	Self-reported time spent walking, and time in light, moderate and vigorous intensity physical activity	Participation in recommended levels of vigorous-intensity PA was associated with a reduced likelihood of watching television more than 10 hours per/week (OR = 0.71).	3 / 8 37.5%
5- Buckworth 2004 (USA)	493 college students, mean age 21±4.0 years	Self-reported time spent watching television, using a computer, and studying	Self-reported physical activity using the CARDIA Physical Activity History questionnaire	For males, computer use was inversely associated with MVPA. No associations observed for males between TV viewing and PA. In females, TV viewing was inversely associated with PA, no associations were seen with computer use and PA.	3 / 8 37.5%
6- Martınez-Gonzalez (2005) Spain	40 obese women, aged 20-50 years	Self-reported television viewing, computer use, driving, socialising. Values combined to provide total sitting time	RT3 accelerometer	Inverse association between total sedentary time and energy expenditure estimated using the RT3 accelerometer (Spearman r = -0.42, p<0.01).	6 / 8 75%
7- Bennet 2006 (USA)	486 participants, aged >18 years	Self-reported television viewing	Pedometer step counts (Yamax SW-200)	Each hour of TV viewing was associated with 144 fewer steps/day. For each hour of TV viewing, there was a 16%	6 / 8 75%

				decrease in the likelihood of accumulating 10000 steps/day.	
8- Oppert 2006 (France)	213 men, mean age 44±5 years; 192 women, mean age 42±4 years	Self-reported screen time and reading	Self-reported leisure-time and occupational physical activity, using the Modifiable Activity Questionnaire	Reading was inversely associated with occupational PA (r = -0.26, p<0.001) in men, no association seen in women. In women, reading was positively associated (r = 0.36, p<0.001) with LTPA, no association seen in men.	6 / 8 75%
9- Sugiyama 2007 (Australia)	2650 participants, aged 20-65 years	Self-reported television viewing	Leisure-time physical activity, from the IPAQ Long.	A significant negative association was found between TV time and LTPA in women but not in men (statistical values not given).	5 / 8 62.5%
10- Healy 2008 (Australia)	169 participants, aged 30-87 years	Accelerometer-determined total sedentary time	ActiGraph 7164	Sedentary and light-intensity time were strongly inversely correlated (Pearson's r =0.96); correlations were weak between sedentary and moderate-to-vigorous–intensity time (Pearson's r=0.27)	8 / 8 100%
11- Chang 2008 (Taiwan)	2,353 participants, aged >40 years	Self-reported television viewing	Self-reported leisure time physical activity	Weak inverse associations between TV viewing and occupational PA (r = -0.08, p<0.05), and total activity (r = -0.09, p<0.001).	4 / 8 50%
12- Sugiyama 2008 (Australia)	2210 participants, aged 20 - 65 years	Self-reported leisure-time sedentary	International Physical Activity Questionnaire	Weak inverse association between leisure time sedentary	6 / 8

		behaviour	(IPAQ Short)	behavior and LTPA (r = -0.07).	75%
13- Ballard 2009 (USA)	116 male undergraduates, mean age 19.5 years	Self-reported time spent watching television, playing video games and reading	International Physical Activity Questionnaire (IPAQ Short)	Small but significant inverse associations seen between measures of video game play and frequency and intensity of PA (correlations range: r = 0.20 – 0.22).	5 / 8 62.5%
14- Ekelund 2009 (UK)	192 participants	Accelerometer-determined total sedentary time	ActiGraph 7164	Time spent sedentary was inversely associated with time spent in light-intensity activity (r = 0.52, P<0.0001).	8 / 9 88.9%
15- Helmerhorst 2009 (UK)	376 participants, mean age 49.4±7.7 years	Total sedentary time measured via calibrated heart rate monitoring	Individually calibrated minute-by-minute heart rate monitoring	Sedentary time was inversely correlated with MVPA (r = -0.34; p < 0.001)	8 / 9 88.9%
16- Dunton 2009 (USA)	10 984 participants, aged >21 years	Self-reported total leisure time and transport related sedentary behaviour	Self-reported total leisure time and transport related moderate to vigorous physical activity	Total time spent in PA was inversely associated with total time spent in sedentary behaviours (χ2 =59.35, p<0.001). Time spent watching TV was inversely related to time spent in LTPA (χ2 = 124.01, p<0.001). Time spent in LTPA was positively associated with time spent playing games (χ2 = 23.55, p<0.001) and reading (χ2 = 79.62	5/ 8 62.5%

				p<0.001). Computer use was unrelated to LTPA.	
17- Rouse 2010 (UK)	46 males (mean age 20.2 years), 38 females (mean age 19.5 years).	Multiple domains of sedentary time assessed via ecological momentary assessment diaries	Multiple domains of physical activity assessed via ecological momentary assessment diaries	Significant inverse association between PA and sedentary technology for males (r = -0.217, p < 0.05), no association seen in females. No associations observed between sedentary social and sedentary study and PA in males and females.	4 / 8 50%
18- Patel 2010 (USA)	53,440 men and 69,776 women	Self-reported leisure-time sitting	Self-reported leisure-time physical activity	No significant association between leisure time sitting and PA (r = -0.03).	3 / 9 33.3%
19- Touvier 2010 (France)	698 men and 691 women, aged 45-64 years	Self-reported television viewing	French self-administered version of the Modifiable Activity Questionnaire (MAQ)	Changes in TV viewing differed according to category of changes in walking habits in women; those who increased their duration of walking by 2 h/week or more decreased time spent watching TV by 11.5 min/day.	7 / 9 77.8%
20- Teychenne 2010 (Australia)	3645 women, aged 18–45 years	Self-reported total siting time, watching television, sitting at a computer	International Physical Activity Questionnaire (IPAQ Long)	No significant interactions between LTPA, sitting time and risk of depression in unadjusted or adjusted models.	6 / 8 75%
21- Dunstan 2010 (Australia)	8800 participants,	Self-reported	Self-reported physical	Weak, but statistically significant	8 / 9

	aged >25 years	television viewing	activity, using the Active Australia questionnaire	association between leisure-time exercise and TV viewing (Spearman r=-0.03, p< 0.01).	88.9%
22- Lynch 2010 (USA)	111 breast cancer survivors, mean age 48.5±18.7 years	Accelerometer-determined total sedentary time	ActiGraph 7164	Correlation between log moderate-to-vigorous intensity activity and sedentary time was strong (Pearson's r = -0.66). Light intensity activity and sedentary time were almost completely inversely correlated (Pearson's r = -0.99)	7 / 8 87.5%
23- Bauman 2011 (20 Countries)	49,493 adults, aged 18–65 years	Total sitting time (IPAQ short)	International Physical Activity Questionnaire (IPAQ Short)	Linear inverse association between decreasing levels of high PA and increasing sitting time (p<0001). Those reporting low or moderate PA were 3 and 2.2 times more likely to be in highest sitting category (versus high PA group).	6 / 8 75%
24- Lakerveld 2011 (Australia)	2,191 men and 2,650 women aged ≥25 years	Self-reported television viewing	Physical activity assessed using the Active Australia Survey	Linear regression analyses revealed that every additional hour of TV viewing measured at baseline was associated with a decrease in PA 5 years later in women (OR = 1.46). No associations observed in men.	4 / 9 44.45%

25- Tudor-Locke et al. 2011 (USA)	1781 males, mean age 46.5 years; 1963 females, mean age 47.7 years	Accelerometer-determined total sedentary time	ActiGraph 7164–derived steps/day and activity counts/day	The relationship between steps/day and time spent in sedentary behaviour was inverse and moderate (R^2= 0.25).	8 / 8 100%
26- Bonomi, et al 2012 (Netherlands)	20 participants, aged 26–60 years	Tracmor accelerometer	Tracmor accelerometer, activity intensity classified using classification tree algorithm.	Inverse association observed between sedentary time and active standing (r = -0.87, P<0.001).	8 / 8 100%

Numbers have been added to the references contained in the above table to enable cross-comparisons to the same papers summarised in Tables 2.2 and 2.3.

* Papers with a study quality score equal to or over 75% were classified as high quality, based on a median split using the ratings of the included studies. Studies with a higher score had higher study quality. Prospective studies were scored out of 9 while cross sectional studies were scored out of 8.

2.4.2 Measurements

The majority of studies (n=20) used self-reported methods to measure both physical activity and sedentary behaviour. The remaining studies (n=6) used objective measures, of which 4 were cross-sectional and 2 were prospective. In studies utilising objective methods, 4 used the ActiGraph (10, 14, 22, 25) for both sedentary behaviour and physical activity. One study used flex heart rate (15) for both sedentary behaviour and physical activity and one used RT3 accelerometer for monitoring sedentary behaviour and physical activity (6) (Table 2.3).

2.4.3 Associations between sedentary behaviour and physical activity

Table 2.2 summarises the associations between sedentary behaviours and physical activity. From the 26 included studies, 5 domains of sedentary behaviour and 9 domains of physical activity were examined. Television viewing (TV) was the most commonly assessed sedentary behaviour (n=12). In these studies, six papers (50%) reported a small inverse association (1, 2, 5, 12, 19, 21), three studies (25%) reported a moderate inverse association (9, 23, 24), one paper (8%) reported a large inverse association (22), and two studies (16.7%) found no association between TV viewing and all evaluated aspects of physical activity (4, 7). 'Exercise' was the most commonly assessed domain of physical activity in association with TV viewing time. TV viewing was inversely associated with exercise in five out of five studies (Table 2.2).

Total daily sedentary time was the second most commonly assessed sedentary behaviour (n= 10). In these studies, three papers (30%) reported a small inverse association (8, 10, 17), three studies (30%) a moderate inverse association (6, 15, 25), and five studies (50%) found a large inverse association between overall sedentary time and all reported domains of physical activity (10, 14, 16, 22, 26). Light activity and MVPA were the most commonly assessed domains of physical activity in association with total daily sedentary time. Total daily sedentary time was inversely associated with time spent in light activity in four studies (40%) and MVPA in four studies (40%) (Table 2.2).

‘Sitting time’ was assessed in four studies with two papers (50%) reporting a small inverse association (20, 23), one study (25%) a moderate inverse association (3) and one (25%) found no association between sitting time and all reported domains of physical activity (18). Leisure-time physical activity (LTPA) and walking were the most commonly assessed domains of physical activity in association with sitting time. Sitting time was inversely associated with LTPA in two studies (50%) and walking in two studies (50%) (Table 2.2).

General screen time was assessed in three studies which all reported a small inverse association (5, 13, 20) with all evaluated aspects of physical activity (Table2.2). Occupational sedentary time was assessed in two studies, in which both studies (8, 11) reported a small inverse association with LTPA (Table 2.2).

PA SB	Work PA(n= 4)*	Transport PA (n= 5)	LTPA (n= 9)	Domestic PA (n= 1)	Walking (n= 5)	General PA (n= 5)	Light PA (n= 4)	MVPA (n= 4)	Exercise (n= 7)
Television viewing		4^{0}, 5^{-}	9^{--}, **12**$^{-}$, 24^{--}L		**7**^{0}	1^{-}, **2**$^{-}$, 19^{-}L			5^{-}, 9^{--}, **2**$^{-}$, **21**$^{-}$**L, 22**$^{---}$
General Screen time	13^{-}, **20**$^{-}$	5^{-}, 13^{-}	13^{-}	13^{-}	13^{-}				
Occupational sedentary time			**8**$^{-}$, 11^{-}						
Overall sitting time	**23**$^{--}$		**3**$^{--}$, **20**$^{-}$		18^{0}L, **23**$^{--}$				18^{0}L
Overall sedentary time	**8**$^{-}$	17^{-}	16^{---}		**26**$^{---}$	**6**$^{--}$, **15**$^{--}$**L**	**10**$^{---}$, **14**$^{---}$**L**, **22**$^{---}$ **, 25**$^{--}$	**10**$^{-}$, **14**$^{--}$**L**, **22**$^{---}$**, 25**$^{--}$	17^{-}

Table 2.2: Associations between domains of sedentary behaviour and domains of physical activity

(0): No association (-): Inverse and Small association (--): Inverse and Moderate association (---): Inverse and Large association

* Domestic PA: Such as; yard activities and gardening *L: Longitudinal study *Exercise: Such as; Running, Biking, Aerobic, swimming * General screen time: (e.g. composite score of television viewing plus computer use) * Bold Numbers: High quality studies (Studies with scores higher than 75% in quality of study) *n: “n” after the domain of sedentary behaviour is the number of studies which evaluated this domain. *LTPA: Leisure time physical activity.

The numbers in this table relate to the study numbers from Table 2.1

Table 2.3: Studies with objective measurements of sedentary behaviour and physical activity

Study identifier, Author (year), country	Measurement tool, including accelerometer cut-points where relevant in counts/minute	Number of days of monitoring, plus daily wear time (mins/day)	Light intensity activity (mins/day)	Moderate-vigorous intensity activity (mins/day)	Sedentary time (mins/day)	Analysis and results
6- Martınez-Gonzalez (2005) Spain	Triaxial accelerometer (RT3 Triaxial Research Tracker) energy expenditure estimation (kcal day^{-1})	The participants wore the RT3 for 3 days in a typical week and 2 days at the weekend. They could take it off for sleeping at night and for hygiene.	-----	------	-----	Inverse association between total sedentary time and energy expenditure estimated using the RT3 accelerometer (Spearman r = -0.42, p<0.01).
10- Healy et al, (2008) Australia	ActiGraph 7164 SB: <100 LPA: 100–1951 MVPA: ≥1952	Participants requested to wear the accelerometer throughout waking hours for 7 consecutive days. Daily wear time not given.	39% of wear time	4% of wear time	57% of wear time	Sedentary and light-intensity time were strongly inversely correlated (r =0.96); correlations were weak between sedentary time and MVPA (r=0.27).
14- Ekelund et	• ActiGraph 7164 • SB: <100 • LPA: 101–1,951 • MPA:1,952–5,724	Participants required to have >4 consecutive days of monitoring.	Men: 297 ± 77	Men: 29 ± 16	Men: 452± 84	Time spent sedentary was significantly and inversely associated with time spent in light-intensity activity.

al. (2009) UK	• VPA: >5,725	Daily wear time: Men: 778 mins/day Women: 765 mins/day	Women: 321 ± 70	Women: 25 ±17	Women: 419 ±85	(*r* =0.52, *P*<0.0001)
15-Helmerhorst et al (2009) UK	Physical activity and sedentary time measured objectively by individually calibrated minute-by-minute heart rate monitoring. Sedentary time was calculated as the heart rate observations (in minutes) below an individually predetermined threshold (flex heart rate) and expressed as a percentage of total monitored time. The percentage of time spent above 1.75 × resting heart rate represented MVPA.	Heart rate monitor worn throughout waking hours for 4 days. Daily wear time not given.	66.1% of wear time	1.9% of wear time	32.9% of wear time	Sedentary time was inversely correlated with time in MVPA (r = -0.34; P<0.001).
22- Lynch et al (2010) USA	• ActiGraph 7164 • SB: <100 • LPA: 100–1951 • MVPA: ≥1952	Participants requested to wear the accelerometer throughout waking hours for 7 consecutive days Daily wear time: 14.0 ± 1.9 hours/day	32.6 % of wear time	1.1% of wear time	66.3% of wear time	LPA and sedentary time were almost completely inversely correlated (r = -0.99), strong inverse correlation between MVPA and sedentary time (r = -0.66).

25- Tudor-Locke et al. 2011 (USA)	- ActiGraph 7164 - SB: <100 - Low PA: 100-499 - LPA: 500-2019 - MPA: 2020-5998 - VPA: ≥5999	Participants requested to wear the accelerometer throughout waking hours for 7 consecutive days. Daily wear time: 14.0 ± 0 hours/day.	Low PA (n = 3744): 199.9 (95% CI: 196.8 - 203.1) mins/day LPA (n = 3744): 141.1 (95% CI: 137.3 - 145.0) mins/day	MPA (n = 3710): 22.3 (95% CI: 21.0 - 23.6) mins/day VPA (n = 1143): 5.4 (95% CI 5.0 - 5.9) mins/day	Sedentary (n = 3744): 479.1 (95% CI: 473.5 - 484.7) mins/day	There was a moderate, inverse association between steps/day and time in sedentary behaviour (R^2 = -0.25)

Abbreviations: SB – Sedentary behaviour; PA – physical activity; LPA – light physical activity; MPA – moderate physical activity; MVPA – moderate to vigorous physical activity; VPA – vigorous physical activity.

2.5 Discussion

The purpose of this systematic review was to appraise and summarise the literature on associations between sedentary behaviour and physical activity in adults. The associations between these behaviours were evaluated across five domains of sedentary behaviour and nine domains of physical activity. The most commonly reported method of assessing sedentary behavior and physical activity in the included studies was via self-report. The majority of these studies reported small to medium inverse associations between sedentary behavior and physical activity. Six studies objectively assessed sedentary behavior and physical activity, with these studies generally demonstrating small to medium inverse associations between sedentary time and MVPA, but medium to large inverse associations between sedentary behavior and light intensity physical activity.

Based on the assessment of study quality, 15 studies were categorised as high quality, with an overall quality score equal to or above 75%. These studies provided evidence of an inverse association between sedentary behaviour and physical activity, ranging from small to large, with only one high quality study reporting no association between sedentary time and physical activity (Teychenne et al., 2010). In contrast, those studies deemed of lower quality reported small or no associations (n = 3) between sedentary behaviour and physical activity. Findings suggest that relationships between sedentary behaviour and physical activity exist, however the strength of the association varies depending on the domain studied, the method of measurement (self-report versus objective assessment), and on study quality. This finding is similar to that of Pearson et al. (2014) who recently conducted a systematic review examining the association between sedentary behaviour and physical activity in children and adolescents. In their review, studies employing objective measurements and those assessed to be of higher quality reported stronger associations between these behaviours.

TV viewing was the most commonly reported sedentary behaviour, with the majority of studies reporting small to medium inverse associations between TV viewing time and physical activity across multiple domains. In the studies assessing general screen time, similar small to medium inverse associations were seen with physical activity. Due to the self-report nature of these particular sedentary behaviors, it is difficult to conclude whether TV viewing and screen time displaces physical activity.

Stronger evidence in support of the displacement hypothesis (Mutz et al, 1993) is provided from studies with objective monitoring. Five of the six studies which objectively measured sedentary time and physical activity used accelerometers, and reported small to medium inverse associations between sedentary time and MVPA, and medium to large inverse associations between sedentary behavior and light intensity physical activity. For example, the correlation coefficients between sedentary time and light intensity physical activity in the studies of Healy et al. (2008), Lynch et al. (2010) and Bonomi et al. (2012) ranged from 0.87 to 0.99. The studies applying objective monitoring were all classified as high quality studies, with their quality scores ranging from 88 to 100%. These studies therefore provide strong evidence for large inverse associations between sedentary time and light intensity activity.

Given light physical activity typically involves standing and light ambulation, these incidental behaviours tend to be more prevalent when an individual is not sitting, as opposed to MVPA which is likely to be more structured. It is therefore logical to expect a stronger relationship between sedentary behavior and light activity, with sedentary time more likely to displace light intensity activities than MVPA. Given the strong links between sedentary behavior and light physical activity, interventions targeting breaking up sedentary behaviour, and/or reductions in sedentary behavior should initially target increases in light intensity activity. Moving populations from sedentary behaviours into activities involving light intensity activity will likely be more achievable and sustainable, and could have substantial effects on public health (Healy et al. 2007; 2008; Dunstan et al 2012; Carson et al. 2013). For example, Dunstan et al. (2012) have recently shown that breaking up sedentary behaviour every 20 minutes with 2 minutes of light walking significantly improves glucose and insulin regulation. Such behavior modifications may be achievable for the vast majority of adults. Experimental evidence on the optimum duration of such light intensity breaks is still in its infancy however, and further research is required before such recommendations can be incorporated into health guidelines.

Whilst the studies using objective measures were all classified as high quality, it should be cautioned that the majority of these studies used accelerometers (five out of six) which do not directly measure sitting. Accelerometers are not capable of distinguishing between different postures; they provide an estimation of sedentary time through a lack of movement counts. Hence periods of standing still can be misinterpreted as sitting (Atkin et al. 2012). Further research would benefit from the use of an inclinometer, as used elsewhere (Tigbe et al. 2011), which is capable of distinguishing between different postures.

The majority of studies included in the review were cross-sectional, with just 23% being prospective. Because of the limited evidence from prospective studies, it is necessary for researchers to pay more attention to people’s sedentary behaviour and physical activity in the long term. Overall strengths of this review include the multiple domains of sedentary behaviour and physical activity included, from a range of studies with diverse sample characteristics. We utilized a broad search criteria, including both electronic and manual sources, and a large number of studies were screened for eligibility. However, few of the included studies aimed to address directly the question of interest to this review. The association between sedentary behaviour and physical activity was frequently reported as a descriptive finding within a methods, results or discussion section. Therefore, we cannot rule out the possibility that some relevant studies were not identified for the current synthesis. However, the validity of this modified checklist has not been determined therefore this should be highlighted as a limitation of this study. Moreover, few studies provide time stamped data thus are unable to say whether one behaviour truly displaces another. Time of day may be an important factor in this regard. For example, TV viewing late in the evening is unlikely to displace physical activity, whereas the same sedentary behaviour during the day might do.

This review is the first of its kind to present a synthesis of the evidence documenting the associations between sedentary behavior and physical activity in adults. The findings suggest that sedentary behavior is inversely associated with physical activity, with the strongest associations seen with light intensity physical activity.

2.6. Conclusions

Given the high volumes of time adults reportedly spend in sedentary behavior, along with the detrimental effects of sedentary behaviour on health (Wilmot et al, 2012), interventions are urgently needed to re-address the balance between sedentary behaviour and physical activity. Findings of this review suggest weak to moderate inverse associations between sedentary behavior and physical activity, with stronger evidence from objective monitoring studies reporting larger associations between sedentary behavior and light intensity activity. The evidence from this review, although limited, suggests that sedentary behaviour may displace time spent in light intensity activity. Interventions promoting reductions in sedentary behaviour through the promotion of light activities may have the potential to have a large impact on public health.

Chapter 3

Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour

This study chapter examines the utility of the definition of sedentary behaviour by assessing the energy cost (METs) of common sitting, standing and walking tasks in healthy weight and obese participants. Findings of this study have been published in BMC Public Health (Mansoubi M, Pearson N, Clemes SA, Biddle SJH, Bodicoat DH, Tolfrey K, Edwardson CL and Yates T. (2015), Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour. BMC Public Health, 15:516 doi: 10.1186/s12889-015-1851-x.) Findings from this chapter have also been presented as an oral presentation at the International Society for Behavioural Nutrition and Physical Activity (ISBNPA) 2013 congress in Belgium.

Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour

3.1 Abstract

Sedentary behavior is defined as any waking behavior characterized by an energy expenditure of 1.5 METS or less while in a sitting or reclining posture. This study examines this definition by assessing the energy cost (METs) of common sitting, standing and walking tasks. Fifty one adults spent 10 minutes during each activity in a variety of sitting tasks (watching TV, Playing on the Wii, Playing on the PlayStation Portable (PSP) and typing) and non-sedentary tasks (standing still, walking at 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, and 1.6 mph). Activities were completed on the same day in a random order following an assessment of resting metabolic rate (RMR). A portable gas analyzer was used to measure oxygen uptake, and data were converted to units of energy expenditure (METs). Average of standardized MET values for screen-based sitting tasks were: 1.33 (SD: 0.24) METS (TV), 1.41 (SD: 0.28) (PSP), and 1.45 (SD: 0.32) (Typing). The more active, yet still seated, games on the Wii yielded an average of 2.06 (SD: 0.5) METS. Standing still yielded an average of 1.59 (SD: 0.37) METs. Walking MET values increased incrementally with speed from 2.17 to 2.99 (SD: 0.5- SD: 0.69) METs. The suggested 1.5 MET threshold for sedentary behaviors seems reasonable however some sitting based activities may be classified as non-sedentary. The effect of this on the definition of sedentary behavior and associations with metabolic health needs further investigation.

3.2 Introduction

Over the past few decades, the way in which we live our everyday lives has changed dramatically. Technological advances, societal influences and environmental attributes have significantly influenced the way we socialize, travel, work and shop resulting in substantial proportions of the day spent in sedentary pursuits, or sitting (Clemes et al, 2014). A growing body of epidemiological evidence has linked sedentary behavior to health risks including an increased risk of type 2 diabetes [Proper et al, 2011; Wilmot et al, 2012; Edwardson et al, 2012), the metabolic syndrome (Edwardson et al, 2012; Lynch et al, 2010; Biswas et al, 2015), cancer (Chau et al, 2012; Lynch et al, 2010), obesity (Biswas et al, 2015; Thorp et al, 2010) and all-cause and CVD mortality [Wilmot et al, 2012; Chau et al, 2012; Matthews et al, 2012). These associations have been shown to be at least partially independent of physical activity, suggesting that sedentary behaviors have the potential to influence risk of disease, independent of physical activity levels. Furthermore, recent reviews have noted that there is an inverse association between some sedentary behaviors (mostly TV viewing or screen time) and leisure-time physical activity in adults (Mansoubi et al, 2014; Rhodes et al, 2012), providing evidence for time displacement.

Such evidence requires us to examine sedentary behavior as a concept in itself and there are a growing number of analytical considerations regarding what constitutes sedentary behavior (Sedentary Behaviour Research Network, 2012, p. 540). Sedentary behavior is not simply a lack of physical activity or a failure to meet recommended levels of moderate-to-vigorous physical activity [Hamilton et al, 2008; Pate et al, 2008; Tremblay et al, 2010; Yates et al, 2011), this should be defined as 'inactivity' (Sedentary Behaviour Research Network, 2012, p. 540). Sedentary behavior has recently been defined as "*any waking behavior characterized by an energy expenditure of ≤1.5 METs while in a sitting or reclining posture*" (page 540) (Sedentary Behaviour Research Network, 2012, p. 540). This definition acknowledges the importance of posture but also energy poorly understood. For example, in the compendium of physical activities (Ainsworth et al, 2011), sedentary activities, such as; sitting at a desk, sitting in a vehicle, sitting watching television, have been coded with MET values ranging from 1.0-2.5, but standing activities, such as watering the lawn or garden, which are not classified as sedentary in the above definition due to the upright posture in which they are performed, are coded with a MET value of 1.5 (Ainsworth et al, 2011). In addition, playing computer games (often categorized as sedentary behaviors in self-report questionnaires) have been found to have MET values as high as 4.5 (O'Donovan et al, 2012).

Limited numbers of studies (Byrne et al, 2005; Weyand et al, 2013) have examined the differences in energy cost of lifestyle activities in healthy weight, overweight and obese adults. It has been shown that energy cost of activities such as walking could be predicted by body weight (Byrne et al, 2005; Weyand et al, 2013). However the examination of the MET definition of sedentary behavior is required across body composition groups to ascertain the widespread applicability of this definition. The aims of this study were therefore (a) to measure energy expenditure during common sitting, standing and walking tasks and (b) to examine the utility of the 1.5 MET definition of sedentary behavior in distinguishing between common sitting and standing activities in healthy weight and obese participants.

3.3 Methods

3.3.1 Study design

This study was an experimental cross-over trial (Figure 3.1 shows the flow of participants through the study). In total, there were three conditions (sitting, standing/very light walking, and light-moderate walking). Within each condition there were several activities (see Figure 3.1). All participants completed each of the conditions and each of the associated activities. The order of the conditions and activities were randomized. First, participants were randomized to the order in which they undertook each of the three conditions with stratification for BMI (healthy weight vs. obese) and sex (male vs. female). Second, participants were randomized to the order in which they undertook each of the activities within the three conditions, without any further stratification. The study was approved by the Loughborough University Ethical Advisory committee and all participants provided written informed consent.

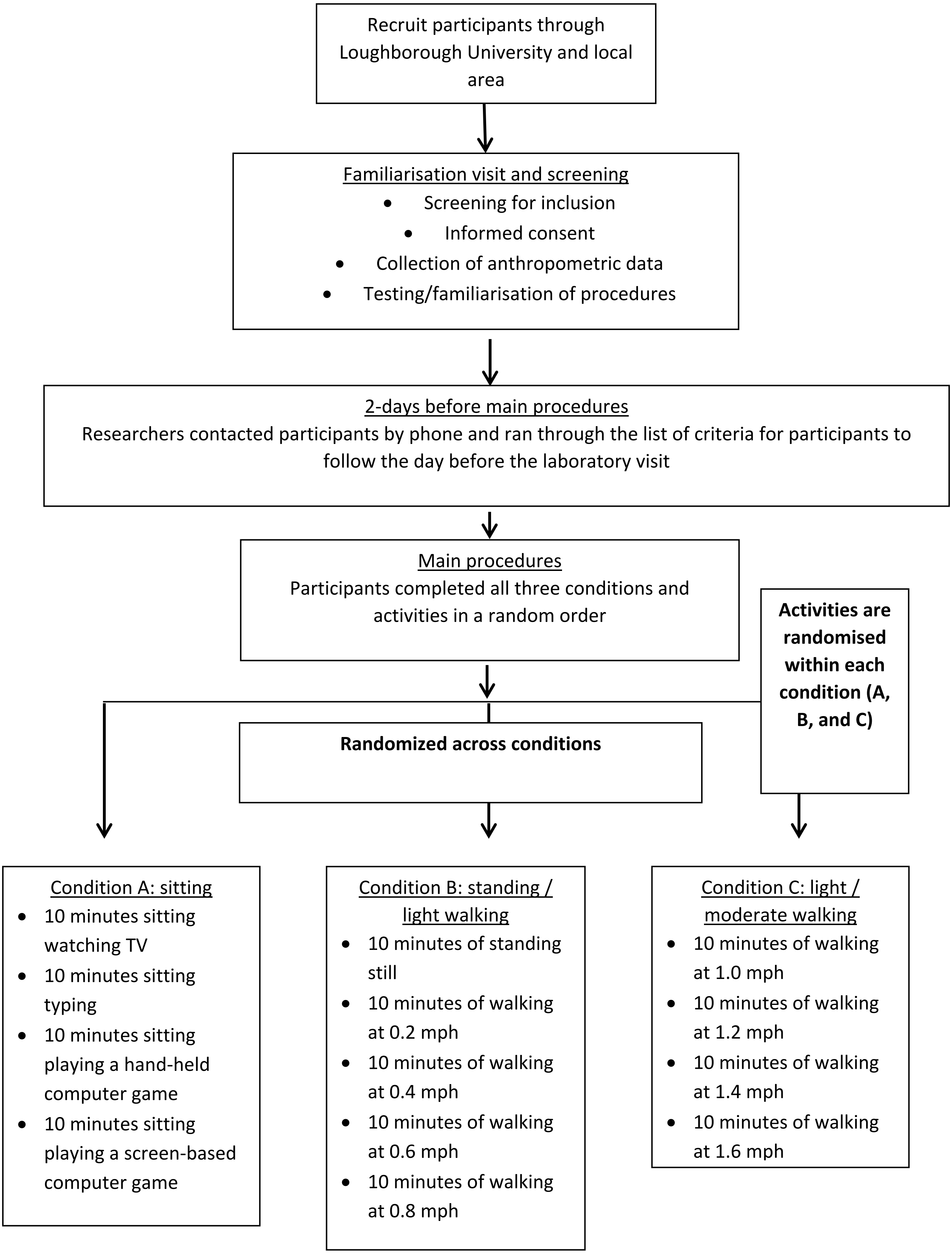

Figure 3.1: Flowchart for the participants included in the MET study

3.3.2 Participants and recruitment

Recruitment was purposefully undertaken based on a 2 x 2 format that required equal numbers of male/female and healthy weight (BMI<25kg/m^2) and obese (BMI>30kg/m^2) participants, over the age of 18 years. A convenience sample of participants was recruited from the staff population at Loughborough University (n=49) and from the local community (n=2). The study was advertised across the Loughborough campus through posters placed on noticeboards and through electronic advertisements placed on electronic noticeboards (for example, the For Sale and Wanted webpage). Local community participants were participants' family members which one of them was a pilot and another one was a teacher. In addition to the study advertisements, participants were also recruited via word of mouth. Within the sample of Loughborough University staff, participants were employed within the Engineering and Computer Science departments, and from within the School of Sport, Exercise and Health Sciences). Most of the recruited participants in this study were White and British. People who displayed an interest in participating in the study received a study information pack (information sheet, consent form and the health screening questionnaire) detailing the study and requirements (Appendices 3.1-3.3). Exclusion criteria included the presence of any physical conditions or illnesses which prevented full participation in the study, or an inability to communicate in spoken English. Fifty-one adults (25 males [13 healthy weight and 12 obese]) and 26 females [14 healthy weight and 12 obese]) completed the laboratory protocol. And 1 male participant did not attend in the lab for the measurement.

3.3.3 Sample size

To detect a significant association between walking speed and MET level, in order to evaluate how MET levels increase from standing to light walking activities, a minimum of 9 participants per group (male, female) was required. This was based on assuming 1-beta = 0.8, alpha = 0.05 and $R^2 = 0.6$ (O'Donovan, 2012).

3.3.4 Familiarization visit and screening

Potential participants were invited to the laboratory at least 10-days before the main test for a familiarization visit. During this visit, participants were screened for inclusion/exclusion criteria into the study. Eligible participants were shown the designated experimental area and provided with an opportunity to try some of the experimental activities (e.g. walking on the treadmill), familiarize themselves with the gas mask, and ask questions about the protocol. During this visit, anthropometric measures were taken which included height (measured using a portable stadiometer, Seca UK), waist circumference (measured mid-way between the lower rib margin and the iliac crest using anthropometry tape) and body weight and composition. Body composition was measured using a Tanita Body Composition Analyzer (model: BC-418 MA, Tanita, UK, Figure 3.2). This device measures body composition using 8-point bio-impedance analysis. Percent body fat measured using the Tanita BC-418 has been shown to correlate highly with the reference measure of dual-energy X-ray absorptiometry (DXA) (Pietrobelli et al, 2004). As impedance fluctuates with the distribution of body fluid, to improve accuracy, participants were required to urinate before the measurement of percentage body fat was taken.

Figure 3.2. Tanita Body Composition Analyzer, model: BC-418 MA, Tanita, UK this device has been used for the measurement of; weight, body fat%, BMI, Body fat (kg) Photo link: http://www.scalesexpress.com/tanita-bc-418ma-segmental-body-composition-analyser-class-iii.html

3.3.5 Experimental protocol

As energy expenditure increases substantially during and following vigorous physical activity, and as recovery time varies depending on the intensity, duration, type of activity, and fitness level of the individual, participants were asked to refrain from vigorous activity for 48 hours before attending the laboratory (Compher et al, 2006) In addition, due to their influences on resting metabolic rate, participants were also asked to abstain from caffeine and alcohol for 36 hours before the experimental protocol (Compher et al, 2006). Participants were asked to consume their usual evening meal between 17:00 and 19:30, and they were given a snack (cereal bar) to eat up until 20:00 the day before attending the laboratory (Appendix 3.4). Participants arrived at the laboratory at 08:00 following an overnight fast, with only water consumed from 20:00 the evening before. Participants were asked to arrive by car to eliminate uncontrolled activity and 500 mL of water was consumed at least 60 min before arriving at the laboratory.

Upon confirmation that participants had complied with the pre-study requirements (Appendix 3.5), participants' spent 60 minutes in a semi-supine resting position under a ventilated hood (GE Nutrition. UK)(Figure 3.3).GEM ventilated hood is a gold standard device for the resting metabolic rate measurement (Kearney et al, 2006; McDoniel, 2007) Resting Metabolic Rate (RMR) was quantified over the second 30 minute period. Following the RMR measures under the ventilated hood, participants wore a face-mask, which was connected to an open circuit breath-by-breath automated gas-analysis system measuring expired respiratory gas fractions (Cortex Metalyzer, Leipzig, Germany)(Figure 3.4). Participants spent a further 30 minutes in a semi-supine state to repeat the RMR measure with the breath-by-breath automated gas-analysis system. This was done to allow a comparison between measurement types (ventilated hood vs. breath-by-breath analyzer) to ensure consistency with measurements taken during the protocols described below.

Figure 3.3. The measurement of resting metabolic rate using the GEM ventilated hood. The study participant is spending 60 minutes in a semi-supine resting position under the ventilated hood (GE Nutrition. UK).

Following the assessment of RMR participants consumed a standardized breakfast following recommendations from the Food Standards Agency (FSA) that breakfast should constitute 20% of daily energy intake (FSA, 2014). For males this consisted of: 80 g Weetabix minis cereal (299 kcal) + 250 mL semi-skimmed milk (123 kcal) + one banana (~80 kcal). For females the meal consisted of: 60 g Weetabix minis cereal (224 kcal) + 200 mL semi-skimmed milk (98 kcal) + one banana (~80 kcal). Following a 20 minute rest period, participants performed a series of activities under three conditions (A - sitting, B - standing and very light walking, C - light walking)

The ‘sitting’ condition (condition A) involved the following four activities. 1) sitting watching television (TV: an episode of a TV drama shown to each participant), 2) sitting typing (each participant copied the same text from the same book, Figure 3.4), 3) sitting playing a hand-held computer game (participants played a tennis game with a PSP [PlayStation Portable, Sony]) and 4) sitting playing a TV screen-based computer game (participants played a tennis game with the Wii)(See Figure 3.5). The ‘standing and very light walking’ condition (condition B) included five activities: standing still (participants asked to stand as if they were waiting in a queue/line) and light walking at 0.2, 0.4, 0.6, and 0.8 miles/h on a treadmill (Technogym, Excite Med, UK). The ‘light-moderate walking’ condition (condition C) involved participants walking on a treadmill at 1.0, 1.2, 1.4, and 1.6 miles/h. Each activity within the three conditions was conducted for 10 minutes, with expired gas collected during the last 5 minutes. In between each condition (A, B and C), participants were offered a 5-minute break to remove the face-mask for their comfort. Respiratory gas was collected using the Cortex breath-by-breath automated gas-analysis system.

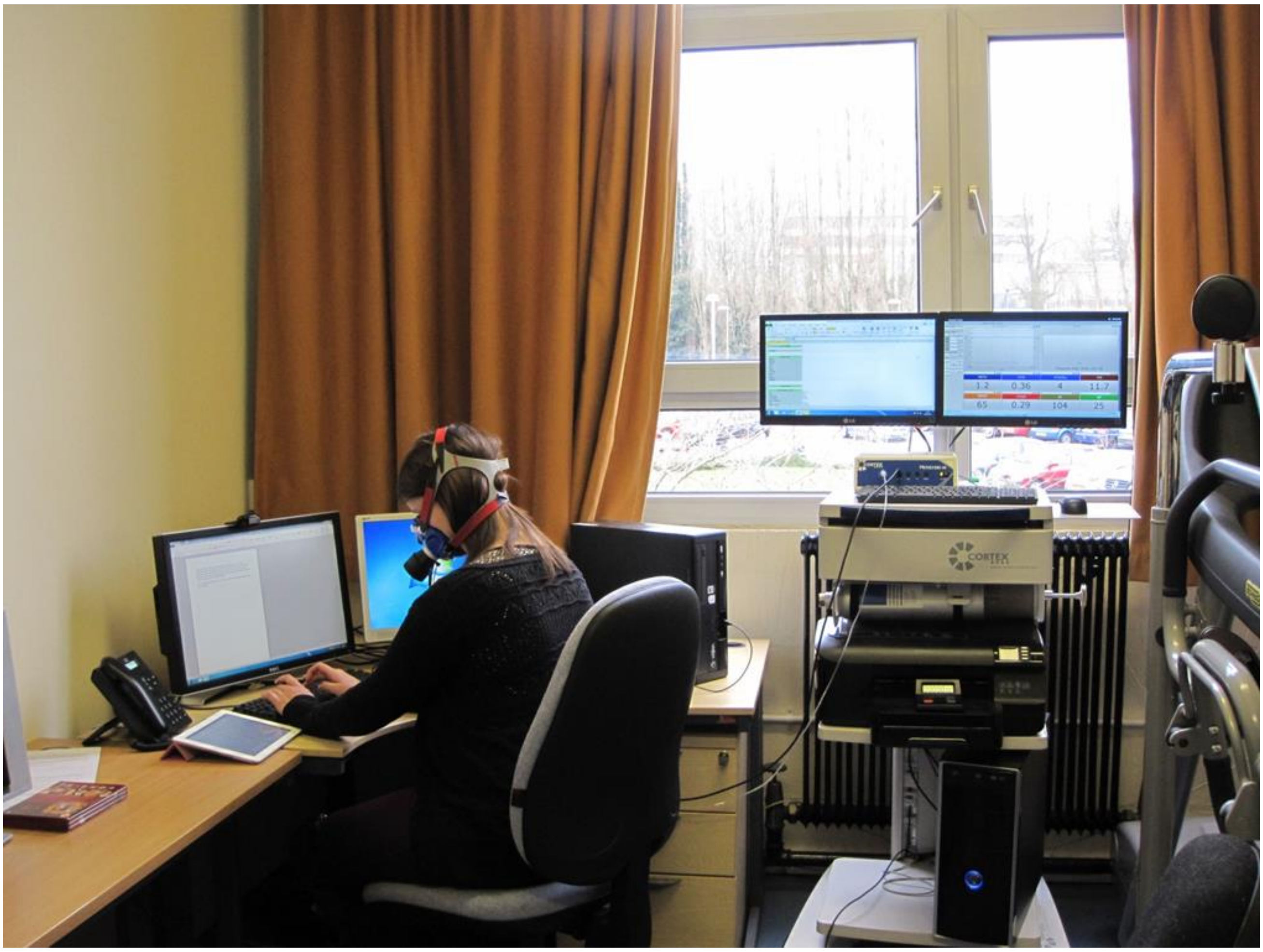

Figure 3.4. A picture of a participant undertaking the typing condition. The participant is wearing a face-mask, connected to an open circuit breath-by-breath automated gas-analysis system which measures expired respiratory gas fractions (Cortex Metalyzer, Leipzig, Germany) and provides an estimate of energy expenditure.

Figure 3.5 A picture of a participant undertaking the playing Wii condition and wore a face-mask, connected to an open circuit breath-by-breath automated gas-analysis system which measures expired respiratory gas fractions (Cortex Metalyzer, Leipzig, Germany) and provides an estimate of energy expenditure.

3.3.6 Statistical analyses

To achieve the primary aim, summary measures of the MET values associated with each activity were produced. The MET values were calculated using the standardized MET formula: MET = VO_2 (mL/kg/min)/3.5 (mL/kg/min). We also derived a second index by calculating multiples of resting metabolic rate (mRMR) by dividing VO_2 during each activity by VO_2 at rest; unlike standardized METs, mRMR takes into account individual differences in VO_2 during rest. The Shapiro-Wilk test confirmed that all data were normally distributed. Differences between the BMI groups were tested using independent t-tests. Generalized Estimating Equations (GEE) were used to determine the association between walking speed and average MET values. These models took into account the repeated measurements taken on the same individuals (Hanley et al, 2003). P < 0.05 was considered significant and all tests were 2-sided. All statistical analyses were performed using SPSS version 22 (IBM SPSS Statistics). Data are displayed as mean (± SD) and mean (95% CI) in the text and tables.

3.4 Results

Fifty-one adults (25 males [13 healthy weight and 12 obese) and 26 females [14 healthy weight and 12 obese]) completed the laboratory protocol. The characteristics of the participants are displayed in Table 3.1.

Table 3.1: Descriptive anthropometry data

Group	Gender	Body mass (kg)	Stature (m)	BMI (kg/m^2)	Body fat (%)	Waist circumference (cm)	Age (years)
Healthy Weight	Male	70.4 (6.5)	174.8 (7.3)	23.1 (1.5)	16.5 (3.5)	84.8 (1.5)	32.7 (13.8)
	Female	57.8 (7.3)	161.9 (6.5)	22.01 (1.9)	23.7 (6.7)	72.1 (1.9)	29.1 (3.6)
Obese	Male	92.9 (9.4)	170.7 (8.6)	31.8 (1.8)	29.1 (7.5)	104.4 (5.8)	38.2 (14.6)
	Female	91.6 (12.8)	164.4 (9.7)	33.8 (3.8)	38.4 (8.9)	104.3 (11.2)	32.5 (12)

3.4.1 Resting metabolic rates

The mean (SD) absolute VO_2 level measured by the GEM ventilated hood for the whole sample was 245 (44) mL/min. Resting values were slightly higher in the obese participants (256 (49) mL/min) in comparison to the healthy weight participants (235 (38) mL/min). After adjusting the results for participants' body mass, mean (SD) VO_2 for the whole sample was 3.28 (0.74) mL/kg/min (obese participants: 2.81 (0.62) mL/min/kg; healthy weight participants: 3.71 (0.58) mL/kg/min). Resting VO_2 values were similar when using the Cortex calorimeter (3.28 (0.29) mL/kg/min), no significant differences between methods were observed (p=0.959).

3.4.2 mRMR and MET values of different activities

For the whole sample, mean (SD) standardized MET values for inactive sitting tasks ranged from 1.33 (0.24) to 1.45 (0.32), see Table 2. The more active, yet still seated, games on the Wii yielded an average of 2.06 (0.50) METS. Standing yielded an average of 1.59 (0.37) METs. Walking MET values increased incrementally with speed from 2.17 (0.5) at 0.2 miles/h to 3.22 (0.69) METs at 1.6 miles/h.

Mean (SD) mRMR values for inactive sitting tasks ranged from 1.45 to 1.56 (0.27-0.65) METs. Active seated games on the Wii yielded an average of 2.2 (0.43) METS (see Table 3.2). Standing yielded an average of 1.71 (0.29) METs. Walking MET values increased incrementally with speed from 2.33 (0.28) to 3.46 (0.54) METs.

mRMR values were not significantly different between healthy weight and obese participants nor between males and females for any activities (Table 3.2). However, for standardized METS in all activities there were significant differences between obese and healthy weight participants (Table 3.2). Obese participants had significantly lower MET values for all activities. There was no significant differences between male and female MET values ($p>0.05$) (data not shown). Generalized Estimating Equations (GEE) showed that walking speed predicted standardized MET values. Each 1 mile/h increase in walking speed was associated with a 0.79 ($p<0.001$) increase in MET value. These values were not modified by obesity status. (Table 3.3)

Table 3.2: Metabolic rate during some sitting activities and slow walking measured from the sample as a whole and in the normal weight and obese group separately. The table also shows the p values resulting from comparisons of the MET values measured during each task between normal weight and obese participants. Standard MET values have been calculated through the standardized MET formula: MET = VO_2 (mL/kg/min)/3.5 (mL/kg/min) and mRMR values have been calculated using participants' resting metabolic rate instead of 3.5.

	Standard MET values of sitting, standing and light walking tasks				**mRMR values of sitting, standing and light walking tasks**			
Activity	Total MET	Normal Weight MET	Obese MET	P value for between group difference	Total MET	Normal Weigh MET	Obese MET	P Value for between group difference
TV	1.33(0.24)	1.46 (0.19)	1.17 (0.20)	**$p < 0.001$**	1.45 (0.27)	1.40(0.20)	1.51 (0.33)	0.151
Typing	1.45(0.32)	1.62(0.23)	1.23(0.28)	**$p < 0.001$**	1.56(0.16)	1.57(0.18)	1.54 (0.16)	0.651
PSP	1.41(0.28)	1.58(0.21)	1.21(0.22)	**$p < 0.001$**	1.52(0.16)	1.50(0.13)	1.54(0.20)	0.358
Wii	2.06(0.50)	2.29(0.44)	1.80(0.44)	**$p < 0.001$**	2.22(0.43)	2.18(0.41)	2.28(0.46)	0.401
Standing Still	1.59(0.37)	1.74(0.34)	1.41(0.33)	**$p < 0.001$**	1.71(0.29)	1.65(0.22)	1.78(0.33)	0.105
Speed(mph)	**Treadmill Walking**							
0.2	2.17 (0.5)	2.44(0.44)	1.87(0.40)	**$p < 0.001$**	2.33(0.28)	2.31(0.28)	2.36(0.29)	0.509
0.4	2.27(0.26)	2.56(0.49)	1.94(0.44)	**$p < 0.001$**	2.43(0.28)	2.41(0.25)	2.44(0.33)	0.788
0.6	2.40(0.54)	2.67(0.46)	2.09(0.45)	**$p < 0.001$**	2.58(0.32)	2.52(0.26)	2.63(0.38)	0.228
0.8	2.55(0.62)	2.84(0.54)	2.21(0.53)	**$p < 0.001$**	2.73(0.37)	2.69(0.34)	2.77(0.41)	0.411
1.0	2.66(0.61)	2.97(0.46)	2.32(0.57)	**$p < 0.001$**	2.85(0.34)	2.81(0.33)	2.89(0.35)	0.401
1.2	2.83(0.67)	3.17(0.55)	2.45(0.59)	**$p < 0.001$**	3.03(0.36)	2.99(0.32)	3.06(0.41)	0.543
1.4	2.99(0.69)	3.30(0.57)	2.63(0.64)	**$p < 0.001$**	3.21(0.39)	3.12(0.35)	3.30(0.42)	0.150
1.6	3.22(0.53)	3.60(0.70)	2.80(0.63)	**$p < 0.001$**	3.46(0.54)	3.41(0.55)	3.53(0.52)	0.439

Table 3.3: Effect of walking speed on the METs increase

		95% Confidence Interval		P value
Parameter	B	Lower	Upper	Sig.
Obesity	0.152	-0.026	0.330	0.095
Speed	0.792	0.751	0.832	**$p < 0.001$**

3.5 Discussion

Sedentary behavior has been defined as any waking behavior characterized by an energy expenditure of ≤1.5 METs while in a sitting or reclining posture (Sedentary Behaviour Research Network, 2012, p. 540). Our study broadly supports this definition, but suggests that some sitting behaviors, such as playing a Wii computer game, may have a MET value above this threshold. Conversely, standing behaviors may actually have MET values below 1.5 when accompanied by no ambulation particularly in obese participants. MET values also increased rapidly with walking speed so that every increase in walking speed of 1 mph increased MET values by 0.79. MET values were significantly different between obese and healthy weight individuals during all conditions, but not between males and females. When standardized against resting metabolic rate, there were no significant differences in MET values (mRMR) between the healthy weight and obese groups, or between males and females.

Our results are broadly consistent with other studies which have measured sitting energy expenditure. These studies have shown that inactive sitting based activities (such as TV viewing) have MET values below 1.5 (Lante et al, 2010; Dos Anjos et al, 2011; Swartz et al, 2011; Whybrow et al, 2013; Newton et al, 2013). Our finding that metabolic activity during standing is similar or even lower than some sitting activities is consistent with other studies which have shown no significant differences between sitting and standing MET values (Cox et al, 2011, Weyand et al, 2009) Taken together, these results have important implications.

Sedentary behaviors have been strongly linked to metabolic health, morbidity and mortality with experimental research confirming the benefit of breaking sedentary behavior with bouts of light walking (Dunstan et al, 2012; Wilmot et al, 2012). But it is currently unknown whether the positive benefits of reduced sedentary behavior are primarily driven by increases in energy expenditure that accompany the transition into light activity, or to differences in postural allocation, or a combination of both (Thorp et al, 2014).

These results suggest that the energy gap between many sitting activities and standing without ambulation may be negligible; therefore suggesting differences in energy expenditure may be unlikely to explain any metabolic advantages of substituting sitting for standing based activities, unless accompanied by light movement or ambulation. We add to existing data by showing that any form of ambulation substantially elevates VO_2 and accompanying MET values even at very low speeds of walking such as 0.2 mph. This finding could be very important for behavioral change interventions which promote standing with very light movement. Such interventions may be feasible in the workplace to reduce, and break up, prolonged sitting in those with predominantly sedentary occupations, such as office workers (Clemes et al, 2014; Thorp et al, 2014).

The present results show that there were significant differences in standardized MET values between healthy weight and obese participants during all activities. This study therefore emphasizes the limitation of using a standardized resting VO_2 value of 3.5 ml/kg/min across all individuals. Although obese individuals have a higher absolute VO_2 value, the values per kg of body weight tends to be substantially lower than healthy weight individuals given that adipose tissue is less metabolically active than lean body mass. These findings are consistent with other studies that highlight the limitations of using a standardized number of 3.5 (mL/kg/min) for calculating metabolic rate (Byrne et al, 2005; Weyand et al, 2013). These findings could have important implications when METs are used for evaluating or prescribing physical activity intensity category (light, < 3 METs; moderate, 3–6 METs; vigorous, > 6 METs) (Pate et al, 1995). Using a standardized equation which is not adjusted for personal differences, could also affect the MET compendium (Ainsworth et al, 2011). For example in our study with the mRMR equation, moderate activity begins after a speed of 1.2 mph but with the standardized equation, moderate physical activity was observed at a walking speed of 1.6 mph. However, it should be noted that mRMR values were consistent across healthy weight and obese individuals which in turn were similar to the standardized MET values for healthy weight individuals. Therefore, although of academic interest, these finding do not justify the need to reclassify activity METs or intensity thresholds for different groups and suggest that standardized values give a good indication of the degree to which RMR are elevated across different body weight ranges.

This study showed that with every 1 mph increase in walking speed, metabolic rate will significantly increase by 0.79 METs, and this was the same for healthy weight and obese participants. This result is consistent with other studies which published regression equations to predict walking (Km/h) METs and energy expenditures (Bubb et al, 1985; McDonald et al, 1961), across different body size groups (Brooks et al, 2005; Weyand et al, 2013).

It was observed in this study that no significant differences in RMR were observed between the GEM ventilated hood and the Cortex calorimeter. To our knowledge, this is the first study to compare the Cortex calorimeter against a gold standard ventilated hood. These findings confirm the validity of the measures of energy expenditure taken by the Cortex in the main laboratory protocol. Findings also support the use of the Cortex calorimeter in studies where the assessments of RMR using a ventilated hood are not feasible.

The limitations of this study include having a relatively small sample and the assessment of a limited number of activities. Study strengths however include the novel comparison of energy expenditures during some lifestyle activities in a stratified sample of males and females, and healthy weight and obese adults.

3.6 Conclusion

The 1.5 MET threshold seems to be reasonable at distinguishing between most sitting and standing behaviors, however some common sitting behaviors may have a MET level above this. These findings have relevance to interventions aimed at reducing sitting and support the need for further research to unpick the minimum amount of ambulatory activity that needs to accompany standing in order to provide clinically meaningful benefits.

Chapter 4

Validity of the ActiGraph Inclinometer Algorithm for Detecting Sitting and Standing Postures

Validity of the ActiGraph Inclinometer Algorithm for Detecting Sitting and Standing Postures

This chapter describes the assessment of the criterion validity of the ActiGraph inclinometer algorithms for detecting sitting and standing postures when worn on the thigh and waist.

Findings from this chapter have been presented as an oral presentation at the International Congress on Physical Activity and Public Health in 2014 (Brazil, Rio de Janeiro) (Maedeh Mansoubi, Natalie Pearson, Stuart JH Biddle, Charlotte L Edwardson, Thomas Yates, Stacy A Clemes, Validity of the ActiGraph Inclinometer Algorithm for Detecting Sitting and Standing Postures).

4.1 Abstract:

The aim of this chapter was to assess the criterion validity of the ActiGraph inclinometer algorithms for detecting sitting and upright postures when worn on the thigh and waist. Thirty-nine adults (46% female, age: 31.0±8.8 years, BMI: 26.7±5.0 kg/m^2) were directly observed whilst participating in a range of seated activities (typing on a computer, watching television, playing a hand held computer game, seated playing on a Wii) and non-sedentary tasks (standing still, walking at 0.4-2.6 km/h), each lasting 10 minutes. Participants wore two ActiGraph GT3X+ accelerometers, one on the anterior aspect of their right thigh and one on their right hip. Time recorded in each posture according to the inclinometer algorithms during each task was compared to direct observation for each wear location. The inclinometer algorithm of the thigh-worn ActiGraph was 100% accurate at detecting upright postures in all non-sedentary tasks. During the sedentary tasks the error ranged from 4.7-8.1%. The error of the inclinometer algorithm of the waist-worn ActiGraph ranged from 2.4-39.1% for detecting non-sedentary tasks, with the exception of walking at 2.6 km/h (100% accurate). During the sedentary tasks the error ranged from 16.7-30.6%. The validity of the ActiGraph inclinometer algorithm for detecting sedentary and non-sedentary postures is improved when the device is worn on the anterior aspect of the thigh.

4.2 Introduction

Technological advances, societal influences and environmental attributes have significantly influenced the way we socialize, travel, work and shop resulting in substantial proportions of the day spent sedentary (Clemes et al, 2014). Sedentary behaviour has been defined as "*any waking behaviour characterised by an energy expenditure ≤1.5 METs while in a sitting or reclining posture*."(page 540) (Sedentary behaviour research network, 2012). High levels of sedentary behaviour have been shown to negatively affect health (Chau et al, 2013; Wilmot et al, 2012; Tomaz et al, 2014), and interventions are needed to combat this prevalent lifestyle behaviour. However, the accurate measurement of sedentary behaviour is essential to further our understanding of the links between sedentary behaviour and health, sedentary behaviour prevalence, determinants of sedentary behaviour and for the evaluation of interventions.

Due to their widespread use in physical activity research, accelerometers have become a popular choice of instrument for the objective estimation of sedentary time in addition to physical activity. However, accelerometers are commonly worn on the waist and have traditionally not provided information on body posture. They simply provide an estimate of sedentary time based on low levels of, or no, movement. Hence periods of standing still can therefore be misinterpreted as sitting (Atkin et al, 2012).

The ActiGraph accelerometer is a widely used accelerometer to provide a measure of sedentary behaviour, with a threshold of <100 counts per minute (cpm) commonly applied to denote sedentary time in adults (Craig et al, 2003). Significant associations between sedentary behaviour measured using this threshold and health indicators (e.g. blood glucose, waist circumference) have been identified in adults (Healy et al, 2007, 2008a,2008b). However, despite the widespread use of this cut-point (Hagstromer et al,2007; Matthews et al, 2008; Healy et al, 2011) this value was not empirically derived and studies reporting the validity of this cut-point are limited and conflicting (Hart et al, 2011a, 2011b; Kozey-Keadle et al, 2011). Research has shown that using this method to estimate sedentary time could mis-classify standing, which is accompanied with a lack of ambulatory movement but potential health benefits (Chaput et al, 2015). Therefore, there is a need for objective devices that can directly measure sitting and upright postures.

The newer versions of the ActiGraph accelerometer (GT3X and GT3X+) can produce information on body posture through the application of proprietary software algorithms created by the manufacturer. The algorithms, which have been developed for waist-worn and thigh-worn ActiGraphs, categorise the wearers' data into time spent sitting/lying, standing or device off. Few studies have described the validity of these algorithms (Carr et al, 2012; Steeves et al, 2014; Berendsen et al, 2014; Skotte et al, 2014). For example Carr et al (2012) examined the accuracy of the intensity and inclinometer output of two waist worn accelerometers (ActiGraph GT1M and GT3X+) under controlled conditions during various sedentary and light-intensity activities in a sample of 36 participants. Their sedentary behaviours included lying down, sitting watching television, and sitting using a computer, while their upright postures included standing still, walking at 1.0mph, pedalling at 7.0mph, and pedalling at 15.0mph. Their findings showed that both monitors accurately measured most behaviours (Carr et al, 2012).

In another study, Steeves et al. (2014) compared sitting, standing, and stepping classifications from thigh-worn ActiGraph and activPAL monitors under laboratory and free-living conditions with 21 participants and showed that differences in data processing algorithms may have resulted in observed disagreement in posture and activity classification between the thigh-worn ActiGraph and the activPAL in specific activity and/or posture types (Steeves et al, 2014). Berendsen et al. (2014) examined the validity of three different monitors at the same time: activPAL3, ActiGraphGT3X and CAM under controlled (n = 5) and free-living conditions (n = 9). This study showed that posture classification during sitting, lying and upright time was correct 33.9% of the time for the ActiGraph (worn at the waist) while the activPAL and CAM were100% accurate. Skotte et al. (2014) evaluated the validity of the ActiGraph GT3X+ inclinometer algorithms when worn on the thigh and hip during controlled and free-living conditions. Under free living conditions, the thigh-worn device demonstrated improved sensitivity (98%) and specificity (93%) for detecting sitting time compared to the hip-worn device (73 and 58% respectively).

Given the likelihood that accelerometers will continue to be used by researchers as a tool to measure both physical activity and sedentary behaviour, it will be important to determine the most valid method of using accelerometer data to provide an estimate of sedentary behaviour. The aim of the present study therefore was to assess the criterion validity of the ActiGraph inclinometer algorithms for detecting sitting and standing postures when worn on the thigh and waist.

4.3 Methods

4.3.1 Design and data collection

The data reported in this chapter were collected during the laboratory study reported in Chapter 3. In brief, this study was an experimental cross-over trial. In total, there were three conditions (sitting, standing/very light walking, and light walking). Within each condition there were several activities. See below and Chapter 3 (pages 67-69 for further details about the study design). All participants (see Chapter 3 (pages 63 for detailed information on the sample, recruitment methods and inclusion/exclusion criteria) completed each of the conditions and each of the associated activities. The original study was approved by the Loughborough University Ethical Advisory Committee and all participants provided written informed consent. Whilst the primary aim of the original study was to determine energy expenditure during common sitting and standing tasks, all participants wore two ActiGraph accelerometers (see Figure 4.1) throughout the protocol. The data from these measures are described within this chapter.

4.3.2 Measures

The ActiGraph GT3X+ (Actigraph LLC, Pensacola, FL, USA) is a small, lightweight tri-axial accelerometer (See Figure 4.1). Two devices were worn by all participants; the first was placed around their waist using an elasticated belt. The device was worn on the right side of the body above the mid-line of the thigh. The second device was placed on the anterior aspect of the non-dominant thigh, attached using an elasticated belt placed around the thigh. The devices were initialised to record data at 30Hz, and during the initialisation process the wear location (i.e. thigh or waist) was selected to ensure the appropriate inclinometer algorithm was applied to the data. According to the manufacturer, the GT3X+ inclinometer is capable of describing positional information during periods of inactivity due to gravitational forces acting on the orientation on the 3 axes. For example, when the device is worn on the waist, during periods of standing still the y-axis alone should contain the total acceleration due to gravity. As the individual reclines in a sitting posture, the offset angle of the y-axis increases. The software uses the following algorithm to estimate body posture based on the offset angle of the y axis when worn on the waist: standing = <17 degrees; sitting = 17 – 65 degrees; lying = >65 degrees, unless the offset angle of the z axis exceeds 22 degrees when the device would be classified as off (further technical details can be found in an inclinometer white paper provided by the manufacturer: https://docs.google.com/document/d/1EBAEcAL34k0ONZOgfXZPsMJJC-Uy9d49FFyPnmPH3Qc/edit?hl=en&authkey=CM--zvgE&pli=1). No information has been released by the manufacturer on the algorithm applied to thigh-worn data.

Figure 4.1. The ActiGraph GT3X+ (Actigraph LLC, Pensacola, FL, USA) is a small (4.6cm x 3.3cm x 1.5cm), lightweight (19g) tri-axial accelerometer. In this study participants wear one of the devices on their non- dominant thigh and another one around their waist http://www.actigraph.nl/en/product/7/gt3x.html

4.3.3 Procedure

As described in Chapter 3 (pages 67 – 69), participants performed a series of activities under 3 counter-balanced conditions (conditions A, B, C). The ‘sitting’ condition (condition A) involved the following four activities: 1) sitting watching television (TV: an episode of a TV drama), 2) sitting typing (each participant copied the same text from the same book), 3) sitting playing a hand-held computer game (participants played a tennis game with a PSP), and 4) sitting playing a TV screen-based computer game (participants played a tennis game with the Wii). The ‘standing and very light walking’ condition (condition B) included five activities: standing still (participants were asked to stand as if they were waiting in a queue) and walking at 0.4, 0.6, 1.0, and 1.3 Km/h on a treadmill (Technogym, Excite Med, UK). The ‘light walking’ condition (condition C) involved participants walking on a treadmill at 1.6, 1.9, 2.3, and 2.6 km/h. Each activity within the three conditions was carried out for 10 minutes under direct observation. The experimenter logged the time (start time and end time) participants spent in each condition, these data were compared to time-stamped data provided by the ActiGraphs and used in the analyses for this chapter (see below).

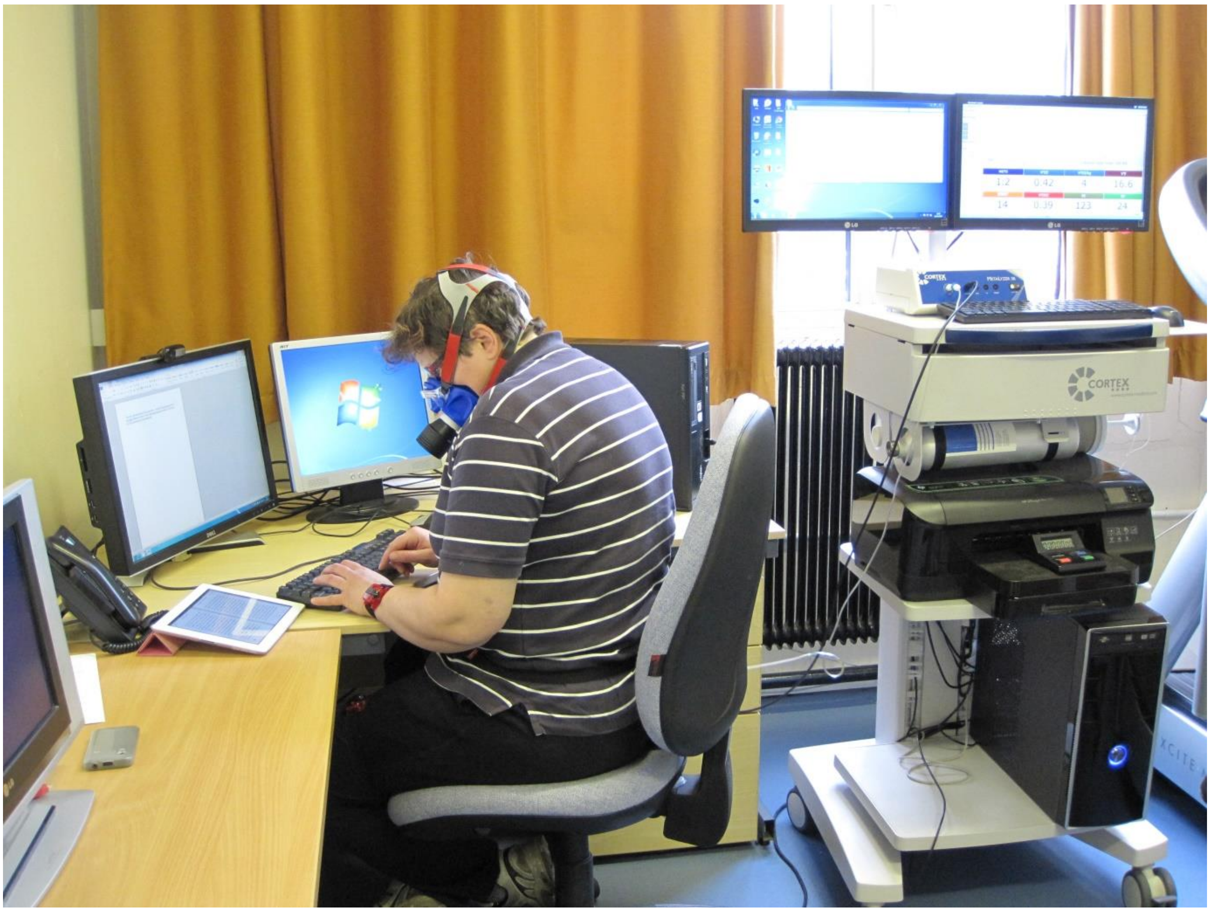

Figure 4.2. A participant taking part in the seated condition. The ActiGraphs were worn around the waist and on the anterior aspect of the thigh.

4.3.4 Data analysis

Data were collected during each activity for 10 minutes and downloaded and summarised at 15 second epochs using ActiLife version 6. The ActiGraph inclinometer algorithms coded posture into standing, sitting/lying, or device off for each epoch. Time recorded in each posture according to the inclinometer algorithm during each task was compared to direct observation for each wear location. The first two minutes and the last two minutes of data for each activity were removed from the analyses leaving six minutes for each activity (Carr et al, 2012). The sum of the number of epochs correctly classified as either sitting/lying or standing, based on direct observation of posture, during each activity, were calculated for each participant. The absolute percentage error ([number of epochs incorrectly classified/total number of epochs]*100) for each participant were calculated for each experimental activity. The mean percentage errors for each activity were then calculated for the sample as a whole for the waist and thigh worn devices.

4.4 Results

Of the fifty-one participants completing the protocol and used in the analyses presented in Chapter 3, ActiGraph data were obtained from 39 (46% female, age: 31.0±8.8 years, BMI: 26.7±5.0 kg/m^2) (see Table 4.1 for participant characteristics). Four participants reported not feeling comfortable when wearing the ActiGraphs, these individuals therefore chose not to wear the devices during the laboratory protocol. For five participants, the ActiGraphs positioned on their thighs fell off during the walking conditions. As the data were therefore incomplete for these individuals, they were removed from the analyses. Data from a further three participants were not included in the analyses due to a technical fault at the download stage.

Table 4.1: Descriptive characteristics of the sample, data are the mean and SD.

Demographic variable	Mean (± SD)
Age (years)	31.03 ± 8.7
Height (cm)	168.9 ± 10.1
Weight (kg)	77.6 ± 19.2
BMI (kg/m^2)	26.6 ± 5.02
Body Fat %	24.8 ± 8.1
Waist circumference (cm)	88.6 ± 14.5

Table 4.2 shows the absolute percent error of the ActiGraph inclinometer algorithms for identifying sitting/lying and upright postures during each condition, for each wear location. The inclinometer algorithm of the thigh-worn ActiGraph was 100% accurate at detecting standing postures in all non-sedentary tasks (standing still and slow walking). During the sitting tasks for this wear location, the error of the inclinometer algorithm ranged from 4.7% to 8.1%. The error of the inclinometer algorithm of the waist-worn ActiGraph ranged from 2.4% to 39.1% for detecting non-sedentary tasks, with the exception of walking at 2.6 km/h where it was 100% accurate in detecting standing. During the sitting tasks for this wear location, the error of the inclinometer algorithm ranged from 16.7% to 30.6% (Table 4.2).

Table 4.2 Inclinometer error percentage for detecting sitting and standing postures using different ActiGraph wear locations. A value of zero represents zero error, i.e., the inclinometer algorithm was 100% accurate at detecting the specific posture

Activity Error %	0.4 Km/h	0.6 Km/h	1 Km/h	1.3 Km/h	1.6 Km/h	1.9 Km/h	2.3 Km/h	2.6 Km/h	Standing still	TV	Wii	PSP	Typing
Thigh	0	0	0	0	0	0	0	0	0	4.6	7.8	6.6	8.1
Waist	38.4	34.2	39.06	35.2	30.7	18.8	2.4	0	38.009	22.9	30.6	16.7	30.6

4.5 Discussion

The current study indicates that the validity of the ActiGraph inclinometer algorithms for detecting sitting and non-sedentary postures is improved when the device is worn on the anterior aspect of the thigh rather than wearing it on the waist. This result is consistent with manufacturer guidelines which state that thigh-worn devices are inherently better at detecting sedentary (sitting/lying) versus non-sedentary (standing/stepping) time than waist-worn devices.

The present study used various sitting, standing and slow walking postures to assess the ActiGraph inclinometer algorithms validity. This study adds to the growing body of literature on the validity of the ActiGraph inclinometer algorithms at different wear sites. Carr et al. (2012), for example, examined the validity of the ActiGraph GT3X+ inclinometer algorithm at detecting a range of sitting, lying and standing tasks (including slow walking at 1 mph) against direct observation in 36 adults. In this study participants wore the two ActiGraph monitors on a belt over their left or right hips. In this study it was observed that the inclinometer algorithm correctly identified sedentary time between 63-67% of the time during the sedentary tasks, and non-sedentary time between 61% and 72% of the time during the standing and slow walking tasks, respectively. The findings from this study are consistent with the current study which showed that the waist worn inclinometer algorithm detects body posture correctly 60% of the time during slow walking (1.0 Km/h), with the validity increasing to 97-100% during faster walking. Findings of the present study are also similar to those of Berendsen et al. (2014), where it was observed that the waist worn ActiGraph was 33.9% accurate at distinguishing between sitting, lying and upright postures under controlled conditions.

The findings of the present study showed that the thigh worn ActiGraph inclinometer algorithm is 100% accurate for detecting body posture during slow walking and standing tasks. The results also showed that the thigh worn ActiGraph inclinometer algorithm was 95.4%- 91.1% accurate during four different sitting tasks. These findings are consistent with a study by Steeves et al. (2014) which compared sitting, standing, and stepping classifications from thigh-worn ActiGraph and ActivPAL monitors under laboratory and free-living conditions with 21 participants. In this study it was observed that in the laboratory, both monitors correctly classified standing time 100% of the time (Steeves et al., 2014). Also the current study is consistent with the findings of Skotte et al. (2014) who observed that the thigh-worn ActiGraph inclinometer algorithm was superior to the waist-worn algorithm at detecting sitting and non-sitting postures during controlled and free-living conditions in 17 participants.

The strength of this study is the use of the criterion measure of direct observation as the comparison measure, along with the range of both sedentary and non-sedentary conditions. The limitation of this study however is the small and homogeneous sample which limits generalisability. A further limitation of this study is the lack of a comparison measure such as the activPAL. The activPAL has consistently been shown to be a valid measure of posture in laboratory studies (Kozey-Keadle et al. 2011, Hart et al. 2011. Berendsen et al. 2014, Steeves et al. 2014) and further research should directly compare the validity of the thigh worn ActiGraph and the activPAL under laboratory and free-living conditions. Further studies with larger samples and also comparing different inclinometer devices in different body postures could be helpful for researchers to advance our understanding of the most accurate approach to objectively quantifying posture.

4.6 Conclusion

This study adds to our limited knowledge on the validity of the ActiGraph inclinometer algorithms applied to waist-worn and thigh-worn devices under controlled conditions. The study has demonstrated that the validity of the ActiGraph for detecting sitting and non-sedentary postures is improved when the device is worn on the anterior aspect of the thigh.

Chapter 5

Using sit-stand workstations in offices: is there a compensation effect?

Using sit-stand workstations in offices: is there a compensation effect?

This chapter examines the impact of sit-to-stand workstations on office workers sedentary time at work, and whether office workers compensate for any changes in workplace sitting by changing their sedentary time and physical activity outside working hours. This chapter has been published in Medicine & Science in Sports & Exercise (Mansoubi M, Pearson N, Biddle SJ, Clemes SA. Using sit-to-stand workstations in offices: is there a compensation effect? Epub: DOI: 10.1249/MSS.0000000000000802)

The findings from this chapter have also been presented at the International society for Behavioural Nutrition and Physical activity (ISBNPA), 2015 conference in Edinburgh.

The published version of this chapter featured in an article for the New York Times which is accessible via the following link:

http://well.blogs.nytimes.com/2015/11/04/stand-more-at-work-sit-more-at-home/?_r=0

This study has also been linked to a BBC Persian Health program:

https://www.youtube.com/watch?v=GI7UKUA4fn8&list=PLmdEvtplre60DHR3uTnnNd2IvAZ0PDTq2

5.1 Abstract

Sit-to-stand workstations are becoming common in modern offices and are increasingly being implemented in sedentary behavior interventions. The purpose of this study was to examine whether the introduction of such a workstation among office workers leads to reductions in sitting during working hours, and whether office workers compensate for any reduction in sitting at work by increasing sedentary time and decreasing physical activity (PA) outside work. Office workers (n=40; 55% female) were given a WorkFit-S, sit-to-stand workstation for 3 months. Participants completed assessments at baseline (prior to workstation installation), 1-week and 6-weeks after the introduction of the workstation, and again at 3-months (post-intervention). Posture and PA were assessed using the activPAL inclinometer and ActiGraph GT3X+ accelerometer, which participants wore for 7-days during each measurement phase. Compared to baseline, the proportion of time spent sitting significantly decreased (75±13% versus 52±16 - 56±13%), and time spent standing and in light activity significantly increased (standing: 19±12% versus 32±12 - 37±15%, light PA: 14±4% versus 16±5%) during working hours at all follow-up assessments. However, compared to baseline, the proportion of time spent sitting significantly increased (60±11% versus 66±12 - 68±12%) and light activity significantly decreased (21±5% versus 19±5%) during non-working hours across the follow-up measurements. No differences were seen in moderate-to-vigorous activity during non-working hours throughout the study. The findings suggest that introducing a sit-to-stand workstation can significantly reduce sedentary time and increase light activity levels during working hours. However, these changes were compensated for by reducing activity and increasing sitting outside of working hours. An intervention of a sit-to-stand workstation should be accompanied by an intervention outside of working hours to limit behavior compensation.

5.2. Introduction

Technological and social changes have significantly influenced the way we socialize, travel, work and spend our leisure time, and this has resulted in substantial proportions of the day spent in sedentary pursuits (i.e. sitting) (Clemes et al, 2014a). Sedentary behavior has recently been defined as "any waking behavior characterized by an energy expenditure of ≤1.5 METs while in a sitting or reclining posture" (p 540) (Sedentary Behaviour Research Network, 2012, p. 540). It refers to too much sitting rather than too little physical activity.

A growing body of epidemiological evidence has linked sedentary behavior to health risks including an increased risk of type 2 diabetes (Proper et al, 2011; van Uffelen et al, 2010; Yancey et al, 2004), metabolic syndrome (Edwardson et al, 2012; Florez et al, 2005; Ford et al, 2005), cancer (Dallal et al, 2012; Lynch et al, 2010; Matthews et al, 2002), obesity (Chau et al, 2012, Thorp et al, 2010) and all-cause and CVD mortality (Proper et al, 2011; van Uffelen et al, 2010; Dunstan et al, 2010). These associations have been shown to be at least partially independent of moderate-to-vigorous physical activity (MVPA). Furthermore, recent reviews have noted that there is an inverse association between some sedentary behaviors (mostly TV viewing or screen time) and leisure-time physical activity in adults (Mansoubi et al, 2014; Rhodes et al, 2012), providing evidence for time displacement. (where opportunities for physical activity are replaced by sedentary pursuits). Furthermore, research utilising isotemporal substitution modelling, i.e. replacing sitting with standing, walking and/or MVPA has been shown to reduce the risk of all-cause mortality (Stamatakis et al, 2015). Conversely the amount of light-intensity physical activity accumulated, for example during non-exercise related standing activities, has been linked to improved metabolic health (Alkhajah et al, 2012). Importantly these observations are often independent of MVPA and BMI (Thompson et al, 2011). Moreover, breaking long periods of sitting could be a promising avenue for interventions given evidence that increasing the number of breaks in sitting time per day (e.g. going from sitting to standing) is associated with health benefits (Gilson et al, 2012; Swartz et al, 2011).

Adults typically spend time sitting in three domains: the workplace, during leisure time (e.g. at home such as in front of a television) and for transport. Many adults in the UK are employed within sedentary occupations such as office work (Clemes et al, 2012). The majority of office workers' time is spent in sitting activities (Gilson et al, 2012). A recent study has shown that office workers typically sit for >10 hours/day, with over half of their total daily sitting time occurring in the workplace (Clemes et al, 2015). The workplace, therefore, represents a promising environment in which to undertake interventions to reduce sitting time.

The incorporation of sit-to-stand workstations may be an effective strategy for reducing sitting at work. Limited evidence has been published to date on the utility of sit-to-stand workstations although studies are now emerging (Alkhajah et al, 2012; Straker et al, 2013; Healy et al, 2013). According to the ActivityStat hypothesis, when physical activity is increased or decreased in one domain, there will be a compensatory change in another domain, in order to maintain an overall stable level of physical activity or energy expenditure over time (Gomersall et al, 2013). However, no studies exist concerning compensation of sedentary behavior or physical activity with the use of sit-to-stand workstations in office workers. In other words, do those using sit-to-stand workstations during working hours compensate by sitting for longer or being less active outside of work? The purpose of this study, therefore, was to investigate sedentary behavior and physical activity compensation outside working hours in a sample of office workers exposed to sit-to-stand desks in the workplace.

5.3. Methods

5.3.1 Participants

A convenience sample of office workers from a range of administrative departments (including: engineering, finance, facilities and the School of Sport, Exercise and Health sciences) from Loughborough University were recruited. All the participants had to have primarily desk-based jobs and the capacity to include a sit-to-stand workstation on their desk. Participants were recruited through email and posters. Before an initial screening visit (see below), participants were sent a participant information sheet via email (Appendix 5.1) and a copy of the consent form (Appendix 5.2). . Participants with the following conditions were excluded from the study: any physical condition or illness which prevented full participation in the study, inability to communicate in spoken English, pregnant at baseline, planning relocation to another worksite during the study period, and planning holidays during the study period. The study received ethical approval from the Loughborough University Ethical Advisory Committee and participants provided written informed consent. Forty male (45%) and female (55%) office workers age 18 - 65 years commenced the study, most of the participants in this study were White British.

5.3.2 Familiarisation visit and screening

Interested potential participants were invited to the laboratory at least 2 weeks before the main trial for a familiarisation visit. During this visit, participants were screened for inclusion/exclusion into the study using a standard health screening tool (Appendix 5.3). Following successful screening, eligible participants were shown the sit-to-stand workstation, ActiGraph and activPAL assessment devices and provided with an opportunity to try the workstation, familiarize themselves with the measurement devices and ask questions about the protocol. During this visit, anthropometric measures were taken which included height (measured using a portable stadiometer, Seca UK), waist circumference (measured mid-way between the lower rib margin and the iliac crest using anthropometry tape), and body weight and composition (measured using a Tanita Body Composition Analyzer, model: BC-418 MA, Tanita, UK). For further information on the validity of this measure of body composition, see Chapter 3 page 64. Participants were asked to wear the ActiGraph and activPAL for the following 14-days to assess habitual physical activity and sedentary behavior prior to desk installation.

5.3.3 Objectively measured sitting time and physical activity

Participants wore an activPAL3 inclinometer (PAL Technologies, Glasgow, Scotland), which provides a direct measure of postural allocation (sitting or standing) and walking. The activPAL3 is a single-unit monitor based on a uniaxial accelerometer which is worn on the anterior aspect of the thigh (see Figure 5.1).

Figure 5.1. This figure shows the ActivPAL3 which participant wore on the anterior aspect of their thigh. http://www.paltech.plus.com/products.htm

The monitor produces a signal related to thigh inclination and has been shown to be a valid and reliable measurement tool for determining posture during activities of daily living in a healthy population (Busse et al, 2009; Dahlgren et al, 2010; Godfrey et al, 2007; Ryan et al, 2006). With this inclinometer device researchers are able to objectively measure time spent sitting/lying, standing and walking, sit-to-stand transitions and step counts (Ryan et al, 2006; Busse et al, 2005).

The activPAL was placed within a nitrile sleeve and attached to the leg using a waterproof hypoallergenic medical dressing (BSN Hypafix), enabling participants to wear the device continuously (24 h a day) (see Figure 5.1). activPAL data were considered valid if participants wore the device for at least 600 minutes per day on at least three weekdays and one weekend day during each measurement period. Participants were asked to wear the activPAL continuously for two weeks following the familiarization and anthropometry screening visit at baseline, and for seven consecutive days on a further 3 separate occasions: one-week, 6-weeks and 3-months after receiving the sit-to-stand workstation. To be included in the analyses, participants were required to have provided at least four full days (>600 minutes of wear) of data (including at least 3 workdays and 1 non-workday) during each monitoring period.

Along with the activPAL, participants were also asked to wear an ActiGraph GT3X+ accelerometer (ActiGraph, Pensacola, FL, USA) to assess free-living physical activity (See Figure 4.1 in Chapter 4, page 82). In addition to the assessment of physical activity, the accelerometer also provided an *estimate* of sedentary time through lack of movement counts using the widely used <100 cpm cut-point (Atkin et al, 2012). The results of Chapter 4 suggested that the ActiGraph inclinometer was not 100% valid for detecting body posture therefore in this study the ActiGraph was only used for the assessment of physical activity. Data from the sedentary time estimate using the <100 cpm cut-point approach are presented for descriptive purposes only. This triaxial accelerometer is one of the most widely used and extensively validated tools for assessing physical activity intensity (Freedson et al, 1998). The Freedson cut-points were used to estimate time spent in light intensity activity (100 – 1951 cpm) and MVPA (≥ 1952 cpm) (Freedson et al, 1998). Accelerometer data were considered valid if there were more than 600 minutes of monitoring per day (excluding continuous strings of zero counts for 60 minutes or longer) recorded on at least three weekdays and one weekend day on each measurement time point (Matthews et al, 2012).

A two week monitoring period was initially chosen at baseline to examine any reactivity occurring in response to the measurement protocol (Clemes and Deans, 2012). As no significant differences in any behaviour measured occurred between these two weeks (data not shown), the data were averaged across weeks, and seven-day monitoring periods were applied during the follow-up periods. Participants were asked to complete an activity monitor log book over each monitoring period in order to document monitor wear time, start and finish work times on working days and sleep patterns (i.e. time in bed). Participants sleeping times, monitor removal and invalid days were excluded.

5.3.4 Experimental protocol

Following the 14 day baseline assessment, participants received a WorkFit-S, sit-to-stand workstation (Ergotron, Inc, St. Paul, MN, USA) for 3 months (Figure 5.2) alongside a 6-page booklet including information about the advantages of sit-to-stand working. The booklet also contained some guidelines about the desk height adjustment and also introduced an online planning tool for comfortable computing (www.computingcomfort.org). Participants then undertook three, 7-day assessment phases: 1-week, 6-weeks, and 3-months after the desk had been installed. The 1-week follow-up took place 1–3 days after completion of the baseline assessment, with this assessment also corresponding with the first 7 days following workstation installation.

Figure 5.2. A study participant using the Workfit-S sit-to-stand workstation in both sitting and standing postures.

5.3.5 Data processing and analysis

As with any accelerometer worn on the hip, the ActiGraph is not capable of detecting sitting time due to its inability to directly measure posture (Hart et al, 2011). Therefore whilst the ActiGraph accelerometer provides an estimate of sedentary time, these data were included in the results for descriptive purposes only. activPAL-determined sitting, standing and stepping time data were used primarily to address the research question of whether the use of sit-to-stand workstations led to changes in these behaviors during and outside working hours. The ActiGraph data were primarily used to determine whether time in different physical activity intensities (light activity and MVPA) differed during and outside working hours over the intervention period.

All activPAL data were downloaded using manufacturer proprietary software (activPAL Professional v.7.2.29) in 15-s epochs and processed using a customized Microsoft Excel macro. The number of minutes that participants spent sitting, standing and stepping during waking hours (based on participants log book entries) were obtained for each working day.

To enable the examination of the influence of the sit-to-stand desks on behavior during working and non-working hours, sitting, standing and stepping time were extracted for working and non-working hours (based on provided dairy logs) from the daily weekday data. To account for differences in ActivPAL wear times between each segment of the day (working/non-working hours) and between the baseline and follow-up assessments, the proportions of wear time spent sitting, standing and stepping were calculated for each participant during each measurement period. These data were used in the analyses as opposed to the absolute minute data.

All ActiGraph data were downloaded using manufacturer proprietary software (ActiLife v.6.11.8) in 15-s epochs and processed using a customized Microsoft Excel. The number of minutes that participants spent in sedentary, light-intensity activity and in MVPA during waking hours was obtained for each working day. As with the ActivPAL data (and using the same procedures), times spent sedentary, and in light intensity activity and MVPA were calculated throughout waking hours, and during working and non-working hours on workdays for participants. To control for differences in accelerometer wear time, the proportions of time spent in each type of behavior were used in the analyses. Absolute minute data derived from both the activPAL and ActiGraph are presented in the results for descriptive purposes. All participants complied to the monitoring protocol and provided at least 3 workdays and 1 non-workday of activPAL and ActiGraph data during each measurement period. Any days with missing data (due to monitor removal) were treated as missing data and the mean time, and proportion of time, spent in each behavior during and outside of working hours were calculated from the remaining data.

The Shapiro–Wilk test confirmed that all proportion and minute data from both devices were normally distributed. For the activPAL and ActiGraph data, the mean proportions of times spent in each behavior on workdays at baseline, 1-week, 6-weeks and 3-months follow-up were calculated for each domain (waking hours, working and non-working hours) and compared using repeated measures ANOVA’s. In the event of a significant ANOVA result, Bonferroni-corrected post hoc comparisons were undertaken to determine where the significant differences occurred. $P < 0.05$ was considered significant, unless otherwise stated, and all tests were 2-sided. All statistical analyses were performed using SPSS v.22 (SPSS Inc., Chicago, IL, USA). Data are displayed as mean (± SD) in the text and tables.

5.4. Results

Forty male and female office workers age 18 - 65 years completed the study, representing a 100% retention and compliance rate. Participant characteristics are displayed in Table 5.1.

Table 5.1. Demographic characteristics of the study sample (data are presented as the mean±SD)

	Males (n = 18)	Females (n = 22)	Total (n = 40)
Age (years)	31.5±8.6	32.3±7.9	31.9±8.2
Height (cm)	177.4±7.4	165.3±6.2	170.8±9
Weight (kg)	81.5±12	66.6±15.1	73.3±15.5
BMI (kg/m^2)	25.9±3.5	24.3±4.9	25±4.4
Percent body fat	20.5±6.3	29±10.2	25.2±9.5
Waist circumference (cm)	85.5±8.7	75.9±10.8	80.2±10.9

5.4.1 ActivPAL-determined sitting, standing and stepping time

Total sitting time on workdays significantly decreased from 605±83 mins/day at baseline to 517±70 mins/day at 1-week, 546±65 mins/day at 6-weeks and 561±65 mins/day at 3-months follow-up (p<0.001). Total standing time increased significantly from 289±80 mins/day at baseline to 383±85 min/day at 1-week, 350±70 min/day at 6-weeks and 344±68 min/day at 3-months follow-up (p<0.001). No differences were seen for total stepping time. At baseline participants spent 605±83 mins/day sitting on a workday, compared to 357±149 mins/day sitting on a non-workday (p<0.001). On workdays 49.3 % of daily sitting time was derived from sitting at work.

During working hours, compared to baseline, the proportion of time spent sitting significantly decreased at 1-week, 6-weeks and 3-months follow-up (p<0.01), while the proportion of time spent standing and stepping significantly increased at all follow-up periods (p<0.01) (Table 5.2 and Figure 5.3). During non-working hours, compared to baseline, the proportion of time spent sitting significantly increased at 6-weeks and 3-months follow-up while the proportion of time spent stepping significantly decreased at 1-week, 6-weeks and 3-months follow-up (p<0.01). No differences were seen in standing time during non-working hours (Table 5.2).

Table 5.2. activPAL-determined time spent sitting, standing and stepping during and outside working hours on workdays as baseline, 1-week, 6-weeks and 3-months follow-up following sit-to-stand workstation use. Data are presented as the mean±SD. To control for wear time, the proportion data were used in the primary analyses, however the absolute time data (in minutes) are provided for descriptive purposes.

	Working hours on workdays				Non-working hours on workdays			
	Baseline	Week 1	Week 6	3 Months	Baseline	Week 1	Week 6	3 Months
% of wear time spent sitting	76±13	52±16*	56±13*	56±13*	60±11	64±11	66±12*	68±12*
Time spent in sitting (mins)	299±85	254±81*	259±63	266±66	307±82	264±59*	287±66	295±62
% of wear time spent standing	19±12	37±15*	33±12*	32±12*	26±8	24±8	24±9	23±9
Time spent standing (mins)	92±50	238±92*	207±71*	208±66*	198±69	146±47*	144±55*	136±50*
% of wear time spent stepping	5±3	11±5*	12±5*	12±4*	14±5	12±5*	11±4*	9±4*
Time spent stepping (mins)	19±8	52±22*	54±24*	58±17*	71±31	48±23*	45±20*	40±17*
Wear time (mins)	409±69	544±58	519±45	532±47	574±117	457±58	475±73	471±67

*Significantly different to baseline. Add an explanation under here. This is one of the tables that John asked for more information on

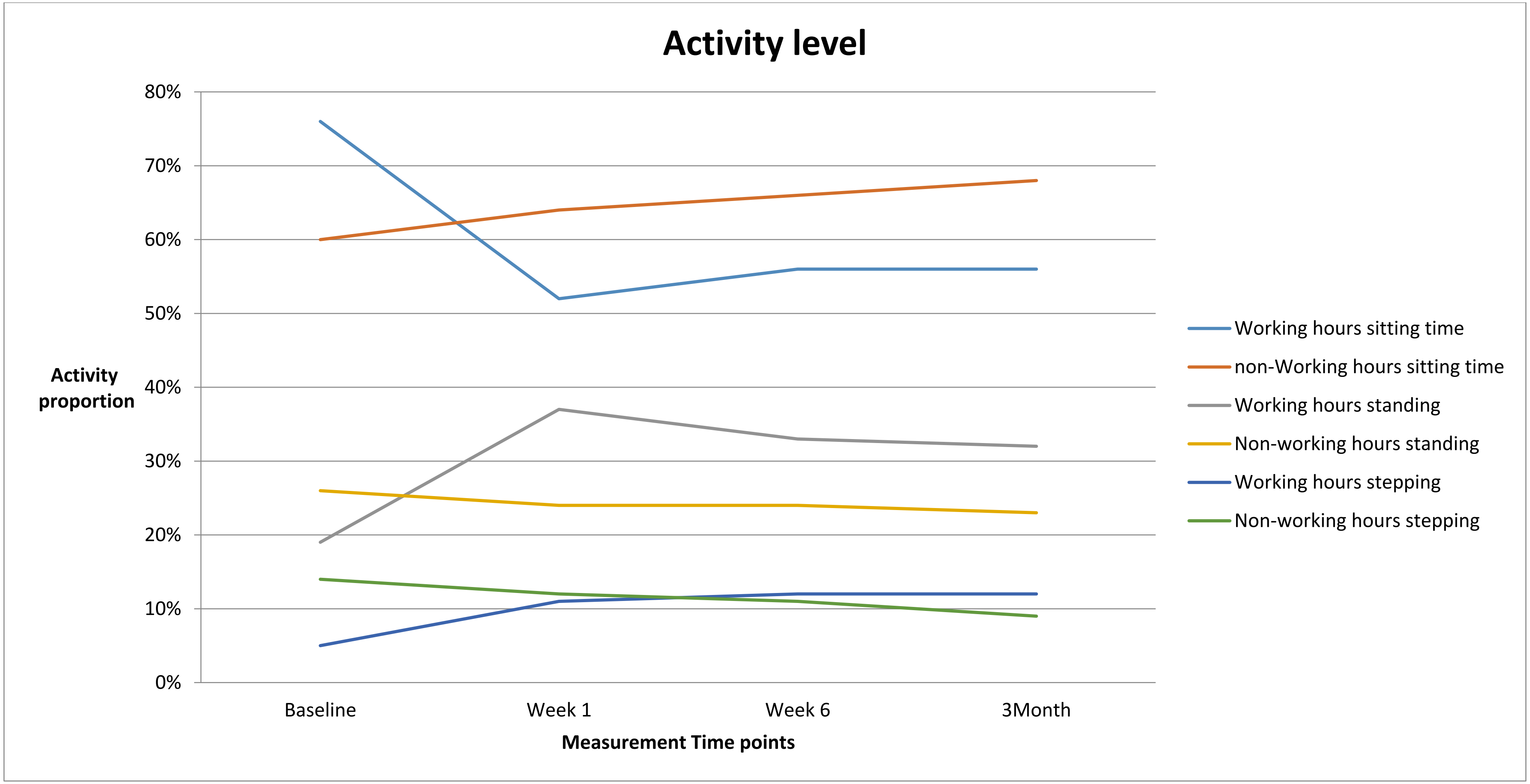

Figure 5.3: The proportion of time spent sitting, standing and stepping during and outside working hours measured using the activPAL at Baseline, Week 1 after receiving the workstation, Week 6 and 3 months. (See the data in Table 5.2)

5.4.2 ActiGraph-determined physical activity and sedentary time

At baseline participants spent 148±31 mins/day in light intensity activity, equating to 16.7% of waking hours. During week 1 of workstation use, daily time in light activity increased to 157±25 mins/day (17.6% of waking hours). There were no significant changes in the overall proportions of times participants spent in light activity on workdays at 6-weeks and 3-months follow-up. At baseline, participants spent 47±16 mins/day in MVPA (5.4% of waking hours) on workdays. There were no significant changes in the overall proportion of times spent in MVPA on workdays at each follow-up period.

During working hours, compared to baseline, the proportion of time spent in light activity significantly increased at 1-week, 6-weeks and 3-months follow-up (p<0.01). The proportion of time spent in MVPA during working hours also increased significantly at 1-week and 6-weeks. During non-working hours, compared to baseline, the proportion of time in light activity significantly decreased at 1-week and 6 weeks follow-up. No significant differences were seen in MVPA during non-working hours. Small, but significant decreases in ActiGraph-determined sedentary time were seen during working hours, relative to baseline, in weeks 1 and 6. Correspondingly, small increases in ActiGraph-determined sedentary time were seen outside working hours in weeks 1 and 6 (Table 5.3 and Figure 5.4).

Table 5.3. ActiGraph-determined time spent sedentary, in light activity and MVPA during and outside working hours on workdays as baseline, 1-week, 6-weeks and 3-months follow-up following sit-to-stand workstation use. Data are presented as the mean±SD. To control for wear time, the proportion data were used in the primary analyses, however the absolute time data (in minutes) are provided for descriptive purposes.

	Working hours on workdays				Non-working hours on workdays			
	Baseline	Week 1	Week 6	3 Months	Baseline	Week 1	Week 6	3 Months
% of wear time spent sedentary	82±5	78±7*	79±6*	80±6	70±7	73±8*	74±8*	72±7
Time in sedentary behavior (mins)	333±40	374±43*	366±41*	366±47*	316±42	299±40*	253±49*	321±56
% of wear time in light activity	14±4	16±6*	16±5*	16±5	21±5	19±5*	19±5*	20±6
Time in light activity (mins)	53±18	79±27*	73±22*	72±24*	96±29	79±23*	78±24*	72±23*
% of wear time in MVPA	4±1	6±3*	5±3*	5±2	9±5	8±6	7±5	8±6
Time in MVPA (mins)	16±8	24±12*	21±10*	17±7	32±19	26±21	24±16*	31±21
Wear time (mins)	440±44	482±34	464±33	458±40	451±63	410±36	412±57	445±67

* Significantly different to baseline same as above tbale – add more detail

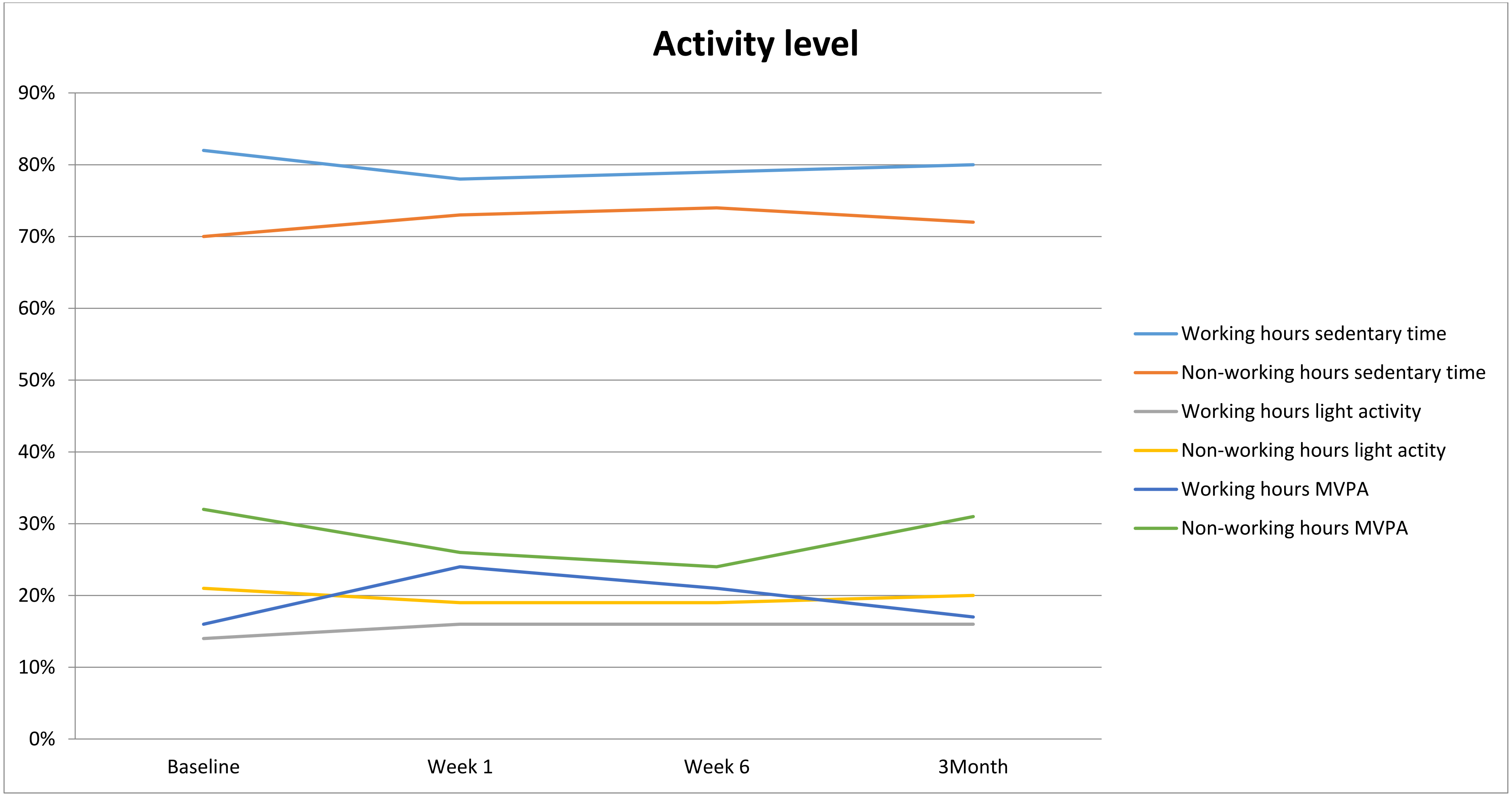

Figure 5.4: The proportion of time spent sedentary, and in light activity and MVPA during and outside working hours measured using the ActiGraph at Baseline, Week 1 after receiving the workstation, Week 6 and 3 months. (See the data in Table 5.3)

5.5. Discussion

This study provides novel evidence of the presence of sedentary behavior compensation outside working hours in office workers utilizing sit-to-stand workstations. At baseline participants were sedentary for ~10 hrs/day on a workday, with ~50% of this total daily sedentary time coming from sitting at work. This is in line with previous research (Chau et al, 2012, Clemes et al, 2015; Clemes et al, 2014a) and confirms the importance of the workplace as a site highly suitable for interventions to reduce sitting time. Results from the current study showed that using sit-to-stand workstations is an effective way of reducing sedentary time during working hours. This result is consistent with other studies (Chau et al, 2014). However, for the first time, this study examined compensation of sedentary behavior outside working hours and findings indicated that participants were more sedentary during non-working hours at 1-week, 6-weeks and 3-months after workstation installation, compared to baseline.

Despite the compensation effect observed in the present study, overall sedentary time across the day was still reduced when participants were using sit-to-stand desks at work. Total daily sedentary times fell to approximately 8.5 hours/day during week 1 of desk use, and gradually rose to 9 hours/day at week 6 and to 9 hours 20 minutes/day at 3-months. Evidence has demonstrated an increased risk of coronary heart disease and mortality in individuals sitting for over 10 hours/day (Petersen et al, 2014), the reductions in daily sedentary times observed in the present study, if maintained, could therefore have clinically meaningful health benefits in the present sample. Our knowledge of a specific duration of sitting time that represents an increased risk of disease is incomplete however, with other research demonstrating that chronic disease risk is increased with sitting durations of over 8 hours/day (George et al, 2013).

The findings also demonstrate that using sit-to-stand workstations are an effective way of increasing standing and stepping time during working hours. These findings are consistent with other studies (Alkhajah et al, 2012; Chau et al, 2014; Healy et al, 2013; Neuhaus et al, 2014). Thus as a result of the intervention, participants time in light intensity activity significantly increased during working hours. Slight increases in MVPA were also observed during working hours during the early weeks of the intervention. A recent study has shown that reallocating just 30 minutes of sedentary time per day to light movement is associated with a 2–4% improvement in cardio-metabolic biomarkers (Buman et al, 2014). Also there is evidence which suggests replacing sedentary time with light-intensity physical activity or MVPA is associated with positive influences on insulin sensitivity (Yates et al, 2015) and plasma glucose (Thorp et al, 2014). Such changes observed in light intensity activity during working hours could lead to important health benefits in previously sedentary office workers.

Results from the activPAL, in terms of stepping time, and findings from the ActiGraph, in terms of time in light intensity activity, both confirmed that the proportion of time in these behaviors reduced outside of working hours during sit-to-stand workstation use. These findings suggest that in order for originally sedentary workers to achieve optimum benefits from sit-to-stand working, interventions and public health messages should also target the promotion of light intensity activities outside of the workplace. Of interest, time in MVPA did not change outside of working hours in the present sample, suggesting that the use of sit-to-stand desks in the workplace may not have a detrimental effect on leisure time MVPA.

Findings of the current study lend partial support to the ActivityStat hypothesis which proposes that as physical activity is increased or decreased in one domain, there will be a compensatory change in another domain (Gomersall et al, 2013). Whilst we saw reductions in sedentary time and increases in light intensity activity during working hours and compensatory changes in these behaviors outside working hours, the magnitude of the compensatory changes were not as great as the changes in sitting and light activity seen during working hours, suggesting that participants did not fully compensate for the beneficial changes made during working hours.

Despite the initial novelty effect, the present results showed that using a sit-to-stand workstation can increase standing time by ~4 h/day in week 1 and ~3.4 h/day at 3-months which suggests that this change could be significant in terms of health (Buckley et al, 2015). Findings demonstrated that participants increased their standing time at work, relative to baseline, by approximately 146 minutes (~2.4 hours) during week 1. Participants' standing time during working hours increased from 91 minutes (~1.5 hours) at baseline to 237 minutes (~4 hours) in week 1, dropping to ~3.5 hours during the subsequent follow-up measurement periods. Whilst direct comparisons with other sit-to-stand workstation interventions are difficult, due to differences in procedures adopted for data processing, the magnitude of the changes in standing time seen in the present study is similar to those observed in other interventions. For example, when normalizing their data to an 8-

hour workday, Healy et al. 2013 and Alkhajah et al. 2012 reported increases in standing time of 121 and 130 minutes/day, in their intervention groups, relative to baseline. According to a recent expert statement, office workers should set their goal to achieve 2 hours/day of standing and light activity (light walking) during working hours, eventually progressing to a total accumulation of 4 hours/day (Buckley et al, 2015). It is recommended in the statement that sit-to-stand desks could be a useful tool in which to support office workers in achieving these goals. The present study supports this statement. The findings indicate however thatsit-to-stand desks may not be sufficient over the long term and therefore in order to keep participants motivated, interventions may need to go beyond simply installing sit-to-stand desks. For example, additional strategies such as educational material on the negative health effects of prolonged sitting, and/or office activities to encourage standing or stepping may need to be adopted in order for office workers to achieve and sustain the recommendations in this expert statement. It should be noted that these recommendations were not based on a comprehensive review of the literature, and further interventions are required to assess their feasibility, adherence and impact on health.

Whilst the activPAL provided the primary measure of sitting in the present study, ActiGraph-determined sedentary time (using the <100 cpm cut-point) was also presented for descriptive purposes. Discrepancies between these two common measures were observed. During working hours at baseline, participants spent 76% of their time sitting according to the activPAL, while the proportion of time spent sedentary according to the ActiGraph was 82%. In week one of the intervention, according to the activPAL the proportion of time spent sitting at work decreased to 52% (representing a reduction of 24%), while the proportion of time spent sedentary at work decreased to only 78% (a reduction of 4%) when assessed by the ActiGraph. These observations suggest that the ActiGraph cut-point approach is not sensitive enough to measure changes in sedentary behavior in interventions, supporting earlier observations (Kozey-Keadle et al, 2011).

This study provides novel information on how sedentary behavior and physical activity are compensated outside working hours in a sample of office workers from the UK exposed to sit-to-stand desks. The objective measurement of posture and physical activity using the activPAL ActiGraph are strengths of this study as such measures overcome the limitations of bias and recall, common with self-report measures. Limitations of this study include the small and relatively homogenous convenience sample and relatively short term follow-up (3 months). The 100%

compliance rates to all measurement phases and the relatively large changes seen in sitting and standing during working hours suggest the present sample may have been a highly motivated group. Similarly high compliance and follow-up rates have been observed however in other workplace sit-to-stand desk interventions, with reported follow-up rates ranging from 81-100% (Alkhajah et al, 2012; Chau et al, 2014; Healy et al, 2013; Neuhaus et al, 2014). Further research should examine the impact of sit-to-stand workstations on sedentary time during and outside working hours in diverse groups to extend the generalizability of the present and existing studies. This study did not employ a process evaluation or any qualitative components. Further research would benefit from the inclusion of such components to help further our understanding of whether participants consciously or sub-consciously change their behaviors outside of the working environment.

In conclusion, the findings suggest that introducing sit-to-stand workstations can significantly reduce sedentary time and increase light activity levels during working hours. However, it appears that the changes in sedentary behavior and physical activity during working hours were compensated for by reducing activity and increasing sedentary behavior outside of working hours. Nonetheless, despite this compensation effect, overall sedentary time was still reduced when office workers used the sit-to-stand workstations relative to their traditional seated desk. Such overall reductions in sedentary time and increases in light activity could lead to substantial health benefits in traditionally sedentary workers. Further research is required to examine the long-term use of sit-to-stand desks on changes in sedentary time, and resultant effects on markers of health. Further studies investigating the notion of behavior compensation are also warranted.

Chapter 6

GENERAL DISCUSSION

Chapter 6 **_General Discussion_**

This thesis has presented four distinct but interlinked studies, which have: reviewed associations between physical activity and sedentary behaviour in adults; examined the energy cost (METs) of common sitting, standing and light physical activity tasks; assessed the criterion validity of the ActiGraph inclinometer algorithms for detecting sitting and standing postures when worn on the thigh and waist; and described the evaluation of an intervention which examined whether the introduction of sit-to-stand workstations in office workers would lead to reductions in sedentary behaviour during working hours and whether office workers would compensate for a reduction in sedentary time at work by increasing sedentary time and decreasing physical activity outside of working hours.

This chapter summarises the main findings, strengths and limitations of each study reported within the thesis, and contextualises the importance of these findings. General conclusions and implications for future research and practice are also offered.

Key findings and implications

6.1 Chapter 2 - The Relationship between Sedentary Behaviour and Physical Activity in Adults: A Systematic Review

To our knowledge, this was the first systematic review of its kind to present a synthesis of evidence documenting the associations between sedentary behaviour and physical activity in adults. The associations between these behaviours were evaluated across five domains of sedentary behaviour and nine domains of physical activity.

One of the key findings of this chapter was that the most commonly reported method of assessing sedentary behavior and physical activity in the included studies was via self-report. The majority of these studies reported small to medium inverse associations between sedentary behavior and physical activity. Only a few studies utilised objective measurements. The studies which objectively assessed sedentary behaviour and physical activity generally demonstrated small to medium inverse associations between sedentary time and MVPA, and medium to large inverse associations between sedentary behavior and light intensity physical activity. Given that light physical activity typically involves standing and light ambulation, these incidental behaviours tend to be more prevalent when an individual is not sitting, as opposed to MVPA which is likely to be more structured. It is therefore logical to expect a stronger relationship between sedentary behavior and light activity, with sedentary time more likely to displace light intensity activities than MVPA. Given the strong links between sedentary behavior and light physical activity, interventions targeting breaking up sedentary behaviour, and/or reductions in sedentary behavior should initially target promoting increases in light intensity activity.

In the context of this thesis, this systematic review was of primary importance as it was instrumental in shaping and informing the direction of the research described in later chapters. While sedentary behaviour has been defined as "*any waking behaviour characterized by an energy expenditure of <1.5 METs while in a sitting or reclining posture*" (Sedentary Behaviour Research Network, 2012, p. 540), the utility of this 1.5 MET definition is poorly understood. For example, in the compendium of physical activities, sedentary activities such as sitting at a desk, sitting in a vehicle, sitting watching television, have been coded with MET values ranging from 1.0-2.5, but standing activities, such as watering the lawn or garden, which are not classified as sedentary activities in the above definition are coded with a MET value of 1.5 (Ainsworth et al. 2011). In addition, playing computer games (often categorised as sedentary behaviours in self-report questionnaires) have been found to have MET values as high as 4.5 (Ainsworth et al. 2011). Moreover, it has been claimed that standing, rather than sitting, can have significant health benefits, yet it is unclear as to the precise MET value of standing and sedentary behaviours. Moreover, unless we have more precise or agreed operational definitions of sedentary behaviour, we will be hampered in our efforts to understand the levels of sedentary behaviour associated with deleterious health outcomes (Ainsworth et al. 2011). Because of the confusion around this issue, further testing was required to examine the accuracy of the 1.5 MET definition for separating sedentary behaviour from light activity. Therefore the current thesis included a lab study to assess the MET values of several daily lifestyle tasks and investigated the distinction between sedentary behaviours (sitting) and light activity.

6.2 Chapter 3 - Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour

Sedentary behaviour, as stated above, has been defined “*any waking behaviour characterized by an energy expenditure of <1.5 METs while in a sitting or reclining posture*” (Sedentary Behaviour Research Network, 2012, p. 540). The aim of this chapter was to examine the utility of this definition in a laboratory study. The findings broadly support this definition, but suggest that some sitting behaviors, such as playing a Wii computer game, may have a MET value above this threshold. Conversely, standing behaviours may actually have MET values below 1.5 when accompanied by no ambulation particularly in obese participants. MET values also increased rapidly with walking speed so that every increase in walking speed of 1 mph increased MET values by 0.79.

This chapter also showed that there were significant differences in standardized MET values between healthy weight and obese participants during all activities. This study therefore emphasizes the limitation of using a standardized resting VO_2 value of 3.5 ml/kg/min across all individuals. Although obese individuals have a higher absolute VO_2 value, the values per kg of body weight tends to be substantially lower than healthy weight individuals given that adipose tissue is less metabolically active than lean body mass.

A very important finding of this chapter was the comparison between resting metabolic rate (RMR) measured between the Cortex calorimeter and the gold standard ventilated hood. The findings showed no significant differences in RMR between the GEM ventilated hood and the Cortex calorimeter. These findings confirm the validity of the measures of energy expenditure taken by the

Cortex in the main laboratory protocol. Findings also support the use of the Cortex calorimeter in studies where the assessments of RMR using a ventilated hood are not feasible.

Physical activity intensities have been categorised as <3 METs for light activity, 3–6 METs for moderate activity and >6 METs for vigorous activity (Pate et al, 1995). According to the findings of Chapter 3, the MET standard formula, which is MET = VO2 (mL/kg/min)/3.5 (mL/kg/min), suggests that standing could be categorised as light activity because the standing still MET value was above 1.5 MET, supporting the use of this definition to some extent. Based on the results of Chapters 2 and 3 an intervention study was designed and evaluated. Chapter 5 describes an intervention which examined whether the introduction of a sit-to-stand workstation among office workers leads to reductions in sedentary behaviour during working hours, and whether office workers would compensate for any reduction in sedentary time at work by increasing sedentary time and decreasing physical activity outside of working hours. For the accurate measurement of sedentary behaviour and physical activity, it was necessary to utilise the right devices for Chapter 5. The ActiGraph accelerometer is a popular device for physical activity measurement but there is lack of evidence to show whether is it valid for recognizing body posture.

6.3 Chapter 4 – Validity of the ActiGraph Inclinometer Algorithm for Detecting Sitting and Standing Postures

The ActiGraph is a popular device for the measurement of physical activity and sedentary behaviour and is widely used by researchers. Therefore it was very important to determine the most valid method of using accelerometer data to provide an estimate of sedentary behaviour. Traditionally researchers have used a threshold of <100 counts per minute (cpm), applied to waist-worn devices, to estimate sedentary time. Acknowledging the limitations of this approach, in that such a threshold does not distinguish between postures, ActiGraph have developed inclinometer algorithms to try to improve the assessment of sedentary behaviour. Chapter 4 examined the validity of the relatively new ActiGraph inclinometer algorithms when applied to waist-worn and thigh-worn devices. There were three different conditions in this study, including; sitting, standing, very light walking, and light walking. Each condition had a different range of activities. This study assessed validity under controlled conditions using direct observation as the criterion measure and adds to the limited body of evidence on the validity of the ActiGraph inclinometer algorithms at different wear sites.

The findings showed that the thigh worn ActiGraph inclinometer algorithm is 100% accurate for detecting body posture during slow walking and standing tasks. The results also showed that the thigh worn ActiGraph inclinometer algorithm is 95.4%- 91.1% accurate during four different sitting tasks. Results from the waist worn device showed that the inclinometer algorithm correctly identified sedentary time between 63-67% of the time during the sitting tasks, and non-sedentary time between 61% and 72% of the time during the standing and slow walking tasks.

Findings from chapter 4 indicate that the validity of the ActiGraph at detecting sedentary and non-sedentary postures is improved when the device is worn on the anterior aspect of the thigh rather than the waist. However, even on the thigh, the Actigraph is not 100% accurate at detecting body posture for sitting tasks. Such results are consistent with those of others. For example Skotte et al. (2014) and Carr et al. (2012) both evaluated the validity of thigh worn ActiGraphs and showed that this device is not 100% valid in detecting body posture when worn on the thigh. Limitations with the use of this device when worn on the thigh were also noticed during the validity study. Four participants reported that the devices were uncomfortable and requested not to wear them during the laboratory protocol, and in five participants the thigh worn ActiGraph fell off their legs during the treadmill walking conditions leading to the loss of data. Based on these observations and the finding that the thigh worn device was not 100% accurate at detecting seated postures, it was decided from this research that in the intervention study reported in Chapter 5, the ActiGraph would solely be used as a measure of physical activity and not sedentary behaviour.

6.4 Chapter 5 – Using sit-stand workstations in offices: is there a compensation effect?

The research reported in Chapter 5 was, to our knowledge, the first to evaluate possible compensation effects from changes to sedentary behaviour in office workers. In this study following the 14 day baseline assessment, participants received a WorkFit-S, sit-to-stand workstation for 3 months. Participants then undertook three, 7-day assessment phases: 1-week, 6-weeks, and 3-months after the desk had been installed.

Results from this study confirmed that participants were less sedentary and more active when using sit-to-stand workstations but this was associated with increased levels of sedentary behaviour in their non-working hours. Results from chapter 5 showed that using sit-to-stand workstations is an effective way of reducing sedentary time during working hours in office workers. However, for the first time, this study analysed compensation of sedentary behaviour outside working hours and findings indicated that participants were more sedentary during non-working hours at 1-week, 6-weeks and 3 months after workstation installation, compared to baseline. Also this study showed that during working hours, compared to baseline, the amount of time spent in light activity increased at 1-week, 6-weeks and 3-months follow-up. The amount of time spent in MVPA during working hours also increased at 1-week and 6-weeks. During non-working hours, compared to baseline, the amount of time in light activity decreased at 1-week and 6 weeks follow-up.

Despite the compensation effect observed in the chapter 5 study, overall sedentary time across the day was still reduced when participants were using sit-to-stand desks at work. This decrease in daily sedentary time could have clinically meaningful health benefits in the study participants, although this needs to be examined in further research. It was therefore suggested that whilst slight compensation in sedentary behaviour appears to exist outside working hours, installing sit-to-stand desks in the workplace is an effective way of reducing overall sedentary time, with the reductions in sedentary time made during working hours outweighing the increases in sedentary time made outside working hours.

The findings from Chapter 5 suggest that sit-to-stand desks may not be enough over the long term, however, as only slight reductions in working hours standing time were observed over the 3 month intervention. Additional strategies such as educational material on the negative health effects of prolonged sitting (Buman et al, 2014) or office activities to encourage standing and stepping may need to be adopted for the long term effective use of sit-to-stand desks. It was also suggested that designing a multicomponent intervention targeting both workplace and leisure time sitting could be a more effective way to reduce total daily sedentary time in office workers.

Whilst the activPAL was the primary outcome measure applied in Chapter 5 to assess changes in sitting time over the intervention period, data collected in this chapter using the ActiGraph also enabled comparisons to be made between sedentary time estimated using the waist-worn accelerometer (applying the traditionally used <100 cpm cut-point) and sedentary time measured using the activPAL. Discrepancies in the proportion of time spent sedentary between these two measures were observed. For example, during working hours at baseline, participants spent 76% of their time sedentary according to the activPAL, this figure increased to 82% when estimated using the ActiGraph. In week one of the intervention, according to the activPAL the proportion of time spent sitting at work decreased to 52% (representing a reduction of 24%), while the proportion of time spent sitting at work decreased to only 78% (a reduction of 4%) when assessed by the ActiGraph. These observations suggest that the ActiGraph cut-point approach is not sensitive enough to measure changes in sedentary behaviour in interventions, supporting earlier observations of Kozey-Keadle et al. (2011). It is highly likely that standing postures are misclassified as sedentary behaviour. It is therefore recommended that where feasible, the activPAL is used as the primary outcome measure in interventions specifically targeting changes in sedentary behaviour.

6.5 Overall discussion:

Given the high volumes of time adults reportedly spend in sedentary behaviour, along with the detrimental effects of sedentary behaviour on health (Wilmot et al, 2012, Biswas et al. 2015), interventions are urgently needed to re-address the balance between sedentary behaviour and physical activity. Findings of this thesis suggest weak to moderate inverse associations between sedentary behavior and physical activity, with stronger evidence from objective monitoring studies reporting larger associations between sedentary behavior and light intensity activity. Interventions promoting reductions in sedentary behaviour through the promotion of light activities may have the potential to have a large impact on public health with positive influences on insulin sensitivity (Yates et al, 2015) and plasma glucose observed in recent studies (Thorp et al, 2014).

The Sedentary Behaviour Research Network's 1.5 MET definition of sedentary time seems to be reasonable at distinguishing between most sitting and standing behaviors, however some common sitting behaviors may have a MET level above this. Caution should therefore be applied when using this definition in certain circumstances, such as when referring to the energy expended during standing still, or during seated game play. Work in this thesis has shown that there are small differences in energy expenditure between sitting and standing still, therefore these differences in energy expenditure may not totally describe the differences in health risks seen with sitting versus standing. Further research is still required to understand the mechanisms of the increasing risk of chronic diseases with prolonged sedentary time. These findings have relevance to interventions aimed at reducing sitting and support the need for further research to unpick the minimum amount of ambulatory activity that needs to accompany standing in order to provide clinically meaningful benefits.

Chapter 4 adds to our knowledge on the validity of the ActiGraph inclinometer algorithms, and extends our knowledge on the validity of the algorithms in a range of laboratory tasks, expanding upon other studies. The validity of the inclinometer algorithms applied to waist-worn and thigh-worn data were not of acceptable levels for use in sedentary behaviour intervention studies. As a result, the activPAL was chosen as the primary outcome measure of sedentary behaviour in the intervention reported in Chapter 5, based on the mounting evidence highlighting this tool as a valid tool of sitting and standing postures (Ryan et al,2006; Busse et al, 2009; Dahlgren, 2010; Godfrey, 2007; Oliver, 2011; Harrington, 2011; Grant, 2006). The findings of this intervention study suggest that sit-to-stand workstation interventions should also target out of work sitting if compensation is to be avoided. Further interventions should also incorporate educational material and additional motivational strategies, such as goal setting, to enhance the sustainability of the intervention during working hours. Future studies investigating the notion of behaviour compensation are also warranted.

6.6 Strengths, limitations and suggestions for further research

The methodology and measurement tools applied throughout this thesis are strengths of this work. For example, the systematic review applied robust procedures to systematically evaluate the evidence on the associations between physical activity and sedentary behaviour. A range of studies with diverse sample characteristics were included in this review. It employed an extensive search criteria, including both electronic and manual sources, and a large number of studies were screened for eligibility. However, few of the included studies aimed to address directly the question of interest to the review. Moreover, few studies provided time stamped data thus it was not possible to conclude from this review whether one behaviour truly displaces another. With the growing use of objective measures of both sedentary time and physical activity over the last 2-3 years (Healy et al, 2015; Yates et al, 2015), this systematic review should be updated in the near future to include these recent studies. This may yield further evidence on time displacement.

The examination of the sedentary behaviour definition was conducted in a controlled laboratory environment. Resting energy expenditure was initially assessed in this study using the gold standard ventilated hood, while the main part of the study used the highly valid measure of indirect calorimetry to assess energy expenditure during a range of seated and upright tasks. This study included the novel comparison of energy expenditures during some lifestyle activities in a stratified sample of males and females, and healthy weight and obese adults. This study also for the first time assessed the validity of the cortex calorimeter device for the measurement of resting metabolic rate. Limitations of this study however included the relatively small sample size and a limited number of seated and upright activities. Further research should examine the utility of the MET threshold definition, using a number of other sedentary and upright postures, not included in the work conducted in this thesis. Further laboratory work into the utility of this definition, coupled with further observational studies on the links between sedentary behaviour and health, and mechanistic studies examining potential mechanisms which may link sedentary behaviour to adverse health should lead to a review of the current definition of sedentary behaviour.

A final limitation of this study was the fact that participants were categorized into the normal weight and obese groups according to their BMI. BMI has a number of limitations which need to be highlighted. According to Bogin et al, (2012), BMI may be sufficient to categorise obesity, but it is not the most appropriate method to determine “fatness” level in people with different body structures such as athletes. Bogin et al, (2012) has further highlighted that BMI is not capable of distinguishing between fat mass and lean body mass. So people with the same BMI might have very different body types and obesity levels (Heymsfield et al, 2015) which could effect their performance on daily tasks and energy expenditure. Recognising the limitations of BMI in terms of not providing a measure of fatness, for descriptive purposes only, in Chapters 3, 4 and 5, participants body composition was also measured using bio-impedance analysis. Waist circumference was also measured in these chapters to try and provide further information, and to avoid over reliance on BMI, when descripting the samples characteristics in this thesis.

During the energy expenditure study, participants also wore two ActiGraph accelerometers, one on the waist and one on the thigh. This enabled a further analysis to be conducted which examined the validity of the inclinometer algorithms applied to these two wear locations against direct observation. However, a limitation of the study was the absence of the activPAL as a further comparison measure. Limited research has been conducted to date which directly compares the validity of the activPAL and the ActiGraph inclinometer algorithms applied to thigh worn devices. Further laboratory and free-living studies are required to examine the validity of the ActiGraph inclinometer algorithms for detecting sedentary time, with head to head comparisons with the activPAL. In addition, usability trials should be conducted which examine the comfort and acceptability of these different measurement tools. Such further research should lead to a consensus on the most appropriate tools for use in intervention studies, surveillance studies and determinants studies, which will lead to a standardisation of measurement approaches across the literature.

A strength of the intervention study reported in chapter 5 was the use of the activPAL to directly measure the primary outcome of posture and the use of the ActiGraph as a tool to measure physical activity. This study provided novel evidence on compensatory behaviours which accompany sit-to-stand desk interventions in the workplace. This study also provided evidence of initial reactivity occurring to this intervention, as gradual reductions in standing time at work were observed over the intervention period. Limitations of this study however include the absence of a control group, a relatively homogenous sample, and no longer term follow-up. To date, limited sit-to-stand workstation interventions have lasted beyond a timeframe of three months (Hall et al, 2015), further research employing randomised controlled designs is required to assess the impact, and long-term effects of sit-to-stand workstations in the workplace.

One the limitations of this thesis includes the small and relatively homogenous convenience sample in all three studies. Most of the participants in this thesis were White British and middle class which can limit the generalisability of these studies. According to Koshoedo et al, (2015), individuals within the UK with different cultures, ethnic groups, income levels and religions will have different “barriers” which can restrict their physical activity level. For example, South Asians living in the UK have been reported to have substantially lower levels of physical activity than White Europeans (Fischbacher et al, 2004, William et al 2011a) and it has been suggested that low levels of activity may contribute to the increased risk of coronary heart disease and diabetes seen in South Asians living in the UK (Fischbacher et al, 2004, William et al 2011b). To date, limited information exists on whether levels of sedentary behaviour differ according to different ethnic groups living in the UK. Further research is required to investigate sedentary behaviour and physical activity levels and patterns in diverse UK samples. Expanding our knowledge on physical activity and sedentary behaviour levels and patterns, along with the perceived barriers to bringing about healthy changes to these behaviours in diverse samples, will lead to the development of tailored, and hopefully more effective, behaviour change interventions.

Conclusions

This thesis found that light intensity physical activity, including standing, could be one of the most efficient and feasible ways to replace sedentary behaviour. Sit-to-stand desks in the workplace appear to be an effective way of reducing office workers sedentary time during working hours over the short term, and despite compensatory effects of the intervention outside work, this intervention led to overall reductions in total daily sitting time. Reductions in sedentary behaviour were replaced with increases in standing and light intensity activity. Such findings add considerably to the existing literature and are important as they suggest that standing more in adults could be important for positive health outcomes. Targeting such facets of behaviour in adults, especially office workers, holds great potential for behaviour change strategies which could have a large impact on public health.

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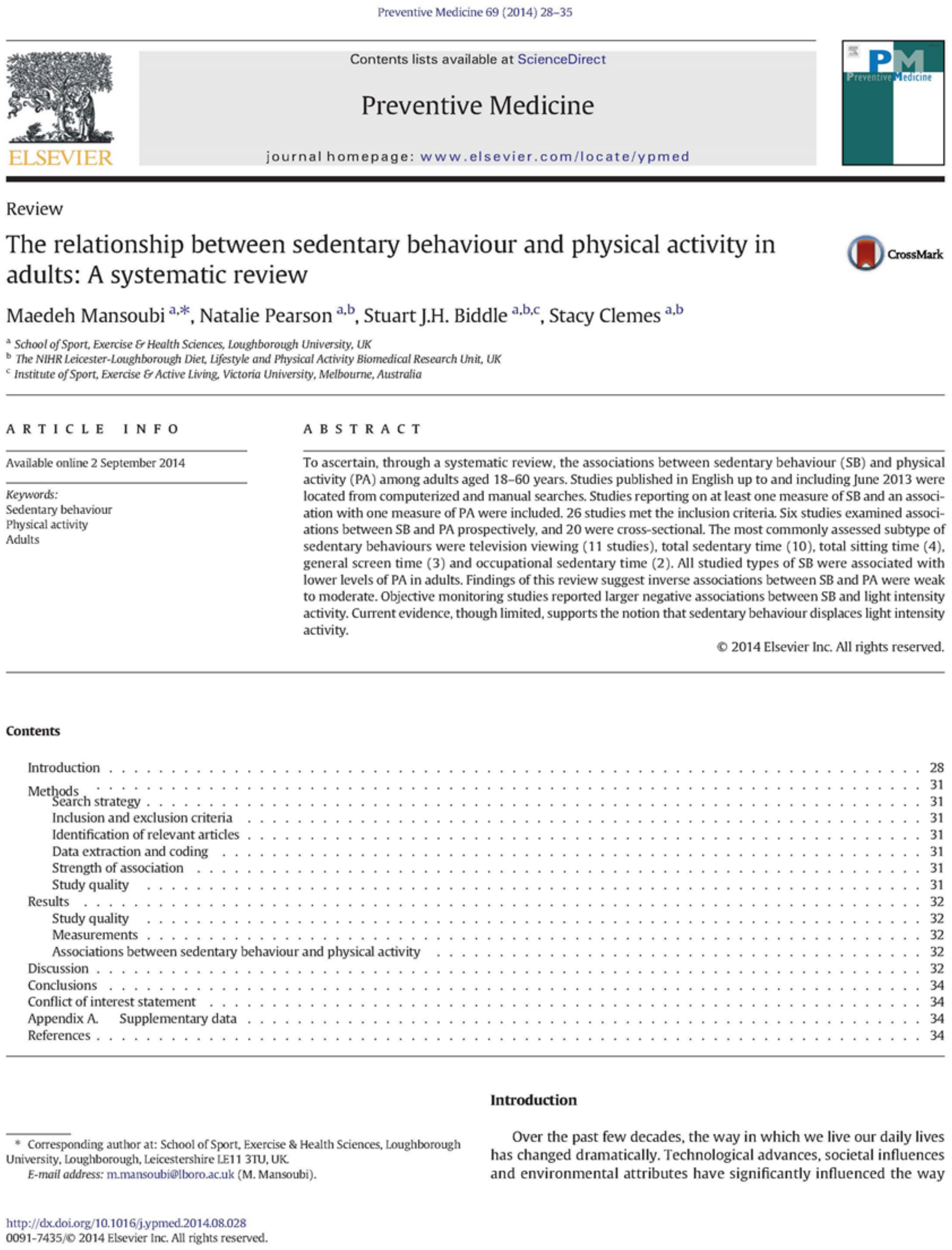
Appendices

Appendix 1.1: First page of Systematic review paper



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Review

The relationship between sedentary behaviour and physical activity in adults: A systematic review

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ABSTRACT

To ascertain, through a systematic review, the associations between sedentary behaviour (SB) and physical activity (PA) among adults aged 18–60 years. Studies published in English up to and including June 2013 were located from computerized and manual searches. Studies reporting on at least one measure of SB and an association with one measure of PA were included. 26 studies met the inclusion criteria. Six studies examined associations between SB and PA prospectively, and 20 were cross-sectional. The most commonly assessed subtype of sedentary behaviours were television viewing (11 studies), total sedentary time (10), total sitting time (4), general screen time (3) and occupational sedentary time (2). All studied types of SB were associated with lower levels of PA in adults. Findings of this review suggest inverse associations between SB and PA were weak to moderate. Objective monitoring studies reported larger negative associations between SB and light intensity activity. Current evidence, though limited, supports the notion that sedentary behaviour displaces light intensity activity.

Contents

Introduction

Over the past few decades, the way in which we live our daily lives has changed dramatically. Technological advances, societal influences and environmental attributes have significantly influenced the way

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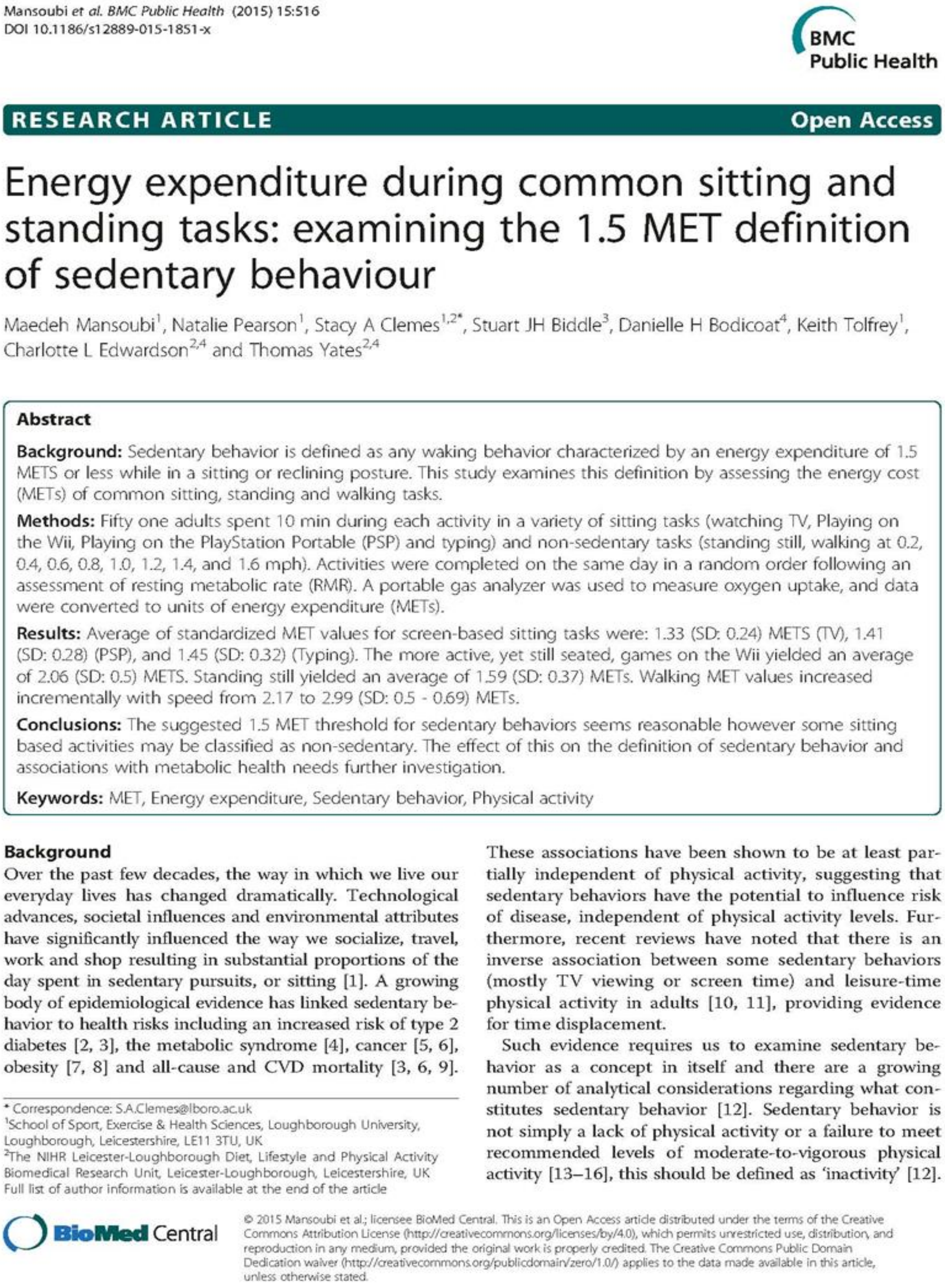
Appendix 1.2: First page of MET paper



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RESEARCH ARTICLE Open Access

Energy expenditure during common sitting and standing tasks: examining the 1.5 MET definition of sedentary behaviour

Maedeh Mansoubi[1], Natalie Pearson[1], Stacy A Clemes[1,2*], Stuart JH Biddle[3], Danielle H Bodicoat[4], Keith Tolfrey[1], Charlotte L Edwardson[2,4] and Thomas Yates[2,4]

Abstract

Background: Sedentary behavior is defined as any waking behavior characterized by an energy expenditure of 1.5 METS or less while in a sitting or reclining posture. This study examines this definition by assessing the energy cost (METs) of common sitting, standing and walking tasks.

Methods: Fifty one adults spent 10 min during each activity in a variety of sitting tasks (watching TV, Playing on the Wii, Playing on the PlayStation Portable (PSP) and typing) and non-sedentary tasks (standing still, walking at 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, and 1.6 mph). Activities were completed on the same day in a random order following an assessment of resting metabolic rate (RMR). A portable gas analyzer was used to measure oxygen uptake, and data were converted to units of energy expenditure (METs).

Results: Average of standardized MET values for screen-based sitting tasks were: 1.33 (SD: 0.24) METS (TV), 1.41 (SD: 0.28) (PSP), and 1.45 (SD: 0.32) (Typing). The more active, yet still seated, games on the Wii yielded an average of 2.06 (SD: 0.5) METS. Standing still yielded an average of 1.59 (SD: 0.37) METs. Walking MET values increased incrementally with speed from 2.17 to 2.99 (SD: 0.5 - 0.69) METs.

Conclusions: The suggested 1.5 MET threshold for sedentary behaviors seems reasonable however some sitting based activities may be classified as non-sedentary. The effect of this on the definition of sedentary behavior and associations with metabolic health needs further investigation.

Keywords: MET, Energy expenditure, Sedentary behavior, Physical activity

Background

Over the past few decades, the way in which we live our everyday lives has changed dramatically. Technological advances, societal influences and environmental attributes have significantly influenced the way we socialize, travel, work and shop resulting in substantial proportions of the day spent in sedentary pursuits, or sitting [1]. A growing body of epidemiological evidence has linked sedentary behavior to health risks including an increased risk of type 2 diabetes [2, 3], the metabolic syndrome [4], cancer [5, 6], obesity [7, 8] and all-cause and CVD mortality [3, 6, 9]. These associations have been shown to be at least partially independent of physical activity, suggesting that sedentary behaviors have the potential to influence risk of disease, independent of physical activity levels. Furthermore, recent reviews have noted that there is an inverse association between some sedentary behaviors (mostly TV viewing or screen time) and leisure-time physical activity in adults [10, 11], providing evidence for time displacement.

Such evidence requires us to examine sedentary behavior as a concept in itself and there are a growing number of analytical considerations regarding what constitutes sedentary behavior [12]. Sedentary behavior is not simply a lack of physical activity or a failure to meet recommended levels of moderate-to-vigorous physical activity [13–16], this should be defined as 'inactivity' [12].

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Chapter 2:

Appendix 2.1: Strength of association

Test statistic						
Strength	r	β (standardised regression coefficient)	R	R^2	d	OR
None (0)	<0.1	<0.1	<0.14	0.02	<0.2	1.0
Small (-) (+)	0.1	0.1	0.14	0.02	0.2	1.174
Medium (--) (++)	0.3	0.3	0.36	0.13	0.5	1.656
Large (---) (+++)	0.5	0.5	0.51	0.26	0.8	2.548

r = pearson correlation; β = standardised regression coefficient (values are based on previous research using these cut points: Robertson et al. (2007) *Organizational Research Methods*; 10; 564: Sawyer et al. (2004) Rheumatology; 43: 325-330; R or Partial R from multiple regression; R^2 or partial R^2 from multiple regression; Effect size, $d = (m_a – m_b)/SD$; OR = odds ratio (values based on Allen and Le (2008) Journal of Educational and Behavioural Statistics; 33 (4), 416–441.

Appendix 2.2: Quality of study and report assessment table

item		**+**	**-**	**?**
Quality of reporting				
1	Adequate* description of sampling population, methods of recruitment, and place of recruitment			
2	Adequate description of the characteristics of the baseline sample (number of participants, sex, age)			
3	Presentation of descriptive data on PA and SB – including point estimates / prevalence and measures of variability (SD, SE, 95% CI)			
Additional items for prospective studies				
4	Description of follow-up duration (month / year of each assessment or age of participants at each assessment), the number and characteristics of participants assessed at each time point			
Response options: '+' yes, criteria met; '-' no, criteria not met; '?' unclear or not sufficiently described To calculate a quality of reporting score – calculate proportion of items scored '+' (denominator is 3 for cross-sectional studies, 4 for prospective studies).				

Study quality (validity/precision)				
Methods for selecting participants				
1	Response rate at baseline at least 70% or if the non-response was not selective (attrition analysis indicates study sample is not different (sex, age, BMI, SES) from population of eligible participants)			
2	Sampling procedure (No procedure reported/narrow procedure (-); diverse (+))			
Methods for measuring sedentary behaviour				
3	Reliable[†] tool used to assess sedentary behaviour			
4	Valid[#] tool used to assess sedentary behaviour			
Methods for measuring physical activity				
5	Reliable[†] tool used to assess physical activity			
6	Valid[#] tool used to assess physical activity			
Statistical analysis				
7	Clear and appropriate method of analysis used			
8	Analysis included attempts to control for confounding			
Additional items for prospective studies				
9	Response rate at follow-up was at least 80% or if the non-response was not selective (attrition analysis indicates study sample is not different (sex, age, BMI, SES) from baseline sample)			

Response options: ‘+’ yes, criteria met; ‘-‘ no, criteria not met; ‘?’ unclear or not sufficiently described

To calculate a quality of reporting score – calculate proportion of items scored ‘+’ (denominator is 9 for cross-sectional studies,10 for prospective studies).

NOTES

* ‘Adequate’ – defined as sufficient information to be able to replicate the study

Sampling procedure – narrow sample (e.g. used only one class or one school for data collection); diverse sample (e.g. community based sample or used multiple schools for data collection).

[†] Reliability: ‘+’ only if sedentary behaviour or physical activity was assessed objectively or if subjective instrument had test-retest reliability ≥0.80 or Kappa / ICC ≥0.70.

[#] Validity: ‘+’ only if sedentary behaviour or physical activity was assessed objectively or if validated subjective instrument with correlations ≥0.80 or Kappa / ICC ≥0.70, or a combination of objective and subjective measures.

Chapter 3:

Appendix 3.1: participant information sheet

Energy Expenditure Study (MET)

Participant Information Sheet

Dr Natalie Pearson, School of Sport, Exercise and Health Sciences, Loughborough University – N.l.pearson@lboro.ac.uk , telephone: 01509 226448

Professor Stuart Biddle, School of Sport, Exercise and Health Sciences, Loughborough University – S.J.H.Biddle@lboro.ac.uk, telephone: 01509 226394

Dr Stacy Clemes, School of Sport, Exercise and Health Sciences, Loughborough University – S.A.Clemes@lboro.ac.uk, telephone: 01509 228170

Maedeh Mansoubi, School of Sport, Exercise and Health Sciences, Loughborough University – M.mansoubi@lboro.ac.uk , telephone: 01509 226452 or 07427164717

Sophie Pain, School of Sport, Exercise and Health Sciences, Loughborough University – S.Pain-08@student.lboro.ac.uk , telephone: 07845 293996

What is the purpose of the study?

The purpose of this study is to investigate the energy we use in common sitting and standing tasks and light walking.

Who is doing this research and why?

This study is one of a number of studies being conducted within the The NIHR Leicester-Loughborough Lifestyle Diet, Lifestyle and Physical Activity Biomedical Research Unit at the University Hospitals of Leicester NHS Trust and Loughborough University. This study is being led by Dr Natalie Pearson, Dr Stacy Clemes and Professor Stuart Biddle in the School of Sport, Exercise & Health Sciences at Loughborough University. The study is part of a student research project and will involve Maedeh Mansoubi and Sophie Pain as part of their studies for PhD and MSc degrees.

Once I take part, can I change my mind?

Yes! After you have read this information and asked any questions you may have we will ask you to complete an Informed Consent Form. However, if at any time, before, during or after the study you wish to withdraw please just contact the main investigator. You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing.

Will I be required to attend any sessions and where will these be?

You will be asked to visit the laboratory on two occasions. On the first visit we will ask you to wear a measuring devise to record your activity for one week. On the second visit we will run the study in the laboratory and we will require you to be in the lab for about 3 hours.

What will I be asked to do during study?

During the first visit to the laboratory a trained experimenter will measure your height, weight, and percent body fat (this simply involves standing on a set of scales). You will then be given two measuring devices - one accelerometer and one posture monitor (shown below) - and asked to wear them throughout waking hours for one week, and to keep a log book of when you wear these devices and take them off. You will also be asked to complete a short questionnaire on your usual physical activity levels. At the end of this one week period, a researcher will collect the monitors and log book from you. After a minimum of two-days following the researchers collecting your monitors, you will be requested to return to the laboratory, and it is during this visit you will be asked to complete several sitting, standing and walking activities while wearing a small mask allowing us to estimate your energy expenditure.

The accelerometer is a small device (4.6cm x 3.3cm x 1.5cm, 19g) that sits on an elastic belt around your waist and can be worn discretely under clothing.

The inclinometer is a small device (5.3 x 3.5 x 0.7cm, 15g) that is attached to your thigh using a hypoallergenic sticky pad. This device is also worn discretely under clothing.

What will I be asked to do before the second laboratory meeting?

- No vigorous physical activity 36 hours before the laboratory visit
- No caffeine, alcohol, or drugs 24 hours before the laboratory visit
- Consume a standardised evening meal between 17.00 and 19.30 on the day before the test
- Consume a small (standardised) snack bar between 19.45 and 20.00 and only water is to be consumed afterwards
- Consume 500ml of water one hour before the lab visit (does not need to be consumed in one go)
- Be transported to the laboratory by car to eliminate any physical activity.

What personal information will be required from me?

We will ask you for your age and we will also measure your height, weight, body fat percentage and blood pressure. All of this information will be kept confidential and at no point will this information be linked to your name.

Are there any benefits for me in taking part?

Yes! In addition to helping medical and scientific knowledge, we believe you will benefit by having personal information made available to you, should you wish, on your energy expenditure at rest and during common daily tasks. This will help you accurately work out your daily calorie requirements..

Are there any risks in participating?

There are no foreseen risks associated with taking part in this study. You may find the study beneficial, as you will receive feedback at the end of the study on your physical activity levels and energy expenditure.

Will my taking part in this study be kept confidential?

If you take part in the research all information collected from you during the course of the research will be kept strictly confidential. All references to participants in the report and any subsequent publications/presentations will be anonymous. The information will be kept in a secure location, accessible only to the researchers. All of the data (questionnaires, documents etc.) will remain the property of Loughborough University and will be destroyed 10 years after completion of the study.

What will happen to the results of the study?

The results will be coded (for anonymity) and analysed by the research team before being reported in research projects. The results may also be presented in appropriate scientific journals and conferences. If you take part in this research, you can obtain copies of these publications from the research team. The data will be stored by the Chief Investigator, Dr Natalie Pearson, at Loughborough University under conditions specified by the Data Protection Act 1998.

If I have more questions who should I contact?

For any questions, you can contact to Dr Natalie Pearson or Maedeh Mansoubi, whose contact details are shown at the top of this Information Sheet.

What if I am not happy with how the research was conducted?

If you have any concerns about this study or the way it has been carried out you should contact the main investigator Dr Natalie Pearson. The University has a policy relating to Research Misconduct and Whistle Blowing which is available online at http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm.

Appendix 3.2: health screening questionnaire

Loughborough University

Number ………………….

Health Screen Questionnaire for Energy Expenditure Study Volunteers

As a volunteer participating in a research study, it is important that you are currently in good health and have had no significant medical problems in the past. This is (i) to ensure your own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Section A: Please complete this brief questionnaire to confirm your fitness to participate:

1. **At present,** do you have any health problem for which you are:

(a) on medication, prescribed or otherwise................. Yes ☐ No ☐

(b) attending your general practitioner .... Yes ☐ No ☐

(c) on a hospital waiting list .... Yes ☐ No ☐

2. **Have you ever** had any of the following:

(a) Asthma .... Yes ☐ No ☐

(b) Diabetes .... Yes ☐ No ☐

(c) Heart problems .... Yes ☐ No ☐

(d) Problems with bones or joints .... Yes ☐ No ☐

(e) Disturbance of balance/coordination .... Yes ☐ No ☐

3. **Has any,** otherwise healthy, member of your family under the

age of 35 died suddenly during or soon after exercise? ... Yes ☐ No ☐

4. Do you have a heart pacemaker fitted?

.... Yes ☐ No ☐

If YES to any question, please describe briefly if you wish (eg to confirm problem was/is short-lived, insignificant or well controlled.)

....

....

5. **Additional questions for female participants**

(a) could you be pregnant? .... Yes ☐ No ☐

Anthropometric measurements

Height: _______________

Weight: _______________

ActiGraph Number: _______________

activPAL Number: ______________

Appendix 3.3: consent form

ENERGY EXPENDITURE STUDY (MET)

INFORMED CONSENT FORM

The purpose and details of this study have been explained to me. I understand that this study is purely for research purposes. The data obtained from the study will be used to enhance academic and health knowledge.

I have understood that all the steps involved in the study will not cause harm to me and that all the procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have sufficiently understood the Information Sheet and this Consent Form.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless, it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in the study.
Yes _____ No_____

Kindly sign this form if you agree to participate.

Surname ________________________ First Name ___________________

Signature _________________________ Date: _________________________

Signature of investigator

Date

Appendix 3.4: Participants info to follow before main procedures

Please do following items from 36 hours before coming for main experiment to the lab:

- ✓ Avoid vigorous activity during the preceding 36 hours
- ✓ Abstain from caffeine, alcohol, or drugs during the preceding 24 hours
- ✓ Consume your usual evening meal between 17:00 and 19:30 the day before the main procedures
- ✓ Consume a provided snack bar between 19:45 and 20:00 the day before the main procedures and only water thereafter
- ✓ consume 500 mL of water at least 60 min before arriving at the laboratory (does not need to be consumed in one go)

Thanks!

Appendix 3.5: checklist for researcher to complete on morning of main procedures

Checklist for researchers to complete on morning of main procedures

1. Time participant arrives at lab: ____________________________

2. How did participant travel to lab: ___________________________

3. Did participant engage in any vigorous activity in the last 36 hours? ______________

4. Is participant fasted? _____________________________________

5. What time did participant eat dinner last night? ____________________

6. What did participant eat for dinner last night? _____________________

7. What time did participant eat snack bar last night? ___________________________

8. Is participant feeling well? _____________________________________

Chapter 5:

Sedentary Behaviour Compensation (SBC)

Appendix 5.1: Participant Information Sheet

Dr Natalie Pearson, School of Sport, Exercise and Health Sciences, Loughborough University – N.l.pearson@lboro.ac.uk , telephone: 01509 226448

Dr Stacy Clemes, School of Sport, Exercise and Health Sciences, Loughborough University – S.A.Clemes@lboro.ac.uk, telephone: 01509 228170

Professor Stuart Biddle, School of Sport, Exercise and Health Sciences, Loughborough University – S.J.H.Biddle@lboro.ac.uk, telephone: 01509 226394

Maedeh Mansoubi, School of Sport, Exercise and Health Sciences, Loughborough University – M.mansoubi@lboro.ac.uk , telephone: 01509 226452 or 07427164717

What is the purpose of the study?

The purpose of this study is to investigate the utility of installing sit-to-stand work station in offices of Loughborough University. The study will investigate the effectiveness of sit-to-stand workstation at reducing sitting time at work.

Who is doing this research and why?

The study is a part of a student research project and will involve Maedeh Mansoubi as part of her PhD. This study is being led by Dr Natalie Pearson, Dr Stacy Clemes and Professor Stuart Biddle in the School of Sport, Exercise & Health Sciences at Loughborough University.

Once I take part, can I change my mind?

Yes! After you have read this information and asked any questions you may have we will ask you to complete an Informed Consent Form. However, if at any time, before, during or after the study you wish to withdraw please just contact the main investigator. You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing.

Will I be required to attend any sessions and where will these be?

You will be requested to visit the laboratory in Mathew Arnold building on one occasion for measurement of height and weight (See below). On the first visit we will ask you to wear a measuring devise to record your activity.

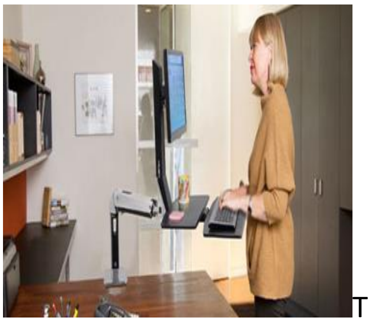
What will I be asked to do during study?

During the first visit to the laboratory a trained experimenter will measure your height, weight, and percent body fat (this simply involves standing on a set of scales). You will then be given two measuring devices - one accelerometer and one inclinometer (shown below) - and asked to wear them throughout waking hours for one week, and to keep a log book of your wear time. You will also be asked to complete questionnaires on your usual physical activity levels, sitting time, musculoskeletal pain and Fatigue. At the end of this one week period, researchers will collect the monitors and log book from you. Following the collection of your monitors, you will receive a sit-to-stand desk for your office which you are free to use for 3 month (Shown below). You will be asked to wear accelerometers in the first week after receiving the desk, in the week 6 and in the week 12. After finishing this 3 month study researchers will ask you to complete a fatigue and musculoskeletal pain questionnaire. Then the sit-to-stand desk will then be collected.

The accelerometer is a small device (4.6cm x 3.3cm x 1.5cm, 19g) that sits on an elastic belt around your waist and can be worn discretely under clothing.

The inclinometer is a small device (5.3 x 3.5 x 0.7cm, 15g) that is attached to your thigh using a hypoallergenic sticky pad. This device is also worn discretely under clothing.

WorkFit-S, Sit-Stand Workstation



The sit-to-stand workstation transforms any surface into a personalized height-adjustable desk. Change from a sitting to a standing position. This sit-stand workstation moves the keyboard and display in one simple motion, making computing comfortable for prolonged periods.

http://www.ergotron.com/Home/tabid/36/Default.aspx

What personal information will be required from me?

We will ask you for your age and we will also measure your height, weight, body fat percentage. All of this information will be kept confidential.

Are there any benefits for me in taking part?

Yes! In addition to helping medical and scientific knowledge, we believe you will benefit by having personal information made available to you, should you wish, on your activity levels and sitting time. This might help you for further health-related decisions and be of personal interest.

Are there any risks in participating?

There are no foreseen risks associated with taking part in this study. You may find the study beneficial, as you will receive feedback at the end of the study on your physical activity levels and sitting time.

Will my taking part in this study be kept confidential?

If you take part in the research all information collected from you during the course of the research will be kept strictly confidential. All references to participants in the report and any subsequent publications/presentations will be anonymous. The information will be kept in a secure location, accessible only to the researchers. All of the data (questionnaires, documents etc.) will remain the property of Loughborough University and will be destroyed 10 years after completion of the study.

What will happen to the results of the study?

The results will be coded (for anonymity) and analysed by the research team before being reported in research projects. The results may also be presented in appropriate scientific journals and conferences. If you take part in this research, you can obtain copies of these publications from the research team. The data will be stored by the Chief Investigator, Professor Stuart JH Biddle, at Loughborough University under conditions specified by the Data Protection Act 1998.

If I have more questions who should I contact?

For any questions, you can contact to Dr Natalie Pearson, Maedeh Mansoubi, Dr Stacy Clemes or Professor Stuart Biddle whose contact details are shown at the top of this Information Sheet.

What if I am not happy with how the research was conducted?

If you are not happy with how the research was conducted, please contact the Mrs Zoe Stockdale, the Secretary for the University's Ethics Approvals (Human Participants) Sub-Committee:

Mrs Z Stockdale, Research Office, Rutland Building, Loughborough University, Epinal Way, Loughborough, LE11 3TU. Tel: 01509 222423. Email: Z.C.Stockdale@lboro.ac.uk

The University also has a policy relating to Research Misconduct and Whistle Blowing which is available online at http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm. Please ensure that this link is included on the Participant Information Sheet.

Appendix 5.2: Consent form

Loughborough University

SEDENTARY BEHAVIOUR COMPENSATION STUDY (**SBC**)

INFORMED CONSENT FORM

The purpose and details of this study have been explained to me. I understand that this study is purely for research purposes. The data obtained from the study will be used to enhance academic and health knowledge.

I have understood that all the steps involved in the study will not cause harm to me and that all the procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have sufficiently understood the Information Sheet and this Consent Form.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless, it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in the study.

Yes _____ No_____

Kindly sign this form if you agree to participate.

Surname _______________________ First Name __________________

Signature ________________________ Date: __________________

Signature of investigator: _______________________________

Date: ___________________________

Appendix 5.3: Health screen questionnaire

Loughborough University

ID Number ....

Health Screen Questionnaire for Sedentary Behaviour compensation Study Volunteers

As a volunteer participating in a research study, it is important that you are currently in good health and have had no significant medical problems in the past. This is (i) to ensure your own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Section A: Please complete this brief questionnaire to confirm your fitness to participate:

1. At present, do you have any health problem for which you are:

(a)	on medication, prescribed or otherwise	Yes ☐	No ☐
(b)	attending your general practitioner	Yes ☐	No ☐
(c)	on a hospital waiting list...	Yes ☐	No ☐

2. Have you ever had any of the following:

(a)	Asthma	Yes ☐	No ☐
(b)	Diabetes	Yes ☐	No ☐
(c)	Heart problems	Yes ☐	No ☐
(d)	Problems with bones or joints	Yes ☐	No ☐
(e)	Disturbance of balance/coordination	Yes ☐	No ☐

3. Has any, otherwise healthy, member of your family under the

age of 35 died suddenly during or soon after exercise? ... Yes ☐ No ☐

4. Do you have a heart pacemaker fitted?

………………………………………………………………………………… Yes ☐ No ☐

If YES to any question, please describe briefly if you wish (e.g. to confirm problem was/is short-lived, insignificant or well controlled.)

………

……

5. Additional questions for female participants

(a) Could you be pregnant? …………………………………… Yes ☐ No ☐

Appendix 5.4: Daily log

Loughborough University

ID: ___________

Starting Date: ___________

Accelerometer: ____________

ActivPAL: ___________

Sedentary Behaviour Compensation Study

Activity Monitor Instructions & Daily Log

Please keep this booklet in a safe place so you can return it to us at the end of the 8 days

If you have any questions or concerns, please contact: Maedeh Mansoubi (M.mansoubi@lboro.ac.uk or 07427164717)

Contents

If you have any further questions about filling in the Daily Log, or how to wear the monitors, please contact:

Maedeh Mansoubi (M.mansoubi@lboro.ac.uk or 07427164717)

1. Introduction and general instructions

The activPAL or thigh monitor is an inclinometer. It measures your posture – specifically your sitting, standing and sleeping time.

The accelerometer or hip monitor measures your intensity of activity and is particularly good at measuring walking and running time.

The data from both monitors will be used to provide an accurate picture of your sitting time and physical activity time across the day.

How long do I wear the monitors for?

- Please wear both monitors **every day for 7 days** removing them on the morning of day 8.
- Please wear the activPAL or thigh monitor continuously (i.e. for 24 hours/day).
- The accelerometer only needs to be worn during waking hours. **Please put it on as soon as you wake up in the morning and take it off just before you go to bed at night.**

Both monitors will need to be removed whilst showering, bathing or swimming and re-attached immediately afterwards. These monitors are not waterproof.

What else do I need to do?

- It is important that you fill in this Daily Log every day for the 7 days while you are wearing the monitors.
- This helps us match the monitor data to your waking hours and patterns during the day.

Returning your monitors and Daily Logs

Please place the monitors and completed Daily Log (and any unused adhesive patches) back into the Activity Monitor Pack and return it to the laboratory on day 8.

2. How to wear the activPAL thigh monitor

- The activPAL or thigh monitor is to be worn continuously for 7 days.
- It is very important that you wear the monitor on your upper mid-thigh and that the 'man' is standing upright – head facing upwards (see pictures).
- During these 7 days, you will need to change the adhesive patches which attach the monitor to your thigh. Extra patches are provide in your Activity Monitor Pack.

<u>To change adhesive patches:</u>

- Remove the activPAL from your thigh and ensure the attachment area is clean and dry.
- Position the activPAL in the same spot as previously (or in the same spot on the opposite leg if your skin is irritated). Please ensure that the man on the front of the monitor is standing up (head facing upwards).
- Remove the backing off a new adhesive cover-patch and place it over the activPAL for a secure fix.

HINT: most people find the adhesive cover-patches last for about 2 days.

If you require assistance re-attaching your activPAL, or if you experience any skin irritation whilst wearing it, please contact Maedeh Mansoubi (M.mansoubi@lboro.ac.uk or 07427164717).

Note: the activPAL will emit a green flash every 6 seconds. This is an indication that it is working and recording data.

3. How to wear the accelerometer (or hip monitor)

- The accelerometer is to be worn for 7 days. Please wear the accelerometer at all times except when removing it for sleep to avoid damage. Please put it on as soon as you wake up in the morning and take it off just before you go to bed at night.

- The accelerometer should be worn continuously throughout waking hours. However, the accelerometers are NOT waterproof and must be removed when bathing, showering and/or swimming.
- The accelerometers do NOT need to be reset at the end of each day, just make sure it is easily accessible in the morning so it can be worn as soon as you get out of bed.

- To give accurate results, the accelerometer belt should be placed on, or as close to, your waistband as possible (if you are wearing a belt, just put the elastic band over your belt). The accelerometer should be placed above the mid-line of the thigh, facing outwards and it should sit on the hip bone (the really pointy bit). Adjust the belt so that it is comfortable (see pictures below).

- The accelerometer can be worn either underneath or on top of your clothing, just as long as it fits snugly around your waistband.

Tips for wearing the monitor

- It may help if you remember to put the monitor on when you wake up by leaving it next to your bed, or on the bathroom counter if you have a shower before you get changed for the day.
- If your clothes have a belt loop, it may be easier to thread the elastic band through the belt loops. This will help to keep the monitor in place.
- Remember that the accelerometers are not waterproof and must be removed when showering, bathing or swimming.

Note: the accelerometer will flash when it is recording data.

4. How to fill in the daily log

- The log is divided into 7 days. Please complete each day's questions as accurately as possible – record the exact times if you an, or to the nearest 5 minutes.
- Start by writing the date in the top row.
- Then record the time that you woke up and the time that you put the accelerometer for the first time that day. If you wore the hip monitor overnight then please tick the corresponding box. If you did not wear the accelerometer at all that day then please tick the corresponding box.
- Then state if it was a work or non-work day. If it was a work day, please record the time you started work and if you had a lunch break. If you did have a lunch break, also record the time your lunch break started and finished. Finally, record what time you finished work.
- Next record any times you removed the activPAL or accelerometer for more than 15 minutes. For the accelerometer, please DO NOT include removal times related to night time sleeping – i.e. only record removal times during waking hours.
- Finally, please record the time that you removed the accelerometer before going to bed and sleep time. If you wear the accelerometer to bed, then simply tick the corresponding box the following morning.
- If you have any other comments, please note them down.

NOTES:

- Midnight = 12am; midday = 12pm
- Sleep and awake times are very important.

Example	**Date: 15/07/2012**
What time did you **wake** up today?	06.15 am / pm
What time did you put the accelerometer on?	06.30 am / pm
Is today a work or non-work day?	[✓ work] / non-work
If it is a work day:	
What time did you **start your work** today?	08.30 am / pm
Did you have a lunch break?	[✓ yes] / no
If yes:	
What time did your lunch break **start**?	12.30 am / pm
What time did your lunch break **finish**?	01.00 am / pm
What time did you **finish your work** today?	04.30 am / [✓ pm]
I wore the accelerometer to bed last night? ☐	I did not wear the accelerometer ☐ay?

During the day today:

Did you remove your activity monitors during the day for more than 15 minutes?

No ☐ Yes ☒

Accelerometer		**activPAL (thigh monitor)**	
Removed at…..	**Put back on at….**	**Removed at…..**	**Put back on at….**
06.30 am/pm **Because**: I went swimming	07.40 am/pm	06.30 am/pm **Because**: I went swimming	07.40 am/pm
am/pm	am/pm	am/pm	am/pm

At the end of the day:

What time did you remove the accelerometer? 09.50 [✓ am] / pm

What time did you go to sleep? 10.20 [✓ am] / pm

Any comments? ____

Day 1 **Date: ____/____/_____**

What time did you **wake** up today? ________ am / pm

What time did you put the accelerometer on? ________ am / pm

Is today a work or non-work day? work / non-work

If it **is** a work day:

What time did you **start your work** today? ________ am / pm

Did you have a lunch break? yes / no

If **yes**:

What time did your lunch break **start**? ________ am / pm

What time did your lunch break **finish**? ________ am / pm

What time did you **finish your work** today? ________ am / pm

I wore the accelerometer to bed last nigh☐ I did not wear the accelerometer ☐

today?

During the day today:

Did you remove your activity monitors during the day for more than 15 minutes?

No ☐ Yes ☐

Accelerometer		**activPAL (thigh monitor)**	
Removed at…..	**Put back on at….**	**Removed at…..**	**Put back on at….**
________ am/pm **Because**:	________ am/pm	am/pm **Because**:	______ am/pm
_______ am/pm **Because**:	________ am/pm	am/pm **Because**:	________ am/pm

At the end of the day:

What time did you **remove** the accelerometer? _______ am / pm

What time did you go to sleep? _______ am / pm

Any comments? ____

Day 2 **Date: ____/____/_____**

What time did you **wake** up today? _______ am / pm

What time did you put the accelerometer on? _______ am / pm

Is today a work or non-work day? work / non-work

If it **is** a work day:

What time did you **start your work** today? _______ am / pm

Did you have a lunch break? yes / no

If **yes**:

What time did your lunch break **start**? _______ am / pm

What time did your lunch break **finish**? _______ am / pm

What time did you **finish your work** today? _______ am / pm

I wore the accelerometer to bed last nigh☐ I did not wear the accelerometer ☐ today?

During the day today:

Did you remove your activity monitors during the day for more than 15 minutes?

No ☐ Yes ☐

Accelerometer		**activPAL (thigh monitor)**	
Removed at…..	**Put back on at….**	**Removed at…..**	**Put back on at….**
________ am/pm **Because**:	________ am/pm	am/pm **Because**:	______ am/pm
_______ am/pm **Because**:	________ am/pm	am/pm **Because**:	________ am/pm

At the end of the day:

What time did you **remove** the accelerometer? _______ am / pm

What time did you go to sleep? _______ am / pm

Any comments? ____

Day 3 **Date:** ____/____/_____

What time did you **wake** up today? _______ am / pm

What time did you put the accelerometer on? ________ am / pm

Is today a work or non-work day? work / non-work

If it **is** a work day:

What time did you **start your work** today? ________ am / pm

Did you have a lunch break? yes / no

If **yes**:

What time did your lunch break **start**? ________ am / pm

What time did your lunch break **finish**? ________ am / pm

What time did you **finish your work** today? ________ am / pm

I wore the accelerometer to bed last nigh☐ I did not wear the accelerometer ☐

today?

During the day today:

Did you remove your activity monitors during the day for more than 15 minutes?

No ☐ Yes ☐

Accelerometer		**activPAL (thigh monitor)**	
Removed at…..	**Put back on at….**	**Removed at…..**	**Put back on at….**
________ am/pm **Because**:	________ am/pm	am/pm **Because**:	______ am/pm
_______ am/pm **Because**:	________ am/pm	am/pm **Because**:	________ am/pm

At the end of the day:

What time did you **remove** the accelerometer? _______ am / pm

What time did you go to sleep? ________ am / pm

Any comments? ____

Day 4 **Date: ____/____/_____**

What time did you **wake** up today? ________ am / pm

What time did you put the accelerometer on? ________ am / pm

Is today a work or non-work day? work / non-work

If it **is** a work day:

What time did you **start your work** today? ________ am / pm

Did you have a lunch break? yes / no

If **yes**:

What time did your lunch break **start**? ________ am / pm

What time did your lunch break **finish**? ________ am / pm

What time did you **finish your work** today? ________ am / pm

I wore the accelerometer to bed last nigh ☐ I did not wear the accelerometer ☐

today?

During the day today:

Did you remove your activity monitors during the day for more than 15 minutes?

No ☐ Yes ☐

Accelerometer		**activPAL (thigh monitor)**	
Removed at…..	**Put back on at….**	**Removed at…..**	**Put back on at….**
________ am/pm **Because**:	________ am/pm	am/pm **Because**:	______ am/pm
_______ am/pm **Because**:	________ am/pm	am/pm **Because**:	________ am/pm

At the end of the day:

What time did you **remove** the accelerometer? ______ am / pm

What time did you go to sleep? ______ am / pm

Any comments? ____

Day 5 **Date: ____/____/_____**

What time did you **wake** up today? ______ am / pm

What time did you put the accelerometer on? ______ am / pm

Is today a work or non-work day? work / non-work

If it **is** a work day:

What time did you **start your work** today? ______ am / pm

Did you have a lunch break? yes / no

If **yes**:

What time did your lunch break **start**? ______ am / pm

What time did your lunch break **finish**? ______ am / pm

What time did you **finish your work** today? ______ am / pm

I wore the accelerometer to bed last nigh☐ I did not wear the accelerometer ☐
today?

During the day today:

Did you remove your activity monitors during the day for more than 15 minutes?

No ☐ Yes ☐

Accelerometer		**activPAL (thigh monitor)**	
Removed at…..	**Put back on at….**	**Removed at…..**	**Put back on at….**
________ am/pm **Because**:	________ am/pm	am/pm **Because**:	______ am/pm
_______ am/pm **Because**:	________ am/pm	am/pm **Because**:	________ am/pm

At the end of the day:

What time did you **remove** the accelerometer? _______ am / pm

What time did you go to sleep? _______ am / pm

Any comments? ____

Day 6	**Date: ____/____/_____**

What time did you **wake** up today? ________ am / pm

What time did you put the accelerometer on? ________ am / pm

Is today a work or non-work day? work / non-work

If it **is** a work day:

What time did you **start your work** today? ________ am / pm

Did you have a lunch break? yes / no

If **yes**:

What time did your lunch break **start**? ________ am / pm

What time did your lunch break **finish**? ________ am / pm

What time did you **finish your work** today? ________ am / pm

I wore the accelerometer to bed last nigh☐ I did not wear the accelerometer ☐

today?

During the day today:

Did you remove your activity monitors during the day for more than 15 minutes?

No ☐ Yes ☐

Accelerometer		activPAL (thigh monitor)	
Removed at…..	**Put back on at….**	**Removed at…..**	**Put back on at….**
________ am/pm **Because**:	________ am/pm	am/pm **Because**:	______ am/pm
_______ am/pm **Because**:	________ am/pm	am/pm **Because**:	_______ am/pm

At the end of the day:

What time did you **remove** the accelerometer? _______ am / pm

What time did you go to sleep? _______ am / pm

Any comments? ____

Day 7 **Date: ____/____/_____**

What time did you **wake** up today? ________ am / pm

What time did you put the accelerometer on? ________ am / pm

Is today a work or non-work day? work / non-work

If it **is** a work day:

What time did you **start your work** today? ________ am / pm

Did you have a lunch break? yes / no

If **yes**:

What time did your lunch break **start**? ________ am / pm

What time did your lunch break **finish**? ________ am / pm

What time did you **finish your work** today? ________ am / pm

I wore the accelerometer to bed last nigh☐ I did not wear the accelerometer ☐

today?

During the day today:

Did you remove your activity monitors during the day for more than 15 minutes?

No ☐ Yes ☐

Accelerometer		**activPAL (thigh monitor)**	
Removed at…..	**Put back on at….**	**Removed at…..**	**Put back on at….**
________ am/pm **Because**:	________ am/pm	am/pm **Because**:	______ am/pm
_______ am/pm **Because**:	________ am/pm	am/pm **Because**:	________ am/pm

At the end of the day:

What time did you **remove** the accelerometer? _______ am / pm

What time did you go to sleep? ________ am / pm

Any comments? ____

Additional notes:

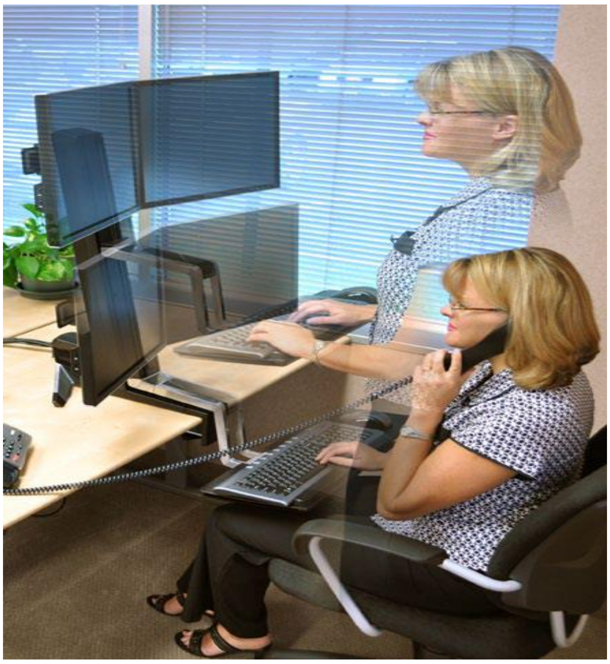
If there is anything else you would like to mention regarding the monitors or the daily log, feel free to comment in the space below:

Notes:

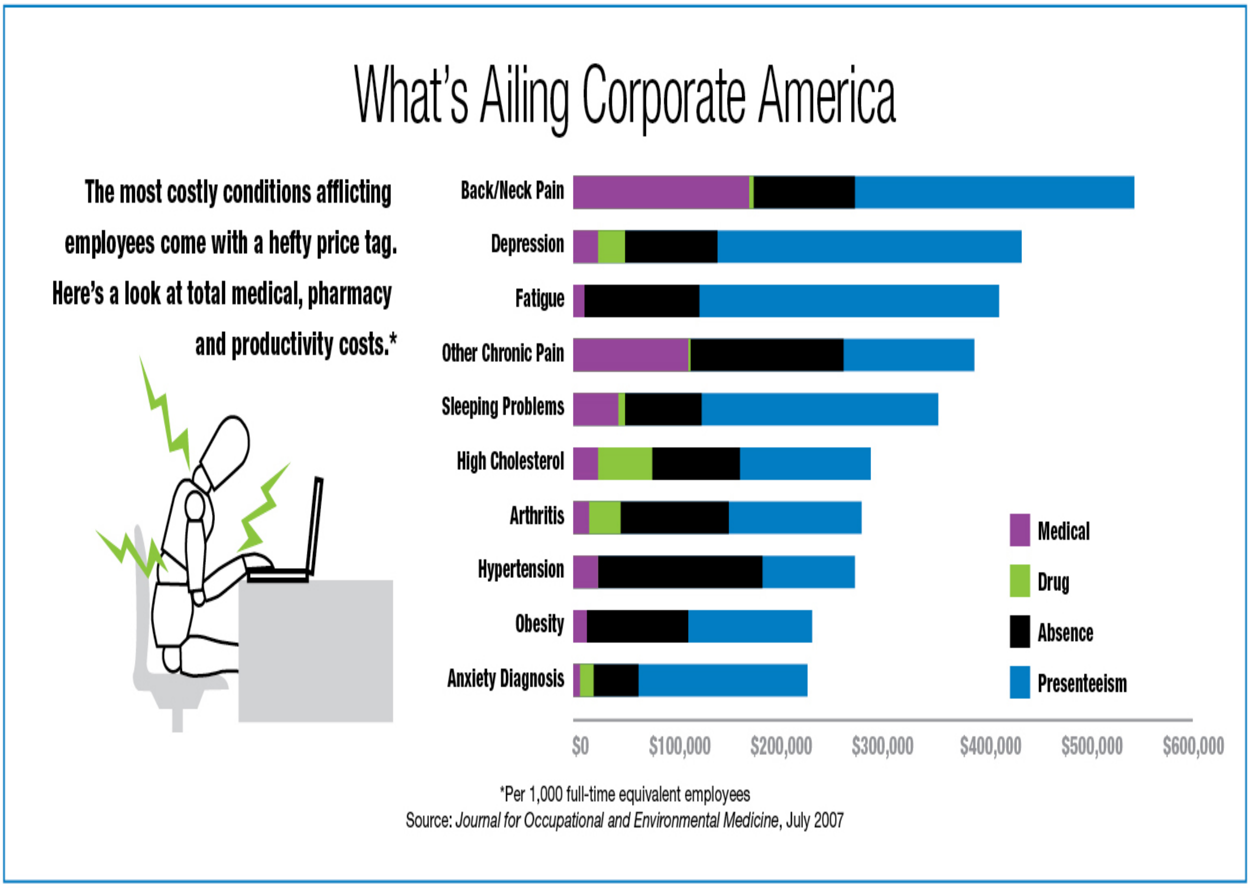
Appendix 5.5: Information about standing at work

Stand More, Sit Less

Start Now!



You can burn 30-60 more calories in an hour by standing!



What's Ailing Corporate America

The most costly conditions afflicting employees come with a hefty price tag. Here's a look at total medical, pharmacy and productivity costs.*

*Per 1,000 full-time equivalent employees

Source: *Journal for Occupational and Environmental Medicine*, July 2007

Benefits of Sit-Stand Work

If you're one of the millions of knowledge workers worldwide who spend the majority of their working day sitting behind a computer, the simplest *non-exercise activity* intervention you can do for yourself is to stand up. Barring medical conditions that prohibit you from doing so (e.g., pregnant women, people with varicose veins), getting out of your chair is like a wake-up call for your body. Engaging in a combination of postures, as is possible with a sit-stand workstation, has many benefits:

- Strengthens leg, ankle and foot muscles

- Improves balance
- Mitigates formation of blood clots deep in the legs
- Squeezes valves in the leg veins, pushing blood upward toward the heart
- Reduces risk of cardiovascular disease
- Improves alertness
- Encourages movement
- Discourages “mindless” snacking
- Allows deep breathing
- Increases good HDL cholesterol levels
- Decreases bad LDL cholesterol levels
- Promotes weight loss
- Is better for the back
- Is a natural posture for humans
- Is less fatiguing

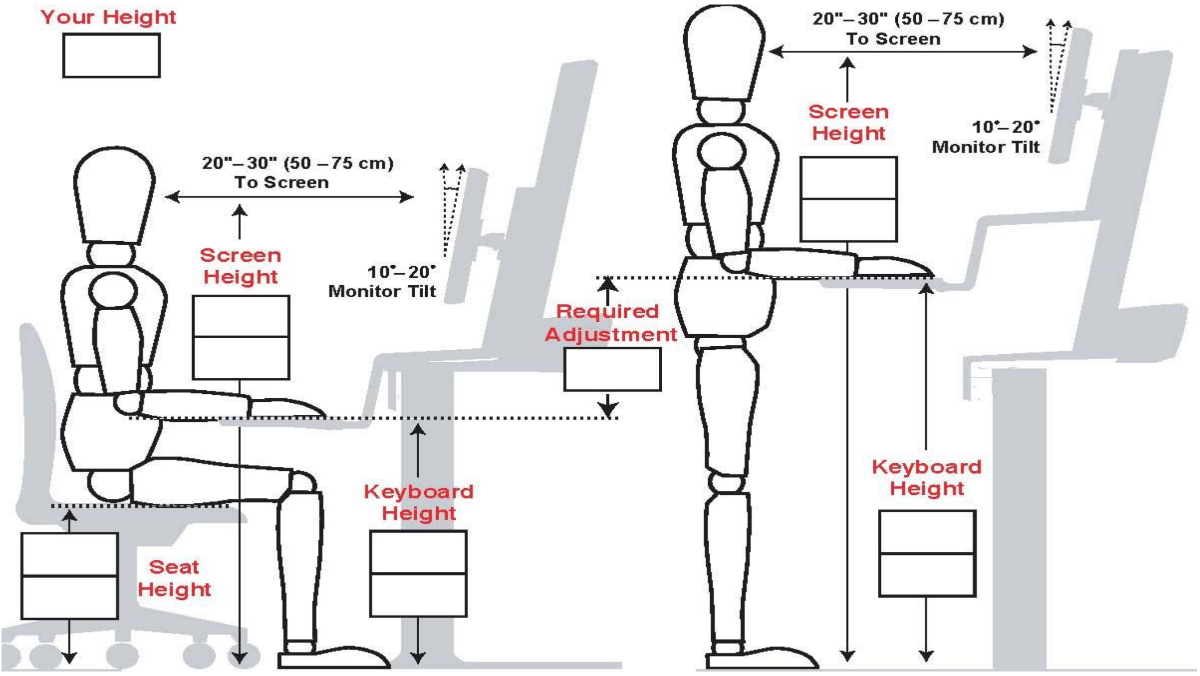
The fundamental notion behind a sit-stand workstation is that it engages all human physiological systems, integrating mechanical, physical and biochemical functions for optimum health. In and of itself, sitting, or indeed any static posture, has a limiting effect on both the electrical and chemical methods used for communication between systems. When these systems operate in balance to maintain stability, there is homeostasis.

Sitting disease reflects a disturbance of homeostasis, a condition known as homeostatic imbalance. Aging is a common example of how the body loses efficiency in its control systems; these inefficiencies gradually result in an unstable internal environment that increases the risk for illnesses, like cancer, which is estimated, will kill 600,000 people in the United States in 2010 alone. “The genes that unmoor normal cell division are not foreign to our bodies, but rather mutated, distorted versions of the very genes that perform vital cellular functions. And cancer is imprinted in our society: as we extend our life span as a species, we inevitably unleash malignant growth (mutations in cancer genes accumulate with aging; cancer is thus intrinsically related to age). If we seek immortality, then so, too, in a rather perverse sense, does the cancer cell.” (Mukherjee, 2010)

Workspace Planner Worksheet

Follow the steps below when planning your workstation using the online Planning Tool at **www.computingcomfort.org**. The values displayed when you click on your height will help you place your equipment to establish Neutral Posture, the basis of a comfortable computing workstation.

Feet	5’0”	5’1”	5’2”	5’3”	5’4”	5’5”	5’6”	5’7”	5’8”	5’9”	5’10”	5’11”	6’0”	6’1”	6’2”	6’3”	6’4”
cm	**152**	**155**	**157**	**160**	**163**	**165**	**168**	**170**	**173**	**175**	**178**	**180**	**183**	**185**	**188**	**191**	**193**

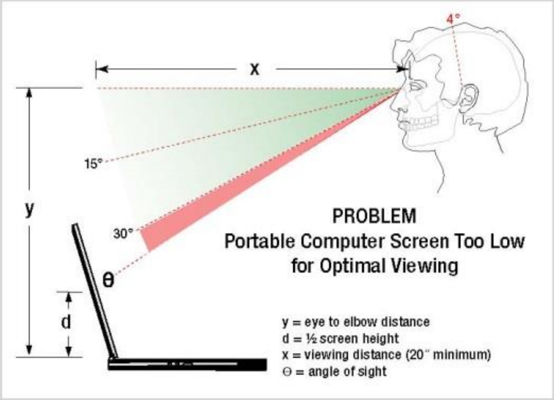


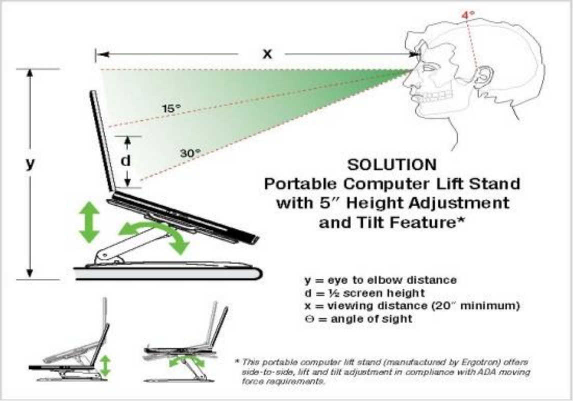
Note: The values represent average dimensions for people of your stature and do not account for variations due to gender, age or body type. Refer to the values as a starting point, rather than the final mounting height of your computer equipment. Values are derived without clothing allowances. Always add shoe height to figure proper measurement. Additional factors may apply. Consult with an ergonomist for more detailed information. Values are based on the 1988 Anthropocentric Survey of the U.S. Army Personnel database. And remember to adjust the position of equipment as your body posture changes!

Eye Height	5% Female	Female	Person	Male	95% Male
Standing	**55.7. ”**	**59.4. ”**	**61.7. ”**	**64.4. ”**	**68.6. ”**

Sitting	**40.8. ″**	**44.0. ″**	**46.1. ″**	**48.5. ″**	**52.1. ″**
Elbow Height					
Standing	**36.5. ″**	**38.8. ″**	**40.4. ″**	**42.5. ″**	**45.4. ″**
Sitting	**20.8. ″**	**23.0. ″**	**24.9. ″**	**27.0. ″**	**29.5. ″**

Monitor and Keyboard Placement.





Adjust the monitor height so that the top of the screen is at or slightly below eye level. Your eyes should look slightly downward when viewing the middle of the screen.

Position the monitor no closer than 20 inches (508 mm) from your eyes. A good rule of thumb is an arm’s length distance. The larger your screen, the more distance you will want.

Adjust the screen position to eliminate glare from windows and ceiling lights.

If lighting conditions permit, tilt the monitor back 10° to 20°: this maintains the same distance between your eyes and the screen as you scan it from top to bottom.

Exception: If using bifocals, lower the monitor below eye level and turn screen upward, tilting it back 30° to 45°.

The centre-line of the keyboard should be level with the height of your elbow.

Tilt the keyboard back 10° so that your wrists remain flat.

More Tips for Comfortable Computing...

Use an adjustable chair. Get comfortable with its features and make adjustments regularly.

Rest your eyes periodically by focusing on an object 20+ feet away.

Stand and stretch your back and arms from time to time.

Position whatever you are looking at most of the time (the screen or reference material) directly in front of you to minimize turning your head.

Remember that even if your workstation is set up properly, you can still get muscle fatigue from being in the same position for too long. Be sure to periodically adjust your monitor, keyboard or chair to stay flexible.

Is the top of your monitor’s screen at eye level? Or if using bifocal lenses, is the screen placed lower and tilted upward?		
Yes	Perfect. Keep your neck comfortably upright when viewing. Placing a screen’s top at or just below eye level allows for correct posture.	☑

Is the screen at least 20 inches (50 cm) from your eyes? Or if using bifocal lenses, is it roughly 16 inches (40 cm) away?		
Yes	Good. Depending on screen size, 20–30 inches or 50–75 cm from the screen is right. If using bifocals, the distance should be roughly 16 inches or 40 cm.	☑

Do your wrists remain flat when typing?		
Yes	Perfect. Wrists should remain flat, creating a straight line from elbows to knuckles.	☑

Are your shoulders relaxed when computing? Are upper arms roughly parallel with your torso?		
Yes	Good. Regardless of posture, position your keyboard so that your	☑

	shoulders remain relaxed, keeping your chest open and wide.	

When seated, are your feet flat on the floor with your hips at a 90–120° angle?		
Yes	Excellent. This indicates that your chair is positioned at a good height and angle, which reduces strain on the lower back.	☑

Can you adjust the height and angle of your monitor, keyboard and chair?		
Yes	Great. Periodically adjust your monitor, keyboard or chair to accommodate slight changes in posture. Staying in exactly the same position for too long cause’s bodily stress and strain.	☑