THE EFFECT OF INTERRUPTING SEDENTARY BEHAVIOUR ON THE CARDIOMETABOLIC HEALTH OF ADULTS WITH SEDENTARY OCCUPATIONS.

Jason Robert Dunning

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DECLARATION

I declare that the work contained in this dissertation is my own, with all assistance acknowledged. It is being submitted for the degree of Master of Science in Medicine at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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Jason Robert Dunning

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ABSTRACT

There has been an increase in the percentage of individuals employed in sedentary occupations over the last 50 years. Prolonged sedentary time has been associated with poorer cardiometabolic health. Interrupting prolonged sedentary activity may attenuate the risk of developing cardiometabolic disease. This study aimed to determine whether prompts delivered via a mobile phone were effective in reducing sedentary behaviour (measured objectively using an Actigraph and activPAL accelerometer) in people with sedentary occupations. Twenty men and women were randomly assigned to either a control or intervention (PROMPT) group. Only participants in the PROMPT group were instructed to interrupt their sedentary behaviour. During the intervention participants in the PROMPT group spent less time in sedentary behaviour (5.5±0.5 hrs/day) during their working day, compared to the control group (6.7±0.6 hrs/day) as measured using the activPAL ($p=0.04$). There was no association between the intervention and cardiometabolic health variables. There were differences in the outputs of ActiGraph and activPAL accelerometers. Interrupting prolonged sedentary time via mobile phone messages may be an effective strategy in reducing total sedentary time in the workplace.

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Acquired immune deficiency syndrome	AIDS
Adenosine triphosphate	ATP
American College of Sports Medicine	ACSM
Arterial oxygen concentration	C_aO_2
Blood Pressure	BP
Body mass index	BMI
Central business district	CBD
C-reactive protein	CRP
Enzyme-linked immunosorbent assay	ELISA
High density lipoprotein	HDL
Homeostatic model assessment (insulin resistance)	HOMA-IR
Human immunodeficiency virus	HIV
Lipoprotein lipase	LPL
Low-and-middle income countries	LMIC
Low density lipoprotein	LDL
Maximum oxygen uptake	VO_{2max}
Moderate-to-vigorous physical activity	MVPA
Metabolic equivalents	METs
Non-communicable diseases	NCDs
Triglycerides	TG
Venous oxygen content	C_vO_2
Waist circumference	WC

CHAPTER 1 – INTRODUCTION

1.1 The movement continuum and health

The changes in personal and public transportation and the advancement of workplace and domestic technologies (including methods of communication and entertainment), has resulted in a reduction in the demand to be physically active. (Owen *et al.*, 2010). Global physical activity levels have been declining rapidly due to reductions in movement in the workplace, home and travel (Ng and Popkin, 2012) and populations have become more sedentary (Owen *et al.*, 2010). Sedentary behaviour is the term used to describe activities of low energy expenditure with particular reference to sitting or similar activities such as those during transportation, television viewing or computer use (Tremblay *et al*., 2010). Light intensity activities, that used to be performed regularly in outside/non-office occupations (such as walking, or household tasks), have also declined in recent decades and have been displaced by time spent in sedentary behaviour (Owen *et al.*, 2010). It is estimated that 53.9% of adults in the United States meet the current guidelines for the recommended levels of physical activity (Hart *et al*., 2016), guidelines which focus largely on time spent in moderate-to-vigorous physical activity (MVPA). Daily movement is now being considered as activities of varying intensity on a continuum. Participation in MVPA is known to have beneficial associations on cardiometabolic health, however MVPA only contributes to a small proportion (<5%) of our daily activities (Chaput *et al*., 2014), with light intensity physical activity and sedentary time both contributing to a significant and distinct proportion of our waking day activities (Figure 1). It is now thought that

offsetting one movement or behaviour for another (for example, sedentary time for time spent in light physical activity) may have positive consequences for one's health.

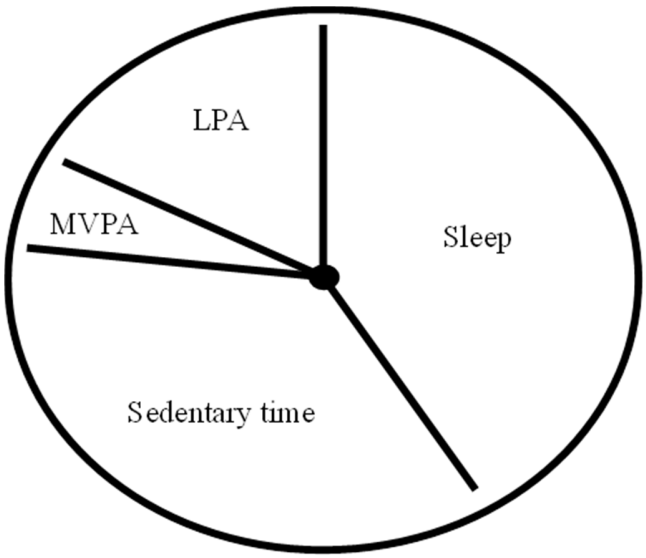

Figure 1. Estimated daily proportion of movement behaviour. Figure adapted from Chaput *et al*., 2014

1.1.1 Transition into sedentary occupations

Over the past 50 years, in the United States, there has been an increase in the percentage of individuals employed in sedentary occupations (Church *et al*., 2011). Similarly, there has been a decline in occupations that require moderate intensity physical activity (Figure 2). With the increase in sedentary occupations, there is increasing interest in evaluating the behaviour of sedentary workers, and the effects

of reduced MVPA and increased sedentary time on health (Straker & Mathiassen, 2009).

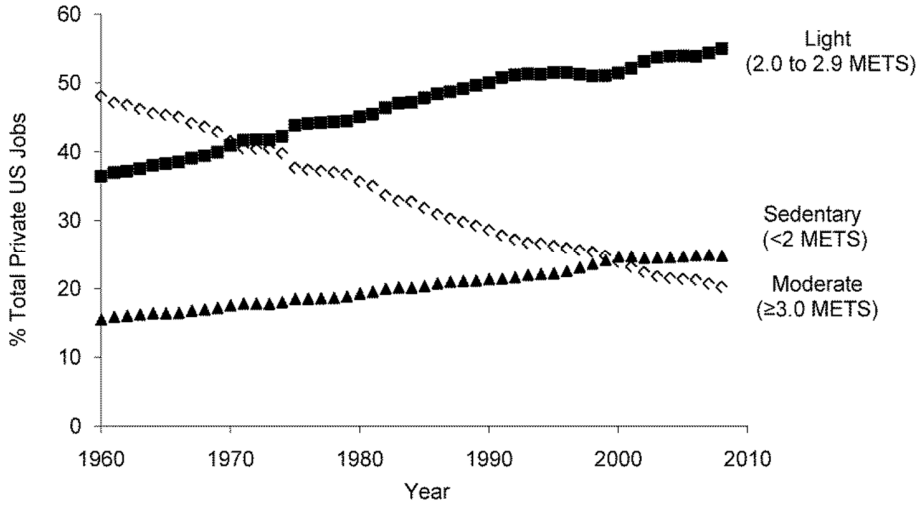

Figure 2. The prevalence of occupations that involve sedentary, light and moderate intensity activities between 1960 and 2008 in the US. From Church *et al*., 2011.

1.1.2 Synopsis of sedentary behaviour and cardiometabolic disease risk

Several systematic reviews on studies of activity and health have documented the relationship between increased sedentary time and an increased risk of cardiometabolic disease (Dunstan *et al*., 2012$_a$; Tremblay *et al*., 2011; Ford & Casperson, 2012). The risk of cardiovascular and/or metabolic disease can often be reduced through means of lifestyle modification or intervention. Hence, physical activity guidelines have been established in order to curb the increased risk in cardiometabolic disease associated with poor lifestyle choices. There is a growing body of evidence describing the deleterious effects of increased sedentary behaviour

on cardiometabolic disease risk. Despite this evidence, current recommendations of physical activity are still stated with a focus on MVPA without considering the inclusion of recommendations for the modification of sedentary behaviour. It is now widely accepted that sedentary behaviour is part of a continuum with MVPA, and that guidelines for reducing prolonged periods of sitting need to be clearly stated. Ultimately, displacing prolonged bouts sedentary behaviour with that of light intensity activity may be an effective strategy for improving lifestyle related health outcomes (Buman *et al*., 2010).

Cardiometabolic disease is a major contributor of the morbidity and mortality in low-and-middle income countries (LMIC), such as South Africa (Yusuf *et al*., 2014). In 2012, the World Health Organization released statistics highlighting the rise of diabetes and other non-communicable diseases (NCDs) within the sub-Saharan African region (World Health Organization, 2012). While the reported cases of infectious diseases outnumbered NCDs in 2008, it was estimated that NCDs could become the primary cause of mortality in African countries within the next two decades (Peer *et al*., 2014). The increase of diabetes is predicted to rise from 19.8 million in 2013 to 41.5 million cases in the African region by 2035 (Peer *et al*., 2014). In 2015, it was reported that over half of the 460 236 deaths recorded in South Africa, were attributed to NCDs (Statistics South Africa, 2017). One of the primary contributing factors to NCDs in South Africa, and other sub-Saharan African countries, is insufficient physical activity and associated metabolic disorders such as obesity and insulin resistance (BeLue *et al*., 2009).

Despite there being evidence that a decrease in sedentary behaviour improves cardiovascular and metabolic health, a simple but effective intervention, which encourages individuals to reduce prolonged sedentary time, is lacking. Furthermore, those that have been done have not conclusively agreed on the ideal method of interrupting prolonged sedentary behaviour and have shown inconsistent findings (Peddie *et al*., 2013; Altenburg *et al*., 2013; Holmstrup *et al*., 2014). Prompts delivered via a mobile phone may be an effective method of interrupting prolonged sitting time. Nowadays, devices such as mobile phones are available to most of the African population (approximately 89% of adults (Poushter & Oates, 2015)), despite socioeconomic status, and these devices provide simple and relatively cost-effective means of communication. Studies that have been able to successfully interrupt sedentary behaviour have shown that the threat of disease risk alone may not be enough to encourage people to reduce their sedentary time (Evans *et al*., 2012) and it is possible that people need to be reminded often in order to effectively reduce prolonged periods of sedentary time. Currently, guidelines for sedentary behaviour exist for Canadian children (Trembley *et al*., 2011) and 24 hour movement behaviour guidelines have been developed and are now in use for children and youth in Canada (Tremblay *et al*., 2016). Guidelines are also being developed and implemented, predominantly for desk-based employees, in the UK (Buckley *et al*., 2015). However, more research in activity behaviours in adults is needed in order to further develop guidelines for workplace behaviour modification, as a way of protecting cardiometabolic health.

1.2 Problem statement

The deleterious effect of prolonged sedentary time on cardiometabolic health has been well documented, globally, in observational studies. The association between the time spent in prolonged bouts of sedentary behaviour and cardiometabolic health in South Africans with sedentary occupations is not clear. An effective method of interrupting sedentary behaviour may be through prompts delivered via a mobile phone, as these devices are commonplace in modern day society. Interrupting prolonged periods of occupational sedentary time may attenuate the negative effects associated with increased sitting time. To date, intervention studies have provided inconclusive reports on the efficacy and benefit of interrupting workplace sedentary time.

1.3 Aim, objectives and hypotheses

The present study aimed to determine whether prompts delivered via a mobile phone were effective in interrupting and reducing the amount of time spent sedentary during the working day. The study also aimed to determine whether these interruptions in sedentary time (delivered over a 10-week period) were associated with cardiometabolic health.

The objectives of this study were to:

- interrupt prolonged periods of sedentary time using prompts delivered via a mobile phone.

- reduce the amount of time spent sitting during the day.
- measure markers of cardiometabolic health before and after the intervention aimed at interrupting sedentary time.
- determine the association between sedentary time, and time spent in physical activity on cardiometabolic health.

I hypothesised that interrupting sedentary behaviour, with the aid of messages delivered via a mobile phone, would be an effective method of reducing the amount of time spent sedentary, and would have a positive effect on the blood markers of cardiometabolic health. Those who spend less time in sedentary behaviour, and have more interruptions in their sedentary time during the day would have better cardiometabolic health.

CHAPTER 2 – LITERATURE REVIEW

2.1 The rising prevalence of inactivity

Urbanization has allowed access to technological advances and the development of infrastructure and personal/public transport systems to contribute to a decrease in daily physical activity and a more sedentary lifestyle (Matthews *et al*., 2008). There has been an increase in workers employed in more sedentary occupations which involve low amounts of physical activity (Kirk & Rhodes, 2011; Straker & Mathiassen, 2009; Church *et al*., 2011). Low physical activity itself has been associated with adverse metabolic conditions which contribute to an increased risk of hypertension, obesity and, diabetes (Warburton *et al*., 2006). Over the 10 year period between 1998 and 2008, there was a noticeable increase in overweight and obesity in the South African population, with more than 70% of women and 45% of men considered overweight (body mass index (BMI) >25 kg.m2) (Bradshaw *et al*., 2010). The weight gain was associated with concurrent increases in the incidence of hypertension, diabetes, high serum low density lipoprotein (LDL) cholesterol concentrations as well as physical inactivity (Bradshaw *et al*., 2010). Overall, the rapid transition from a rural to a more urbanized lifestyle has led to behavioural modifications resulting in lower physical activity levels and therefore an increased risk of NCDs (Micklesfield *et al*., 2014).

The global increase in the prevalence of NCDs such as cardiovascular disease, certain types of cancer and type 2 diabetes, has been a growing concern to healthcare policy

makers for some time. It is estimated that NCDs are responsible for 38 million deaths each year worldwide, with approximately 75% of these occurring in low-and-middle-income countries (LMICs) (WHO, 2012). The primary contributing factors to NCDs in South Africa, and other sub-Saharan African countries, include physical inactivity, high blood pressure (BP), hyperglycemia, and obesity (BeLue *et al*., 2009; Kruger *et al*., 2001). Until recently, particularly in African countries, the threat of communicable diseases were of greater concern and consideration where the majority of attention and resources are focused on the numerous cases of infectious diseases such as HIV and AIDS (Beaglehole & Yach, 2003) rather than those concerning NCDs. However, a recent analysis of mortality in the South African population has revealed that NCDs were the primary cause of death recorded during 2015 (55.5% of total number of deaths), whereas communicable diseases attributed to 33.4% of total number of deaths, while injuries accounting for the remaining 11.1% of total deaths (Statistics South Africa, 2017). Non-communicable diseases including cardiovascular diseases, some cancers, chronic respiratory diseases and diabetes are thought to be preventable - up to 80% of heart disease, stroke, diabetes (Type II), and over a third of cancers could be prevented by decreasing shared risk factors such as tobacco use, unhealthy diet and physical inactivity (Shisana *et al*., 2014). Increasing physical activity has been shown to mitigate the factors contributing to the development of NCDs (Lee *et al*., 2012).

2.2 Physical activity, physical inactivity and sedentary behaviour

Physical activity is defined as "any bodily movement produced by skeletal muscles that result in energy expenditure" (Caspersen *et al.*, 1985). Exercise is therefore a subdivision of physical activity, which is typically structured and repetitive with the aim to improve one's physical fitness (Caspersen *et al.*, 1985). The energy cost of physical activities can be expressed as a multiple of the resting metabolic rate (MET). One MET is defined as the amount of oxygen consumed at rest and is equal to $3.5ml O_2.kg^{-1}.min^{-1}$ (Jetté *et al.*, 1990). The current physical activity guidelines set by the American College of Sports Medicine (ACSM), recommends that healthy adults (18-65 years of age) perform at least 30 minutes per day of moderate-intensity cardiorespiratory exercise training (between 3 and 6 METs) on 5 or more days per week (total time of ≥150 min/wk), at least 20 minutes per day of vigorous intensity (≥6 METs) exercise on 3 or more days per week (total time of ≥75 min/wk) or a combination of moderate and vigorous-intensity physical activity which results in an energy expenditure of between 500 and 1000 MET minutes per week (Garber *et al.*, 2011) (ACSM, 2013). Physical inactivity can therefore be defined as an activity level (and thus energy expenditure) that is insufficient to meet the current physical activity recommendations (Lee *et al.*, 2012).

Sedentary (from the Latin word sedere, "to sit") behaviour is the term used to describe activities of low energy expenditure (<1.5 METs) (Tremblay *et al.*, 2010)

and includes activities such as sitting, lying down, and forms of screen-based work or entertainment (Pate *et al*., 2008). A consensus statement has recently been published providing sedentary behaviour guidelines to desk-based employees in the UK (Buckley *et al*., 2015). The guidelines suggest that desk-based employees stand, or engage in light intensity physical activity for two hours daily, and potentially increase this duration to four hours or more per day in order to attain the greatest health risk reduction (Buckley *et al*., 2015). Daily movement – consisting of activities of varying intensities – is now being considered a continuum, with MVPA contributing to a small proportion of the total day (Figure 1). Hence, a substantial proportion of one's waking day can be spent in sedentary behaviour or activities of light intensity. It is now believed that displacing prolonged sitting or sedentary time with activities of light intensity, such as stepping time (achievable during workplace settings), may have cardiometabolic health benefits, particularly through glucose and lipid metabolism (Healy *et al*., 2015)

For the purpose of this dissertation, being physically active will refer to meeting the 150 min/wk MVPA guidelines; inactivity will refer to not meeting the abovementioned guidelines while being sedentary will refer to spending a significant proportion of one's day in sitting or lying behaviour.

2.3 Measuring sedentary behaviour and physical activity

2.3.1 Measuring sedentary activities and sedentary patterns

It is important in behavioural epidemiological research to accurately measure and report on, not only activity and different intensities of activity, but also behavioural patterns that may have an effect on overall metabolic health between and within individuals over time (Atkin *et al*. 2012). Understanding sedentary behaviour patterns, and how sedentary time is accumulated, may allow for effective intervention strategies to be developed and implemented in order to encourage more active lifestyles (Biddle *et al*., 2004). The methods of assessing sedentary behaviour include subjective measures (self-report questionnaires and diaries/log-books), and objective measures which include the use of accelerometers, posture monitors, and heart rate monitors (Atkin *et al*. 2012). Despite the validity of certain subjective measurements of activity (such as the International Physical Activity Questionnaire (IPAQ) (Kim *et al*., 2013)), there have been reported cases of overestimation of physical activity (Hagstromer *et al*., 2010; Lee *et al*., 2011). In addition, the sedentary behaviour component of the IPAQ has generally shown to have a moderate to poor validity when compared to objectively measured sedentary behaviour (Booth *et al*., 2003; Hagströmer *et al*., 2006). Objective methods of assessing sedentary behaviour have been shown to be reliable in epidemiological studies (Chen & Bassett, 2005) and are effective in assessing participant compliance in intervention studies.

Multi-axis accelerometers, such as the ActiGraph wGT3X-BT accelerometer, are used predominantly for objectively assessing ambulatory activities, such as walking (John & Freedson, 2012) and are typically worn at the hip – although not limited to this position. When worn at the hip, accelerometers cannot accurately distinguish between seated and standing behaviours/activities (Chen & Bassett, 2005; Steeves *et al*., 2015) which therefore makes it difficult to differentiate between light-intensity and sedentary activities. However, postural, thigh-mounted devices, such as the activPAL accelerometers, have been shown to be better suited at distinguishing postural changes, particularly sitting and standing transitions, with greater accuracy than hip-based accelerometers such as the ActiGraph (Grant *et al*., 2006; Kozey-Keadle *et al.,* 2011). In order to determine which method of measurement and/or equipment is appropriate for a particular epidemiological study, one must determine the viability/feasibility when considering the strengths and limitations of each method in comparison to the burden and/or cost presented to both the principal investigator as well as the participant. These features of the different methods used to measure physical activity and sedentary behaviour are summarised in Table 1 (adapted from Atkin *et al*., 2012).

Table 1. Characteristics and limitations of different methods used to measure physical activity and sedentary behaviour.

	SUBJECTIVE		**OBJECTIVE**		
	Self-report questionnaires	**Diaries**	**Accelerometry**		**Heart rate/combined sensing**
			Ambulatory	**Postural**	
Example	IPAQ		ActiGraph	ActivPAL	Actiheart
Cost	Low	Low	Moderate	Moderate	High
Population	Adults	Adults	All population groups	All population groups	All population groups
Participant burden	Low	Moderate	Low	Low/moderate	Low/moderate
Researcher burden	Low	Moderate	Moderate	Moderate	Moderate/high
Dimensions assessed	Specific physical activity and sedentary behaviours, environmental and social context	Specific physical activity and sedentary behaviours, environmental and social context	Total physical activity including activities of different intensity, total sedentary time, including bouts and breaks	Energy expenditure, step count/time, activity score, time spent sitting/standing, posture transitions	Physical activity intensity, frequency and duration
Strengths	Information on behaviour type and context useful for intervention design	May be used to assess concurrent behaviours	Substantial literature on application and analysis	Able to distinguish sitting/standing	Combined movement and physiological data aid identification of monitor wear time
Limitations	Subject to recall and reporting bias	Subject to recall and reporting bias, validation studies lacking	No consensus regarding data processing	Validation studies in free-living conditions lacking	Formal validation studies lacking

*Table adapted from Atkin *et al.*, 2012

2.3.2 The relationship between physical activity and physical fitness and the measurement thereof

Maximal aerobic capacity or maximum oxygen uptake (VO_{2max}) describes the maximum volume of oxygen that is transported from the air to the mitochondria to be used in the process of oxidative phosphorylation in order to create energy in the form of adenosine triphosphate (ATP) (Levine, 2008). Maximum oxygen uptake is generally used to best indicate one's ability to use oxygen for energy production and is therefore a surrogate measure of cardiorespiratory fitness (Astorino, 2009; Levine, 2008) and health (Kodama *et al.*, 2009). Cardiorespiratory fitness has been shown to be a strong predictor of cardiometabolic disease and metabolic syndrome (Kodama *et al.,* 2009; Ekblom *et al.,* 2015). Cardiorespiratory fitness is usually assessed using a progressive incremental exercise test to volitional fatigue, in order to determine maximal aerobic capacity. Maximum oxygen uptake can be measured and defined using the Fick's equation (Levine, 2008):

$$VO_{2max}\ (mLO_2.kg^{-1}.min^{-1}) = \text{Cardiac Output}\ (CaO_2 - CvO_2)$$

Participating in regular physical activity – defined as bodily movement resulting in energy expenditure – relates to changes in physical fitness (Caspersen *et al.,* 1985).

2.3.3 Summary of measurements and equipment for use in sedentary population studies

Methods of assessing sedentary behaviour, and the outcome of lifestyle modification on health, are not without their limitations. The ideal measurements and/or equipment for use in sedentary behaviour studies would need to:

- be adept at distinguishing postural changes or differences (i.e. sitting/standing)
- be accurate and reliable (validated in sedentary behaviour research)
- pose little burden on researcher and participant
- yield data that can be analysed and interpreted efficiently and effectively (Healy *et al*., 2011_a)

A combination of subjective (self-report) and objective (accelerometry) methods of activity measurement would therefore be ideal in epidemiological intervention studies pertaining to sedentary behaviour or lifestyle modification.

2.4 The effects of sedentary behaviour, physical activity and inactivity on cardiometabolic health

It is well known that participating in regular physical activity also translates to an improved physical fitness (Blair *et al*., 1989; Pate *et al* 1995), resulting in an

individual being able to carry out habitual activities without excessive fatigue (Caspersen *et al.*, 1985; Warburton *et al.* 2006). As a result, an increase in one's physical fitness reduces the risk of premature death (Erikssen, 2001). High levels of physical activity have been associated with a lower risk of mortality (Wen *et al.*, 2011) in a dose-dependent response, but beyond certain duration, have no additional benefits (ACSM, 2013). Increased physical activity has been found to improve cardiometabolic health through several mechanisms. These mechanisms include a reduction in abdominal obesity (Kay & Singh, 2006), improved lipid profile (Thompson *et al*., 2001), improvements in endothelial function (DeSouza *et al.,* 2000), BP (Arroll & Beaglehole, 1992), blood glucose homeostasis (Boulé *et al.,* 2005) and insulin sensitivity (Balkau *et al.*, 2008) as well as a reduction in systemic inflammation (Warburton *et al.,* 2006). In 2003, the South Africa Demographic and Health Survey reported 48% of adult men and 63% of adult women to be physically inactive with only 23.6% of adult men and 14% of adult women sufficiently active (the remaining 28.4% of adult men and 22.9% of adult women only minimally active) (Department of Health MRC, 2007). Improving our daily energy expenditure by taking part in more activity, which inevitably leads to less sedentary time, has also been shown to be associated with reduced risk of premature death from all cause (Nocon *et al.,* 2008), and from cardiometabolic disease (Pate *et al.,* 1995) in men and women (primary prevention) and aids in reducing risk of mortality in those with already established chronic cardiovascular diseases (secondary prevention) (Warburton *et al.,* 2006). To reiterate, an individual is classified as inactive if he/she does not meet the recommended physical activity guidelines pertaining to his/her

demographic. Whereas, sedentary time refers to the total time of activities of low energy expenditure and includes a postural component of how this time is accrued.

There is a wealth of literature, typically cross-sectional studies, which have aimed to determine the associations between sedentary time (and how sedentary time is accumulated) and disorders relating to cardiometabolic and cardiovascular disease (Healy *et al*., 2011$_b$; Dunstan *et al*., 2007; Cooper *et al*., 2012; Wijndaele *et al*., 2011; Pereira *et al*., 2012; Ford & Caspersen, 2012). A recent meta-analysis concluded that a greater amount of time spent in sedentary activity increased the odds of developing metabolic syndrome by 73%, and that the risk of developing metabolic syndrome could be reduced by encouraging people to lessen their sedentary behaviour (Edwardson *et al*., 2012). The reported association between increased time spent in sedentary behaviour and risk of metabolic dysfunction is characterized by decreased high-density lipoprotein cholesterol (León-Latre *et al*., 2014), decreased insulin sensitivity (Stephens *et al.,* 2011), increased plasma triglyceride levels (Tremblay *et al*., 2010; Owen *et al*., 2010) and elevated C-reactive protein (CRP) levels (Cooper *et al*., 2012). The above associations are independent of the time spent in MVPA (Cooper *et al*., 2012; Owen *et al*., 2010; Edwardson *et al*., 2012) as well as diet (Katzmarzyk *et al.,* 2009).

Recently, rather than the amount of time spent being inactive, attention has been directed towards time spent being sedentary, and the associations of sedentary behaviour with cardiometabolic health. Individuals who meet the recommended physical activity guidelines for the maintenance of cardiometabolic health may also spend the remainder of their day (i.e. 23.5 hours) in sedentary activity. This idea was conceptualised well by Dunstan and colleagues using the terms “active couch potato” and “active non-couch potato” (Dunstan *et al*., 2010) (Figure 3). Figure 3 is a visual representation of two individuals, both whom meet the current recommended physical activity guidelines set by the ACSM. The “active couch potato” spends the majority of the day sedentary or in activities of low energy expenditure (<1.8 METs), alternatively the “active non-couch potato” spends the majority of the day in light intensity activities (1.8-3.0 METs) with less time spent in sedentary activities (Dunstan *et al.,* 2010). Both individuals meet the recommended MVPA criteria for health enhancement however, it is demonstrated here how the “active couch potato” is likely to be at higher risk of cardiometabolic disease, due to prolonged time in sedentary activities. The concept that individuals may still be at risk of developing cardiometabolic diseases, regardless of whether MVPA guidelines had been met, had implications on whether displacing prolonged periods of sedentary behaviour (similar to that of the “active couch potato” or individuals with sedentary occupations) with non-sedentary/light intensity activities lead to improvements in cardiometabolic health.

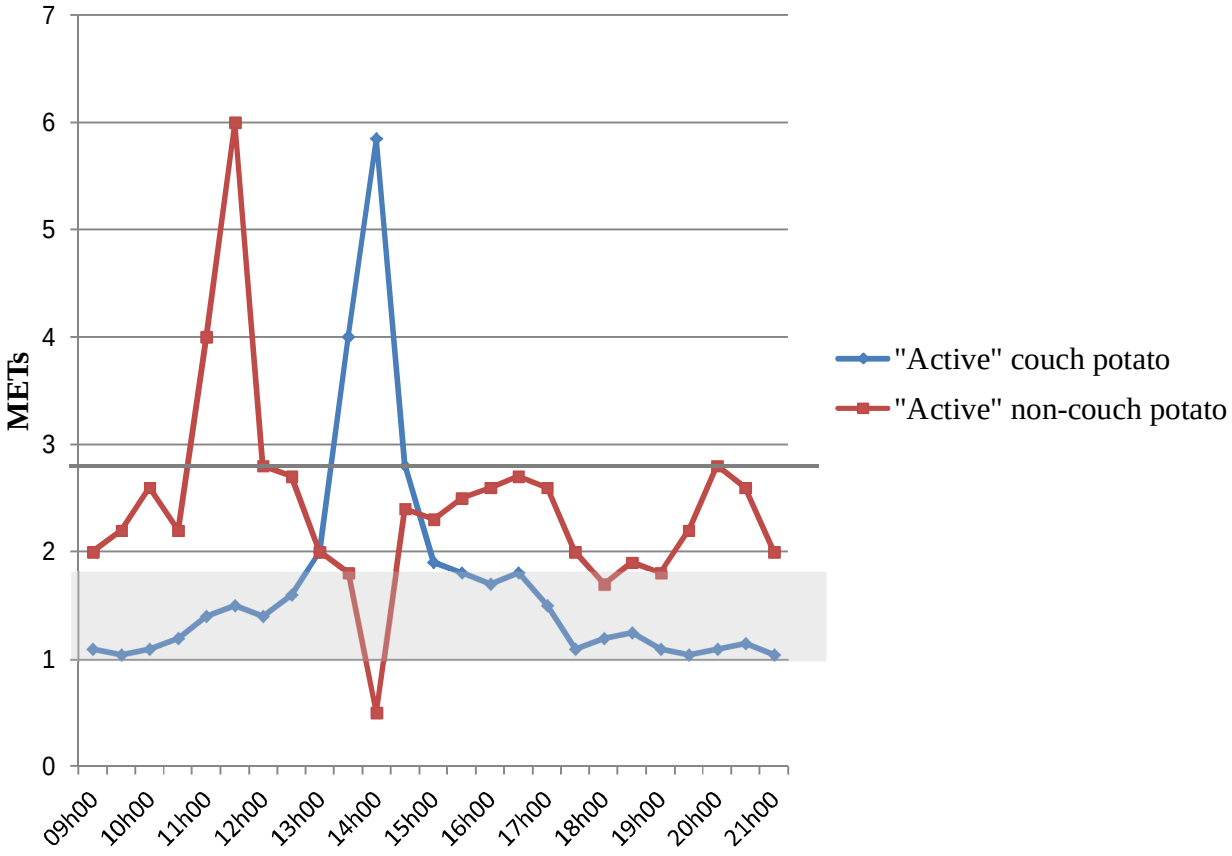

Figure 3. A theoretical representation of the sedentary behaviour and physical activity of two individuals, both of whom meet the recommended physical activity guidelines. Figure taken from Dunstan *et al.*, 2010.

There is now evidence to suggest that offsetting the amount of time spent sedentary by increasing the amount of light physical activity (such as household tasks and walking) during the day, is positively associated with cardiometabolic health (Carson *et al.*, 2013). The Australian Diabetes, Obesity and Lifestyle (AusDiab) study was established to determine the prevalence of diabetes and heart disease in a developed

nation (Dunstan *et al*., 2002). The findings from the AusDiab study demonstrated for the first time using objective methods that light intensity physical activity was beneficially associated with markers of cardiometabolic health independent of MVPA time, while sedentary time was unfavourably associated (Healy *et al*., 2008). These findings are particularly important, as light intensity physical activities have been reported to contribute to a large proportion of one's total daily energy expenditure (Figure 1) (Hamilton *et al*., 2007) compared to moderate and vigorous intensity activity. Substituting sedentary behaviours, such as television viewing time, with time spent in light intensity physical activity, such as household tasks, may be an effective strategy in lowering the risk of type 2 diabetes and cardiovascular disease (Healy *et al*., 2008). Similar associations were found in another cross-sectional study which aimed to use objective accelerometry on 483 Japanese adults to determine whether light-intensity lifestyle activities (categorised between 1.6-2.9 METs) and sedentary time (≤1.5 METs) was associated with metabolic syndrome, independent of MVPA (Kim *et al*., 2013). Both light intensity activity and sedentary time was found to be associated with metabolic syndrome, independent of MVPA and it was concluded that light intensity activities should be promoted in addition to MVPA (Kim *et al*., 2013). In addition, isotemporal substitution models have been used to estimate a displacement or "substitution effect" of replacing activities of one intensity (i.e. sedentary activities) with those of a different intensity (i.e. light physical activities) of an equal duration (Buman *et al*. 2010). The outcome from an isotemporal substitution from Buman and colleagues suggested that both low-light, and high-light intensity physical activity were positively related to physical health in older adults, and that

displacing 30 minutes of sedentary time each day with equal amounts of low- and high-light intensity physical activity had positive health benefits (Buman *et al*., 2010). Furthermore, there have been several more cross-sectional studies finding similar relationships between light intensity physical activity and overall health (Healy *et al.,* 2007; Healy *et al.,* 2008; Loprinzi, 2016) and it has been suggested that sedentary behaviour should be viewed as a distinct and independent risk factor for chronic disease, rather than simply a lack of physical activity (Saunders *et al*., 2012).

2.5 The mechanism of prolonged sedentary time and the adverse effect on cardiometabolic health.

The mechanism of sedentary time and the adverse effect of prolonged, uninterrupted bouts of sedentary time on cardiovascular and metabolic health is not fully understood. One proposed mechanism is thought to involve the loss of thousands of muscular contractions throughout the waking day due to sitting for long periods of time (Hamilton *et al*., 2007). The decreased muscle activation leads to a diminished cumulative energy expenditure which in turn has a negative effect on metabolism (Hamilton *et al*., 2007), WC and body mass (Owen *et al*., 2010). It is also believed that several hours of uninterrupted sedentary behaviour results in decreased activity of lipoprotein lipase (LPL) - an enzyme partly responsible for the breakdown of triglycerides, facilitation of free fatty acid uptake into skeletal and adipose tissue, and HDL cholesterol production (Tremblay *et al*., 2010; Owen *et al*., 2010; Hamilton *et al*., 2004). Low levels of LPL activity are thought to induce dyslipidemia and may increase the risk of cardiovascular disease (Hamilton *et al*., 2007; Tremblay *et al*.,

2010). Decreased muscle LPL activity occurred in both acute and chronic cases of inactivity in rats (Bey & Hamilton, 2003). This reduction in LPL activity was found to be reversible after a single (four hour) session of intermittent treadmill walking at a moderate intensity (Bey & Hamilton, 2003). It has been previously demonstrated that exercise induces human LPL gene expression, particularly in the skeletal muscle, and that more vigorous skeletal muscle activity may promote further increases in LPL production (Zhang *et al.,* 1998). Furthermore, activities which produce low level energy expenditure could activate the postural muscles (i.e. legs and trunk) and it is theorized that this could elicit skeletal muscle LPL changes (Owen *et al*., 2010) (Figure 4). Although this has not been demonstrated in human trials, skeletal muscle LPL changes could play a role in promoting HDL cholesterol production and free fatty acid uptake and ultimately may lead to an overall improvement in metabolic health (Seip *et al.,* 1995). These mechanisms have not been confirmed in intervention studies in humans.

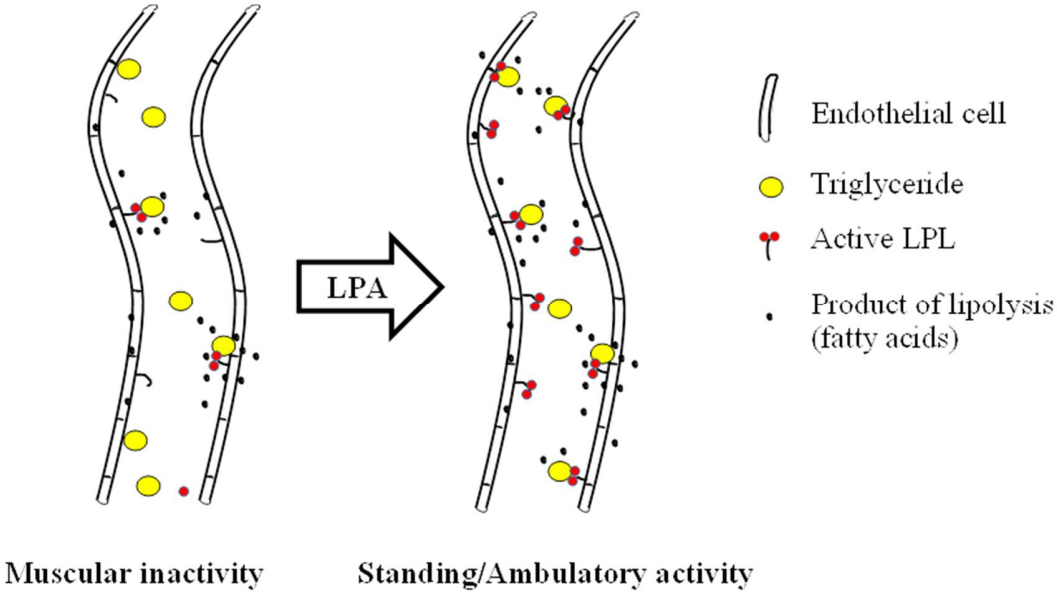

Figure 4. Diagrammatic representation of increased LPL activity after substituting prolonged muscular inactivity with standing or activities of light intensity. Figure adapted from Zderic & Hamilton, 2005.

2.6 Interrupting sedentary behaviour and the effects on cardiometabolic health– the evidence and mechanisms involved

It has been postulated that interrupting prolonged periods of sedentary time (such as those that may occur in a sedentary workplace setting) is a possible method of negating the unfavourable metabolic health outcomes associated with a sedentary lifestyle. There are documented cross-sectional associations between sedentary time and several metabolic outcomes, some of which include waist circumference (WC), body mass index (BMI), triglycerides (TG), cholesterol and BP (Healy *et al.*, 2008).

Further examination into the patterns of sedentary time has revealed that individuals with more frequent interruptions in their sedentary behaviour are often at lower risk of cardiometabolic complications compared to those with fewer interruptions (Healy *et al*., 2008; Bankowski *et al*., 2011). Nevertheless, it is difficult to determine causality from such cross-sectional studies.

A few recent intervention studies have found simple prompts to be effective in reducing prolonged sedentary time in certain populations (Evans *et al*., 2012; Lang *et al*., 2015). In one of such studies, individuals who were exposed to an oral prompt to reduce sitting time were found to stand more compared to the control group who received no prompt (Lang *et al*., 2015). Investigators of another study informed two groups of participants of the benefits of reducing sitting time at work through a brief education session. Prompting software was installed in one of the groups' workplace computers reminding them to stand up every 30 minutes while, the other group received no prompt. The prompting software was superior to education alone in reducing long uninterrupted sedentary periods at work, suggesting that people may need to be reminded frequently in order to effectively reduce prolonged periods of sedentary time (Evans *et al*., 2012).

Current research, that has aimed to explore the association of prolonged sedentary behaviour on health, has found that adults who regularly interrupted sedentary time

had a better cardiometabolic profile than those whose sedentary time was mainly uninterrupted (Healy *et al.*, 2008). Healy and colleagues objectively measured sedentary time for 7 consecutive days in 168 participants using accelerometers. Each interruption in sedentary time, defined as any activity resulting in ≥100 counts per minute (cpm) as recorded by the accelerometer, was considered a break. Healy *et al.* found that breaks in sedentary time were significantly associated with WC, BMI, triglycerides and 2-hour plasma glucose independent of total sedentary time and MVPA (Healy *et al.*, 2008). Similarly, when assessing the association between total sedentary time and WC – an obesity-related health risk (Janssen *et al.*,2004) – the 25% of people who took the most breaks had, on average, a 4.1cm smaller WC than the 25% of people who took the least breaks (Dunstan *et al.*, 2011). Additional findings from several cross-sectional studies have demonstrated positive associations between breaks in sedentary time and a range of cardiometabolic risk variables including BMI (Saunders *et al.*, 2013), High density lipoprotein (HDL), BP, WC, glucose and, insulin (Carson *et al.*, 2014; Bankoski *et al.*, 2011) with several of these studies accounting for MVPA as a possible confounder in their analyses (Saunders *et al.*, 2013; Carson *et al.*,2014; Healy *et al.*, 2011_b).

There is also evidence from intervention studies which suggests that interrupting long periods of sedentary time and substituting it with light intensity physical activity and/or standing may have a beneficial effect on metabolic outcomes in physically inactive individuals (Dunstan *et al.*, 2012_b; Peddie *et al.*,2013; Thorp *et al.*, 2013).

However, intervention studies have reported conflicting findings, with some reporting little or no changes in metabolic health variables when interrupting prolonged sedentary time (Altenburg *et al.*, 2013; Holmstrup *et al.*, 2014) (Table 2). Additionally, many of the randomised crossover trials reported in Table 2 below, have looked at the effects of interrupting prolonged sedentary time in overweight/obese populations or individuals at high risk of developing metabolic disorders, yet few of these studies have interrupted prolonged sitting time in a sample of healthy, yet sedentary individuals.

It is still unclear what mode, duration, intensity or frequency of physical activity is required during these breaks in sedentary time in order to see improvements in metabolic disease risk (Benatti & Ried-Larsen, 2015). In a recent study, ten healthy participants took part in a randomised cross-over design study in which each participant was required to complete three 5-hour trial conditions on three different occasions: 1) uninterrupted sitting; 2) sitting interrupted by standing, and 3) sitting interrupted by light intensity walking (Bailey & Locke, 2015). Each participant was instructed to drink solutions containing a mixture of carbohydrates, fat and protein (designed to best simulate a mixed meal) before commencing the trials in order to determine the post-prandial effect of each trial on glucose metabolism. The light intensity activity involved walking on a treadmill for two minutes, every 20 minutes. The study revealed that short, frequent bouts of light-intensity physical activity (walking) had favorable postprandial responses which may enhance cardiometabolic health. Importantly, this was not the case in the trial that interrupted sitting time with

standing alone (Bailey & Locke, 2015). Since standing is not considered a sedentary activity, the results of the abovementioned study have implications on the importance of the intensity of the breaks when interrupting sedentary time. Further research is needed in order to investigate what intensity is sufficient to elicit cardiometabolic health benefits.

Table 2. Summary of intervention studies: breaks in sedentary time and health outcomes.

Author	**Sample**	**Description of intervention**	**Health/Variable Outcome**	**Sedentary measure**	**Covariates and confounders**	**Outcome**
Pronk, 2012	34 participants	7 week period: Week 1-2: monitoring Week 2-6: Intervention Week 6-7: follow-up	Change scores in sitting time, health risk factors, mood states (self-report)	Self-report	Not reported	Positive (reduced pain, improved mood states). Outcomes negated two-weeks after completing the intervention
Dunstan *et* al.,2012[b]	19 Overweight/obese men and women (age: 46-65y)	Three 5-h trials: -Uninterrupted sitting -Sitting and LPA breaks -Sitting and moderate intensity PA breaks	Glucose, Insulin	ActiGraph accelerometer	Age, sex, weight	Positive (light-and-brisk walking breaks reduced postprandial insulin and glucose response)
Peddie *et al*., 2013	70 New Zealand men and women (age:18-40y)	Three 9-h trials: -Prolonged sitting -Sitting interrupted with single bout of PA -Regular activity breaks	Glucose, Insulin, TG	Self-report	Age, sex, BMI	Positive (frequent breaks reduced postprandial insulin and glucose response) No effect on TG.
Altenburg *et al*., 2013	11 adults (5 men, 6 women; age:18-24y)	Two 8-h trials: -Uninterrupted sitting -Sitting interrupted with cycling	Postprandial C-peptide, glucose, TG, cholesterol	Self-report	Did not adjust for demographic variables	No differences in glucose, TG, cholesterol

Holmstrup *et al*., 2014	11 obese participants (age:18-35y)	Three 12-h trials: - Sedentary - Continuous exercise - Intermittent exercise	Glucose, insulin, c-peptide	Self-report	Not reported	No difference between breaks and glucose response. Positive change between breaks and insulin response and lowering c-peptides.
Bond *et al*., 2014	30 Overweight/obese men and women (age:21-70y)	Three trials: -3-min break after 30 min sitting -6-min break after 60 min sitting -12-min break after 120 min sitting	Sedentary time, LPA, MVPA	SenseWear Mini Armband accelerometer	Did not adjust for demographic variables	Positive (frequent, short activity breaks reduced total sedentary time)
Thorp *et al*., 2014	23 overweight/obese office workers (17 males, 6 females; age: 35-65y)	Two 5-day trials - Prolonged sitting -Sitting interrupted with standing	Insulin, glucose, TG, HDL, LDL	ActiGraph and activPAL accelerometer	Age, sex, time	Positive change in breaks and glucose concentration. No change in insulin and TG.
Bailey & Locke, 2015	10 non-obese adults (7 males, 3 females; mean age: 24.0±3.0y)	Three 5-h trials: -Uninterrupted sitting -Sitting and standing breaks -Sitting and LPA	Glucose, BP, cholesterol, HDL, TG	Self-report (Borg rate of perceived exertion)	Not reported	No difference between breaks and lipidemia/BP. Positive change in breaks with light walking, but not standing.

Abbreviations: MVPA; moderate-to-vigorous physical activity, PA; physical activity, LPA; light physical activity, HDL; high density lipoprotein, LDL; low density lipoprotein, TG; triglycerides, BP; blood pressure, BMI; body mass index.

Overall, the studies described in Table 2 above have conflicting results on health outcomes when prolonged sitting/sedentary time is interrupted. The studies mentioned above include intervention protocols that were relatively short in duration (Dunstan *et* al.,2012; Peddie *et al*., 2013; Altenburg *et al*., 2013; Holmstrup *et al*., 2014; Bond *et al*., 2014; Bailey & Locke, 2015) as well as those over a longer period of time (Pronk, 2012; Thorp *et al*., 2014). These variations in the intervention protocols allow insight into the acute and chronic effects of interrupting sedentary time, yet the outcomes of the abovementioned studies seem inconsistent. Five of the reported studies show a positive outcome between interruptions in sedentary behaviour and their primary investigated health variables (Pronk, 2012; Dunstan *et al*., 2012_b; Peddie *et al*., 2013; Bond *et al*., 2014; Thorp *et al*., 2014). Three of the five studies mentioned above included overweight/obese participants which may explain the positive outcomes reported. Three of the reported studies show little or no change (Altenburg *et al*., 2013; Holmstrup *et al*., 2014; Bailey & Locke, 2015) which may be due to the small sample sizes included in the interventions. Additional intervention studies are needed to further investigate the effect of interrupting prolonged sedentary time on overall health outcomes in healthy, but sedentary individuals. Moreover, studies are needed to evaluate a practical and effective method in which to interrupt sedentary behaviour.

2.6.1 Summary

In summary, there has been an evident rise in individuals employed in predominantly sedentary occupations (Church *et al*., 2011). Prolonged sedentary time has been shown to be associated with disorders related to cardiometabolic disease independent of MVPA (Healy *et al*., 2011$_b$; Dunstan *et al*., 2007). Individuals who meet the recommended MVPA guidelines, but lead predominantly sedentary lifestyles, may have a higher risk of developing cardiometabolic disorders compared to those who are more active throughout the day (Dunstan *et al*., 2010). However, there is now evidence to suggest that interrupting prolonged sedentary time, and substituting sedentary time for time spent in light intensity physical activity, may elicit cardiometabolic health benefits (Buman *et* al, 2010; Dunstan *et al*., 2012$_a$; Peddie *et al*.,2013; Thorp *et al*., 2013). However, intervention studies that have aimed to interrupt prolonged sedentary time have reported conflicting results (Bailey & Locke, 2015) and do not conclusively agree on the best method to interrupt sedentary behaviour. In addition, few studies have aimed to determine the effect of interrupting prolonged sedentary behaviour in a sample of healthy participants with sedentary occupations. Many of the intervention protocols that involve a shorter trial duration when interrupting sedentary behaviour have shown conflicting results. Therefore, in order to determine whether interrupting sedentary behaviour leads to health benefits that accumulate over time, a longer intervention duration may be necessary. Furthermore, short but frequent interruptions in sedentary time (e.g. 20 minute intervals) may be feasible in workplace environments where employees often remain seated for long periods of time (Jans *et al*., 2007). Due to the ubiquitous increase in

the number of people employed in sedentary occupations, it is imperative that interventions are put into place in order to reduce the deleterious effects associated with a predominantly sedentary lifestyle. Ultimately, intervention protocols may need to be established which provide alternative means of activity prescription that are separate from the current activity guidelines set by the ACSM, in order for cardiometabolic health to be improved through modification of sedentary behaviour.

CHAPTER 3 – METHODS AND MATERIALS

3.1 Study design

The study was conducted, following the CONSORT guidelines for randomised control trials (Schulz *et al*., 2010), at the School of Physiology Exercise Laboratory (6^{th} floor), University of the Witwatersrand Medical School, Johannesburg. All participants completed a series of physiological assessments which included providing a blood sample for assessing metabolic health, anthropometric measurements, and measurements of BP and cardiorespiratory fitness (VO_{2max}) on their first visit to the laboratory. Physical activity and sedentary behaviour was assessed at baseline using subjective measures (physical activity (Appendix A) and sedentary behaviour (Appendix B) questionnaires) and during the intervention using objective (accelerometry) methods. Participants were randomised into either an intervention (PROMPT) or a control (CON) group. All participants in the PROMPT group received text messages via a mobile phone over a 10-week period instructing them to interrupt their sitting time during their working time on weekdays only. Participants in the CON group received no prompts and were asked to maintain their current habitual home, and workplace, routines. After the 10-week duration, all participants were invited to return to the School of Physiology Exercise Laboratory for post-intervention assessments and underwent the same physiological examinations that were performed at baseline (Figure 5).

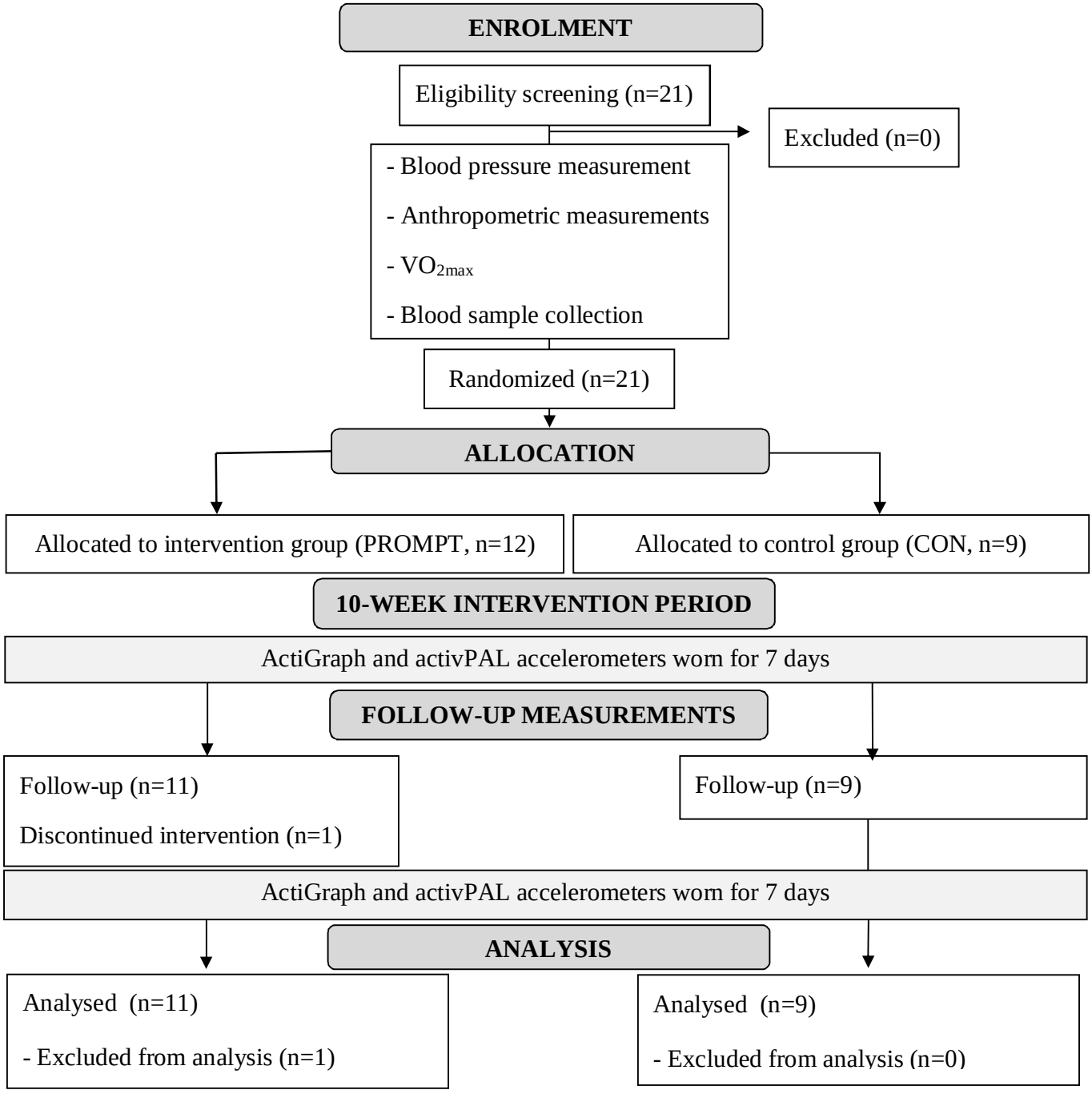

Figure 5. Flow diagram of participant recruitment, study group allocation, and drop-out over the 10-week intervention period

3.2 Participants

Participants were men and women with predominantly desk-based/sedentary occupations recruited from the University of the Witwatersrand as well as from the surrounding Johannesburg CBD by distributing flyers advertising the study and through direct email communication by the primary investigator. Participants were required to visit the Exercise Laboratory before 10h00 and were asked to fast for 12 hours before the assessment as well as to avoid strenuous activity for 24 hours prior to assessment. Participants in both the intervention and control groups were included in the study if they were between 18 to 45 years of age and were considered to be generally healthy as assessed using the general health questionnaire (Appendix C). All participants were also required to have access to a mobile phone capable of receiving text messages. Only participants who reported having sedentary occupations (more than 50% of their working day spent sedentary) were included for analysis in the study. Pregnant women or women who had entered menopause, diabetics, participants classified as obese (BMI >30 kg/m2), with a history of cardiovascular/metabolic disease or those who had had surgery within a year prior to assessment were excluded from the study. Participants on any medications used to treat cardiovascular/metabolic conditions or interfere with the cardiometabolic system were also excluded from the study. Participants were from an office-based workplace, or who had a similar office-based routine, which involved periods of prolonged sitting – and were used as a surrogate for a sedentary population. Overall health, medication use, any history of illness and/or hospital admissions as well as socio-

economic status (assessed by answering questions pertaining to their total income - items that they owned - and level of education) was determined using the general health questionnaire. Twenty-one (n=21) men and women between 18 and 45 years of age volunteered to participate in this study, however one participant was unable to continue the intervention and discontinued due to personal reasons. Participants were randomly assigned into two groups: a control group (CON; n=9), and an intervention group (PROMPT; n=12) (Figure 5) using the Microsoft Office Excel CHOOSE and RANDBETWEEN functions. The CHOOSE and RANDBETWEEN functions (=CHOOSE(RANDBETWEEN(1,2), "A","B") are able to assign each new participant into one of two group, in this instance A=CON and B=PROMPT.

All participants were fully informed of the procedures involved and were required to sign a written informed consent form (Appendix D) before commencement of the study. Participants were free to withdraw from the study, without prejudice, at any point. The study was approved by the Human Research Ethics Committee of the University of the Witwatersrand (protocol no.: M130229 – Appendix E) in accordance with the declaration of Helsinki.

3.3 Procedures and measurements

3.3.1 General health screening, physical activity and sedentary behaviour questionnaire

All participants were required to complete a general health questionnaire before involvement in the study in order to determine overall health status including any recent illness or medication taken in the last six months – this was done to determine eligibility for the study. Participants were also asked to report on their involvement in habitual physical activity during a normal week by completing a validated physical activity questionnaire (PAQ) (Hagströmer *et al.*, 2006). This questionnaire gathers physical activity information from the workplace; travel to-and-from destinations, and recreational activities. Reported activities of light intensity were assigned a score of 3.3 METs, moderate intensity of 4.0 METs and, vigorous intensity of 8.0 METs (IPAQ Research Committee, 2005). The amount of time (in minutes) spent in activities of light, moderate and vigorous intensity was summed for the week, and energy expenditure was reported as MET-hours per week (MET-hrs/week) using the following equation:

MET-hrs/week = ((minutes of light activity)(3.3) + (Minutes of moderate activity)*(4.0) + (minutes of vigorous activity)*(8.0)) / 60*

A validated sedentary behaviour questionnaire was used to assess each participant's weekly sedentary time/behaviour (Rosenberg *et al.*, 2010). The sedentary questionnaire required participants to report on the time spent in several lifestyle-

related sedentary activities (for example: time spent watching television; time spent reading, and/or time spent in work related activities). The total time in sedentary activities was summed and reported as hours of sedentary time per week (hrs/week). All questionnaires were required to be completed upon the first visit to the laboratory.

3.4 Pre-and post-intervention measurements

3.4.1 Anthropometry and blood pressure

Height (to the nearest mm) and weight (to the nearest 100g) was measured using a stadiometer (Holtain, Crosswell, UK) and electronic scale (Dismed, USA) respectively. Participants were measured without shoes and while wearing light clothing. Biceps, Triceps, supra-iliac and sub-scapularis skinfolds (to the nearest 2mm) using Holtain skinfold calipers (Holtain Ltd, Crymmych UK), were used to determine body fat percentage of each participant using the following formulae (Durnin & Womersley., 1974) (Siri WE, 1961):

Percentage body fat (%) = (495 / Predicted Body Density) – 450

where,

Predicted body density (g/ml) (males) = 1.1631 – (0.0631 LOG (Sum of the four skinfolds (mm))

Predicted body density (g/ml) (females) = 1.1599 – (0.0717 LOG (Sum of the four skinfolds (mm))

Brachial BP was measured in all participants by a qualified nurse using a sphygmomanometer and stethoscope (left and right arm). Each participant was instructed to rest for 5 minutes before BP was measured. The average of three measurements was used.

3.4.2 Blood biochemistry

Fifteen millilitres of blood was drawn by a qualified nurse from participants after an overnight fast before commencing the cardiorespiratory fitness assessment. Ten millilitres of blood was collected and analysed by a reputable external laboratory (NHLS, Clinical Laboratory Services) for serum insulin (fasting), glucose (fasting), total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, triglycerides and C-reactive protein (CRP). The remaining 5 millilitres of blood was centrifuged immediately, aliquoted and stored at -8˚C and later analysed for serum lipoprotein lipase (LPL). Serum LPL concentration was detected using a solid phase sandwich ELISA which uses two types of highly specific antibodies (i.e. capture and detection antibodies) (Cell Biolabs, Inc. San Diego). The assay procedure involves immobilising 100µL of the sample of unknown antigen concentration (i.e. LPL), run in duplicate, using an antibody which is specific to the sample antigen (capture antibody), in a microwell plate. An enzyme-linked (detection) antibody is added, establishing a complex with the antigen. After several

"wash" phases, to remove unbound proteins or antibodies, a substrate is added that binds to the antibody-antigen complex which can be visibly detected and measured to determine the quantity of the antigen in the sample (LPL concentration). Insulin sensitivity was estimated using the homeostasis model assessment of insulin resistance (HOMA-IR) (Matthews *et al.*, 1985) which uses the following formula:

HOMA-IR = ((fasting serum insulin (μU/ml))(fasting plasma glucose (mmol/l)) /22.5*

3.4.3 Cardiorespiratory fitness

Cardiorespiratory fitness was assessed at baseline, and follow-up, in all participants after assessing anthropometry, BP, and after blood sample collection. Cardiorespiratory fitness was measured using a progressive incremental exercise test to volitional fatigue, on a treadmill (Startrac, Vancouver, Canada) in order to determine maximum oxygen uptake (VO_{2max}). Maximum oxygen uptake was used to determine if there were any changes in physical fitness after the 10-week intervention. Oxygen consumption, carbon dioxide production, heart rate, ventilation and respiratory rate throughout the procedure were recorded using a computerized metabolic system with an integrated heart rate monitor and receiver (Quark ergo, COSMED, Rome, Italy). The metabolic cart was calibrated using gas (4% CO_2, 16% O_2, Bal. N_2) and in air using a three litre calibration syringe before each cardiorespiratory fitness test. Participants began the test with a one minute warm-up

at a 0% gradient and at a self-selected speed. After the warm up phase, speed was increased to 5.3 km/h which remained constant for the remainder of the test. The gradient was then increased by 2% every minute until the participant reached volitional fatigue or test-termination criteria was met (ACSM, 2013).

3.4.4 Accelerometry

Habitual physical activity and sedentary behaviour levels were measured objectively in each participant using a triaxial ActiGraph accelerometer (wGT3X-BT, ActiGraph, LLC, Fort Walton Beach, FL). The ActiGraph accelerometer is able to objectively measure physical activity intensity by detecting both static and dynamic accelerations (John & Freedson, 2012). Accelerometers were provided to each participant during the first week of the intervention and again on completion of the intervention. Participants were instructed to wear the ActiGraph around their waist (using a Velcro elasticated belt) and on their dominant-side leg for seven consecutive days of assessment. Participants were instructed to only remove the ActiGraph during showering, bathing or swimming activity and before sleeping. The time and duration that the ActiGraph was removed during activities such as swimming was noted daily in a log (Appendix F). Participants were also instructed to record the time that the ActiGraph was removed before sleep, and the time the device was worn the following morning. The sleep data and log books were used for removing sleep information

from the activity data (sleep and non-wear). On completion of the seven day wear period, the ActiGraphs were collected and the data downloaded.

The wGT3X-BT, programmed to record raw data at a frequency of 30Hz, was downloaded using ActiLife software (v6.11.9) (ActiGraph LLC). Data from the vertical acceleration axis were processed and summarised over 60 second epochs. The activity data were analysed using previously validated criteria (Choi *et al*., 2011; Sasaki *et al*., 2011) and processed using a custom built SAS program (McVeigh *et al*., 2016) (v9.3, SAS Institute, Cary, NC, USA). A 90 minute time window for consecutive zero/non-zero counts with tolerance for artefactual movement was allowed in order for the determination and removal of non-wear periods during the day (Choi *et al*., 2011). Any non-wear time and full days of non-wear time were removed. The remaining data were referred to as the 'wear period' which contained the valid data. Data requirements for a valid day included a minimum of 10 hours (600 minutes) of consecutive total activity and activity counts recorded per day (Choi *et al*., 2011). Data were included for analysis if there were four or more valid days. The 'wear period' was split into two categories, "all-day" and "working day". The all-day period included all valid data that were recorded during the wear period (excluding sleep). The working day included all valid activity data between the hours of 09h00 and 17h00 only. Each 60 second epoch of data from all-day and working days were classified as sedentary if less than 100 cpm (Matthews *et al*., 2008), light intensity activity if between 100-2690 cpm and, moderate to vigorous intensity

activity if between 2691-6166 cpm (Freedson *et al*., 2011). The definition of a break in sedentary time has also been previously defined and validated as each period of ≤100 cpm being interrupted by one minute or less of ≥100 cpm (Healy *et al*., 2008) (Cooper et al., 2012) (Matthews *et al*., 2008). Other variables of interest from the Actigraph accelerometer included the time spent in activities of different intensities (light physical activity and MVPA), the number of breaks from sedentary time, the number of prolonged bouts of sedentary time, and periods of prolonged sedentary time greater than, or equal to, 20 minute and 30 minute bouts.

A second accelerometer, the activPAL (PAL Technologies Ltd, Glasgow, Scotland) was used to measure the sedentary behaviours of participants. The activPAL monitor is a small, lightweight device which requires no calibration, and records step number and instantaneous cadence for each period of walking (Ryan *et al*., 2006). Furthermore, the activPAL records postural changes as well as walking in real time (Ryan *et al*., 2006). Participants were instructed to wear the monitors, mid-thigh, on their dominant-side leg for seven consecutive days of assessment. The device is placed within a waterproof sleeve and secured to the leg using a water-resistant dressing. Participants were not required to remove the device during swimming or bathing activities or before sleeping. On completion of the seven day wear period, the activPALs were collected and the data downloaded. A minimum of four days of 10 hours each wear was required for data to be analysed. Again, wear time was subdivided into two categories, “all-day” and “working day”. The all-day period

included all activity data, as well as sleep time (Lyons *et al.*, 2017) as at the time of data analysis there was no automated algorithm for the removal of sleep from the activPAL and sleep times as recorded in the log book were inconsistent. Therefore a working day period was also used in the analysis of the activPAL data (09h00 to 17h00). Variables of interest from the activPAL accelerometer included total sedentary time during the all-day period and the working day.

3.5 Intervention

Identically worded text messages delivered via a mobile phone were sent to participants in the intervention group throughout the 10-week period. The message body was phrased as follows: “Hi there, a reminder to please take a short walk of roughly 45-60 seconds (to fetch water; to the nearest window/elevator or colleague). Thank you”. These messages instructed the participants to stand and take a short walk of approximately 45–60 seconds. The messages were sent every twenty minutes between the hours of 09h00 and 17h00, Monday to Friday. In order to assess compliance, the participants in the intervention group were required to complete a daily log book (Appendix G) and record information such as the number of text messages received and the mode/number of interruptions to sedentary time. During the 10 week intervention, the control group continued with their daily workplace routines as before participating in the study.

3.6 Statistical analysis

Data were analysed using IBM SPSS Statistics Version 24 (IBM Corporation, NY) and expressed as means and standard deviation (SD). The Shapiro-Wilk test was used to determine if data were normally distributed, and relevant parametric or non-parametric statistical tests were used. Significance was set at $p \leq 0.05$. An unpaired t-test was used to determine differences in anthropometric characteristics of participants at baseline. A Mann-Whitney U-test was used to determine differences in the energy expenditure and sedentary time reported from the physical activity and sedentary behaviour questionnaires. A repeated measures ANOVA (group and time as factors) with Tukey's post-hoc test was used to determine whether objectively measured activity was different between the groups during as well as after the intervention. Statistical analyses of the objectively measured activity were performed for both the "all-day" and "working day" (09h00 – 17h00) period. A repeated measures ANOVA (group and time as factors) was then also performed to determine whether the intervention had a significant effect on cardiovascular measures, LPL, BMI and/or markers of metabolic health of the PROMPT and CON groups, before and after the intervention. If a significant interaction was observed, a Tukey's post-hoc test was again used to determine differences in anthropometry, cardiorespiratory fitness, BP, and blood markers of cardiometabolic health between participants in the CON and PROMPT groups. A Pearson correlation was performed to determine the association between sedentary behaviour and physical activity on the markers of cardiometabolic health.

CHAPTER 4 – RESULTS

Twenty-one (9 male, 12 female) healthy, but sedentary participants agreed to take part in the study. One participant withdrew, due to personal reasons, prior to post intervention measurements (Figure 2). Therefore, data from twenty participants were available for analysis. ActiGraph accelerometer data from 18 participants were included in the all-day group analysis, while data from 19 participants were included in the working-day analysis. This was due to participants not meeting valid day inclusion requirements. Similarly, activPAL data from 14 participants were available for analysis, as the remainder did not meet the valid day inclusion requirements. There were two missing data sets for BP due to unavailability of equipment at the time the participant was available for their visit to the laboratory. therefore data from 18 participants were included in the analysis. A sufficient amount of blood could not be be obtained from one participant and therefore data from 19 participants were included in the analysis of cardiometabolic health markers. However, there was sufficient blood from all 20 participants for the analysis of serum LPL.

4.1 Descriptive characteristics

There were no significant differences in baseline and follow-up measurements for weight, BMI, percentage body fat, VO_{2max} between CON and PROMPT groups. There were also no significant differences in subjective measures of physical activity and sedentary behavior at baseline between CON and PROMPT groups (Table 3).

Table 3. Descriptive characteristics, blood pressure, VO_2 max, sedentary time and physical activity of participants at baseline and post-intervention.

	CONTROL (n=9) (4 male; 5 female)		PROMPT (n=11) (4 male; 7 female)		
	Baseline	Post-Intervention	Baseline	Post-Intervention	Interaction p-value
Age (years)	27.1 (5.9)	27.3 (5.7)	27.9 (5.4)	28.1 (5.3)	0.88
Height (m)	1.7 (0.1)	1.7 (0.1)	1.7 (0.1)	1.7 (0.1)	0.53
Weight (kg)	70.0 (10.1)	70.1 (11.1)	69.3 (9.7)	70.1 (12.2)	0.65
BMI (kg/m^2)	24.0 (3.4)	24.0 (3.3)	23.6 (2.1)	23.8 (2.7)	0.75
Percentage body fat (%)	22.6 (8.2)	22.4 (9.2)	26.0 (7.7)	25.7 (7.7)	0.96
VO_{2max} ($mLO_2.kg^{-1}.min^{-1}$)	38.2 (5.5)	38.0 (7.2)	35.1 (3.1)	34.6 (7.6)	0.91
Sedentary time (hrs/weekday)	44.3 (6.8)		46.6 (11.3)		0.66
Physical activity (MET-hrs/week)	19.9 (20.0)		16.8 (16.1)		0.88

All values are mean (SD). BMI, Body mass index; VO_{2max}, Maximum oxygen consumption.

4.2 Sedentary behaviour and physical activity

4.2.1 Actigraph

There were no significant differences in the bouts (≥ 20 minute or ≥ 30 minute) of prolonged sedentary time between CON and PROMPT for both the all-day and the working day period, during and after the intervention as measured using the ActiGraph.

There were no significant differences between CON and PROMPT in the time spent in sedentary, light or moderate-to-vigorous activity for both the all-day and the working day period, during and after the intervention as measured using the ActiGraph. In addition, there were no differences in the way that the groups spent their time in sedentary behaviour for either wear period during or after the intervention (Table 4).

Table 4. ActiGraph data describing participant activity during and after the intervention period.

	CONTROL		PROMPT		
	During	Post-Intervention	During	Post-Intervention	Interaction p-value
All-day (excluding sleep) (n=18: 7 male,11 female)					
Total wear time (hrs/day)	14.0 (0.9)	14.1 (0.8)	13.9 (0.9)	13.6 (1.3)	0.56
Time spent sedentary (hrs/day)	9.5 (0.9)	9.7 (1.1)	9.3 (0.8)	9.4 (1.3)	0.86
Time spent in light activity (hrs/day)	4.1 (0.8)	4.5 (1.6)	4.1 (0.8)	3.8 (0.9)	0.30
Time spent in moderate and vigorous activity (hrs/day)	0.3 (0.2)	0.5 (0.4)	0.5 (0.4)	0.4 (0.2)	0.14
Number of breaks from sedentary time per day (breaks/day)	81.0 (14.0)	85.0 (16.0)	89.0 (11.0)	80.0 (15.0)	0.13
Number of prolonged sedentary bouts ≥20 mins (breaks/day)	7.0 (2.0)	7.0 (2.0)	6.0 (2.0)	7.0 (2.0)	0.23
Number of prolonged sedentary bouts ≥30 mins (breaks/day)	4.0 (1.0)	4.0 (1.0)	3.0 (1.0)	4.0 (1.0)	0.08
Prolonged sedentary time ≥20 min bouts (hrs/day)	4.5 (0.9)	4.3 (1.4)	3.4 (1.0)	4.0 (1.3)	0.15
Prolonged sedentary time ≥30 min bouts (hrs/day)	3.3 (0.7)	3.0 (1.2)	2.1 (0.8)	2.7 (1.0)	0.09
Working day (09h00 - 17h00) (n=19: 8 male, 11 female)					
Time spent sedentary (hrs/day)	6.4 (2.5)	6.4 (1.7)	5.9 (0.5)	6.3 (1.6)	0.73
Time spent in light activity (hrs/day)	2.5 (0.4)	2.6 (0.8)	2.4 (0.7)	2.3 (0.7)	0.39
Time spent in moderate and vigorous activity (hrs/day)	0.3 (0.2)	0.3 (0.3)	0.3 (0.2)	0.2 (0.1)	0.47
Number of breaks from sedentary time per day (breaks/day)	59.0 (24.0)	51.0 (11.0)	53.0 (10.0)	48.0 (9.0)	0.75
Number of prolonged sedentary bouts ≥20 mins (breaks/day)	6.0 (3.0)	5.0 (2.0)	4.0 (1.0)	5.0 (2.0)	0.17
Number of prolonged sedentary bouts ≥30 mins (breaks/day)	3.0 (2.0)	3.0 (1.0)	2.0 (1.0)	3.0 (2.0)	0.27
Prolonged sedentary time ≥20 min bouts (hrs/day)	3.8 (2.3)	3.3 (1.4)	2.1 (0.8)	3.1 (1.7)	0.22
Prolonged sedentary time ≥30 min bouts (hrs/day)	2.8 (1.8)	2.4 (1.2)	1.4 (0.8)	2.1 (1.6)	0.29

All data are mean (SD).

4.2.2 ActiGraph – working day

During the intervention period, participants in the PROMPT group spent 69.1±6.4% of their working day in sedentary activity which remained unchanged (70.8±10.1%) after completing the 10-week intervention (p=0.64). The same participants spent 27.9±6.0% of their working day in light intensity physical activity during the intervention which also remained unchanged (26.7±9.2%) after completing the intervention, when no further instructions to interrupt sedentary time were given (p=0.74). Participants in the CON group, who did not receive prompts, spent 68.7±6.9% of their working day in sedentary activity during the intervention, which remained unchanged (67.8±10.1%) after completing the 10-week intervention (p=0.64). During the intervention period, participants in the CON group spent 28.5±5.8% of their working day in light intensity physical activity and this remained unchanged (28.9±9.7) at the end of the 10-week intervention period (p=0.74).

4.2.3 activPAL – working day

In contrast to the Actigraph activity monitors, the data analysed from the activPAL accelerometers showed that there was a significant difference in the total time spent in sedentary activity in the working day, between the CON and PROMPT groups, during the intervention period. Participants in the CON group, who did not receive prompts to interrupt sitting time, spent more time in sedentary activity (6.7±0.6 hrs/day) compared to participants in the PROMPT group (5.5±0.5 hrs/day) who

received messages instructing them to interrupt sitting time during the 10-week intervention (p=0.04). After completing the 10-week intervention, participants in the PROMPT group increased their sedentary time (6.1±0.9 hrs/day) while participants in the control group reduced their sedentary time (6.2±1.0 hrs/day), however these differences were not significant compared to their total sedentary time during the intervention (p=0.661) (Figure 6).

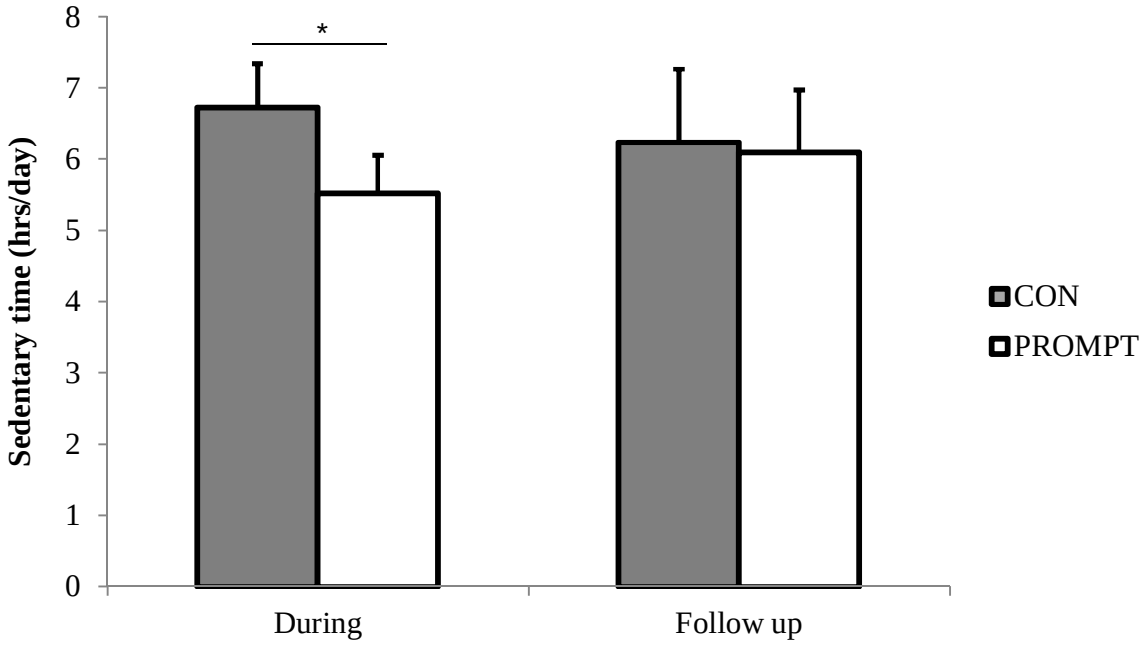

Figure 6. Total working day sedentary time (hrs/day) of participants who did not receive prompts via a mobile phone (CON; n=7) versus participants who received prompts via a mobile phone (PROMPT; n=7) during the 10-week intervention, and at post-intervention follow-up (p=0.04).

4.2.4 activPAL – all-day

When looking at the all-day data, during the intervention, the participants in the PROMPT group spent less time in sedentary activity (17.8±0.8 hrs/day) compared to those in the control group (19.7±0.9 hrs/day) who did not received prompts to interrupt sedentary time (p=0.006). After completing the 10-week intervention, participants in the PROMPT group increased their sedentary time (19.0±0.4 hrs/day) while participants in the control group decreased their sedentary time (19.0±0.4 hrs/day), however this change was not significant compared to the values during the intervention (p=0.581) (Figure 7).

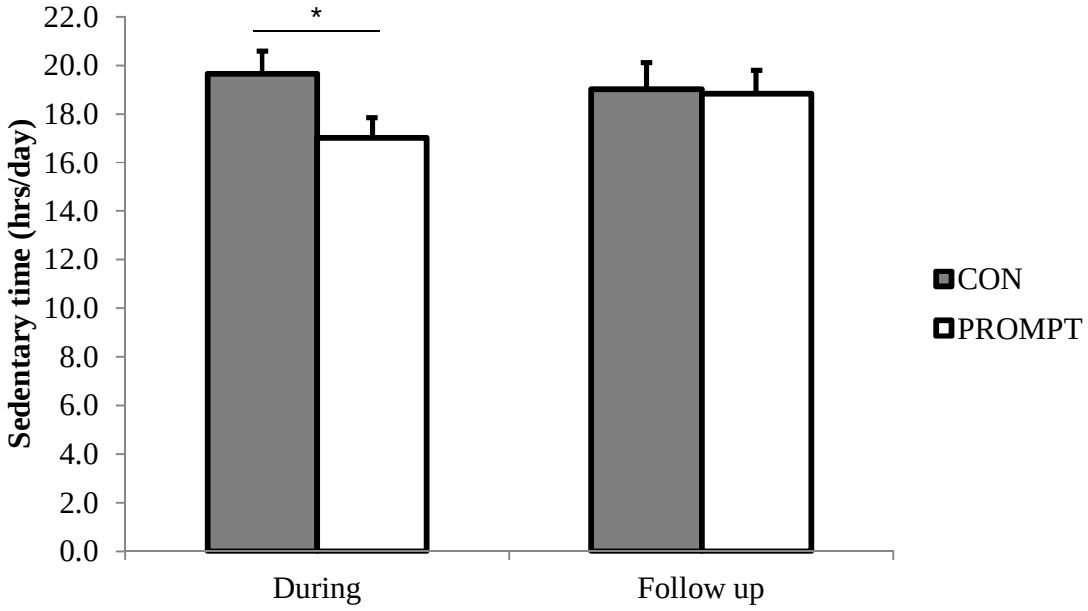

Figure 7. Total all-day (including sleep) sedentary time (hrs/day) of participants who did not receive prompts via a mobile phone (CON; n=7) versus participants who received prompts via a mobile phone (PROMPT; n=7) during and after the 10-week intervention. *p=0.006.

4.3 Cardiometabolic outcomes

4.3.1 Blood pressure

There was no significant change in systolic BP between baseline (CON; 109.0±8.1mmHg, PROMPT; 111.0±12.8mmHg) and post-intervention (CON; 106.1±9.3mmHg, PROMPT; 107.4±8.8mmHg) measurements across the groups (p=0.81). Furthermore, in the CON group (n=7), there was no significant change in

diastolic BP at baseline (71.1±7.8mmHg) compared to post-intervention (68.1±6.1mmHg) measurements (p=0.278). There was, however, a significant reduction in diastolic BP in the PROMPT group (n=11) between baseline (77.5±9.0mmHg) and post-intervention follow-up (71.8±5.6mmHg) (p=0.022) (Figure 8).

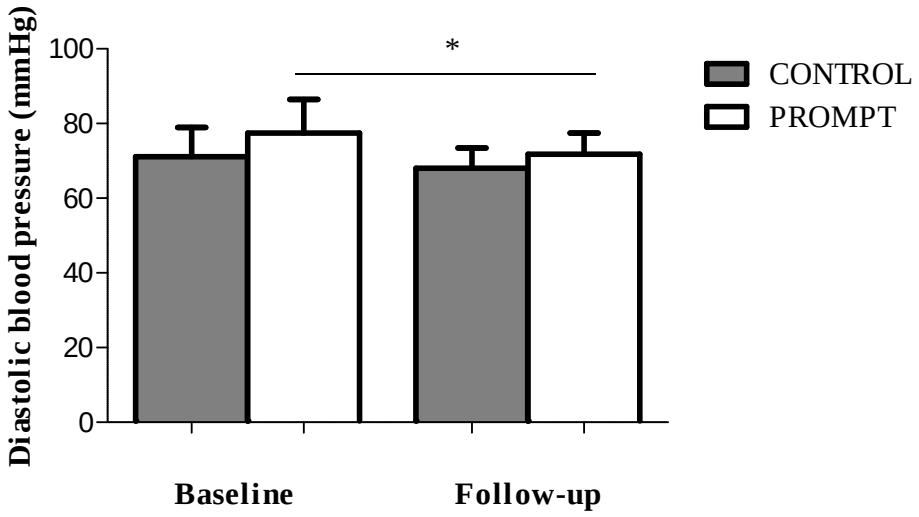

Figure 8. Diastolic blood pressure of CON and PROMPT participants at baseline and post-intervention follow-up (p=0.022).

4.3.2 Blood biomarkers of metabolic health

There were no significant changes in any of the biochemical markers of metabolic health between baseline and post-intervention follow-up for either of the groups. Biochemical markers of metabolic health included HDL, LDL, and total cholesterol, fasting serum insulin, glucose, triglycerides, and C-reactive proteins (Table 5).

Table 5. Participant blood biochemistry at baseline and post-intervention.

	CONTROL (n=9) (4 male, 5 female)		PROMPT (n=10) (4 male, 6 female)			
	Baseline	Post-Intervention	Baseline	Post-Intervention	Normal range	p-value
Insulin (mIU/mL)	5.3 (1.8)	6.1 (3.1)	6.9 (3.0)	7.0 (3.6)	2.1-10.4	0.67
HOMA-IR (units)	1.1 (0.4)	1.2 (0.5)	1.5 (0.7)	1.5 (0.9)	1.7-2.0	0.77
Glucose (mmol/L)	4.5 (0.3)	4.4 (0.4)	4.8 (0.4)	4.8 (0.4)	4.0-5.9	0.93
Total cholesterol (mmol/L)	4.5 (0.7)	4.6 (0.9)	5.0 (0.8)	4.8 (0.6)	4.5-5.2	0.35
HDL cholesterol (mmol/L)	1.5 (0.4)	1.5 (0.4)	1.6 (0.3)	1.4 (0.4)	1.0-1.5	0.37
LDL cholesterol (mmol/L)	2.6 (0.4)	2.6 (0.6)	3.0 (0.9)	2.8 (0.8)	2.5-3.0	0.28
Triglycerides (mmol/L)	1.0 (0.2)	1.0 (0.3)	1.0 (0.6)	1.3 (0.8)	<1.7	0.49
CRP (mg/L)	2.0 (2.1)	1.8 (1.9)	1.4 (0.8)	2.1 (1.2)	0-5.0	0.33

All values are mean (SD). HOMA-IR, homeostasis model assessment for insulin resistance; HDL cholesterol, high density lipoprotein cholesterol; LDL cholesterol, low density lipoprotein cholesterol; CRP, C-reactive proteins; LPL, lipoprotein lipase.

4.3.3 Associations of activity on markers of cardiometabolic health

There were no associations between total sedentary time, time spent in light intensity physical activity and MVPA with any of the abovementioned blood biomarkers of cardiometabolic health.

4.3.4 Lipoprotein lipase

There were no changes in serum LPL concentration between baseline (CON, 1.7±1.0 pg/ml; PROMPT, 1.3±0.8 pg/ml) and post-intervention follow-up measurements (CON, 1.3±0.6 pg/ml; PROMPT, 1.2±0.6 pg/ml) (p=0.27) (Figure 9).

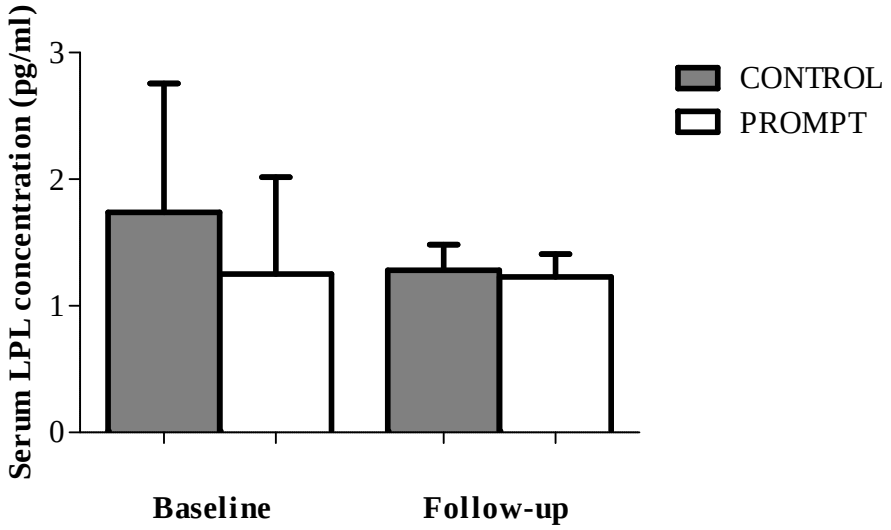

Figure 9. Baseline and post-intervention follow-up measurements of serum LPL concentration in CON and PROMPT groups (p=0.27).

CHAPTER 5 – DISCUSSION

The present study aimed to determine whether prompts delivered via a mobile phone were effective in reducing sedentary behaviour during the day in people with sedentary occupations, and whether these interruptions in sedentary time were associated with improved cardiometabolic health. To my knowledge, this is the first time that mobile phones have been used to interrupt prolonged bouts of sedentary time in a South African population. The data recorded by the ActiGraph and activPAL accelerometers in the present study reported differently on activity outcomes such as the total time spent in sedentary activities. The analysis of the data from the ActiGraph accelerometers showed no change in total sedentary time, time spent in light intensity activity, or time spent in MVPA between the groups during the intervention. However, analysis of the activPAL accelerometer data revealed a significant change in the total time spent in sedentary activity throughout both the all-day, and working day period, during the intervention between the control and intervention groups. Participants in the intervention group had significantly lower sedentary times compared to those in the control group as reported from data analysed from the activPAL accelerometers. The present study therefore demonstrated a possible feasible and practical method to improve patterns of activity behaviours as reported from the activPAL accelerometers, yet this outcome may be dependent on the choice of accelerometer. After the intervention, the differences in sedentary times between the groups were mitigated, suggesting that the effect of the intervention may not be sustained. The study found no differences in anthropometry or blood biomarkers of cardiometabolic health after 10-weeks of interrupting sedentary behaviour via mobile phone prompts, however participants who received

prompts had a significantly lower DBP in compared to their baseline measurements. In addition, there were no changes is serum LPL after interrupting sedentary behaviour.

5.1 Differences in sedentary time reported from the ActiGraph and activPAL accelerometers

The present study presented conflicting data as reported by the two accelerometers. A reduction in sedentary time was detected from analysis of the activPAL data while no change was detected from that of the ActiGraph accelerometer. ActiGraph accelerometers have been found to be a reliable measure of physical activity, however, their ability to measure sedentary behaviours is dependent on thresholds (or activity count cut-points) (Dowd *et al.,* 2012) and to date there is no consensus regarding data processing (Atkin *et al*., 2012). It has been suggested in one study that an ActiGraph cut-point of 150cpm (rather than the widely used cut-point of 100cpm used in the present study) was the most accurate cut-point to define sedentary behaviour (Kozey-Keadle *et al.,* 2011.), however this would not explain the lack of difference between groups during the intervention seen in the present study as both groups' data was analysed in the same manner. Moreover, previous studies have reported inaccuracies when assessing postural transitions using hip based accelerometry (Steeves *et al*., 2015). In a study which aimed to determine the validity of the ActiGraph and activPAL in assessing sedentary behaviours in a free-living environment, it was found that the activPAL was superior in accurately and precisely monitoring sedentary behaviour and reductions in sitting time compared to the

ActiGraph (Kozey-Keadle *et al.*, 2011). In the present study, the type of activity that the participant performed may have influenced whether it was detected as sedentary or light intensity activity. For example a participant in the intervention group may have merely stood up from sitting (to standing) and this would have been recorded as an interruption to sedentary time by the activPAL but if the interruption was not recorded by the ActiGraph as a break in sedentary time (because of the limitation of being worn on the hip) the participant may be considered as still being in sedentary behaviour. Conversely, a participant in the control group may have stood up from sitting and taken part in light activity (i.e. light walking around) and this may have been recorded by the ActiGraph as light activity. The discrepancies thereof may have led to the ActiGraph reporting no difference in sedentary time in this study. Moreover, the accelerometer placement (hip vs thigh) may have led to differences in activity output. However, current data reduction algorithms have been validated for a hip worn ActiGraph only and therefore presents a limitation to studies using ActiGraphs. In addition, participants are able to remove the ActiGraph accelerometers easily, and this may have repercussions on the accuracy of wear-time time analyses. In contrast, the activPAL accelerometer has been found to be an effective and valid measure of posture and postural transitions during everyday activities (Grant *et al*., 2006) and have been recommended for epidemiological studies whereby assessing sedentary behaviour in detail is a primary objective (Owen *et al.*, 2010; Bassett *et al*., 2010; Kozey-Keadle *et al.*, 2011). ActivPAL accelerometers are secured to the thigh and are not as easily removed and/or replaced compared to the ActiGraph accelerometers. Subsequently, the use of activPAL

accelerometers does not rely on subjective reports of wear/non-wear time as these devices remain secured to the thigh over a 24 hour period. The use of two accelerometers highlighted the complexities of assessing sedentary behaviour and the ability to detect changes in lifestyle activities using objective methods. However, direct comparisons between ActiGraph and activPAL accelerometers were not performed and were beyond the scope of the present study. Future studies should also be aware of activity monitor placement when assessing the effects of interrupting sedentary behaviour on cardiometabolic health.

5.2 Interrupting sedentary behaviour and cardiometabolic outcomes

There are no current guidelines available describing the ideal frequency and duration of interruptions in sedentary behaviour in adults (Bond *et al*., 2014), however sedentary behaviour guidelines are of recent interest in high-income countries and are being developed predominantly for desk-based employees (Buckley *et al*., 2015). In addition, 24 hour guidelines have been developed, and implemented, for children and youth in Canada (Tremblay *et al*., 2016). A recent study by Bond and colleagues aimed to reduce sedentary time in overweight and/or obese individuals using a custom-built smartphone application designed to interrupt prolonged sedentary time. The study prompted interruptions in prolonged sedentary behaviour and compared the effects of three different strategies – i.e. a 3-min break after 30 minutes of continuous sedentary minutes; a 6-min break after 60 minutes of continuous sedentary activity, and a 12-min break after 120 minutes of continuous sedentary activity. Bond *et al.* found that the shorter, more frequent physical activity breaks (i.e. 3-min every 30

minutes) were more effective in decreasing the time spent in sedentary behaviour, compared to interrupting sedentary behaviour less frequently with longer physical activity breaks (Bond *et al.*, 2014). Additionally, it seems that the deleterious effect of prolonged sedentary behaviour may also be more apparent among active individuals followed by periods of increased sedentary time (Lyden *et al.*, 2015). Recently, researchers found that 7 days of increased sitting in free-living, moderately active individuals (>150 min moderate physical activity per week) had a negative impact on the markers of cardiometabolic health, and it was concluded that the time in prolonged sitting bouts may be an important contributing factor (Lyden *et al.*, 2015). The present study instructed healthy, but sedentary participants to stand after 20 minutes of continuous sedentary time during the working day and to complete simple tasks, such as walking to a nearby colleague, for a duration lasting approximately 45-60 seconds (i.e. interruptions more frequent than those used by Bond and colleagues, but of shorter duration). Despite the reduction in sedentary activity detected using the activPAL accelerometers, the intervention did not elicit any corresponding changes in the blood biomarkers of metabolic health; however the markers of cardiometabolic health of the sample population in the present study fell within the normal range for a healthy population. This may suggest why, a study that assessed the effects of sedentary behaviour/activity modification on health in non-obese, healthy participants, found little or no difference in cardiometabolic health outcomes with postural changes (such as sitting to standing) alone (Bailey & Locke, 2015). In addition, a randomized control trial that investigated the effect of office workers' sitting time on cardiometabolic biomarkers (including blood pressure,

glucose and lipid metabolism, and a composite overall cardiometabolic risk score) found slight benefits of interrupting sedentary time on biomarkers of cardiometabolic risk, however only after 12 months of intervention – and not for all biomarkers (Healy *et al*., 2017). Nonetheless, the importance of promoting the interruption of prolonged sedentary behaviour in healthy populations (young adults) should be stated, as a review of current research has found sedentary time has been associated with cardiometabolic disease risk and mortality in older adults (de Rezende *et al*., 2014). It is also possible that the effects of a predominantly sedentary lifestyle on cardiometabolic disease risk may only be evident at a later stage of life. The present study did however find a significant reduction in diastolic blood pressure (DBP) in participants who were prompted to interrupt their sitting time compared to those in the control group. Clinically meaningful reductions of DBP have been previously defined as an absolute reduction of DBP of 3 mmHg or more (US Food and Drug Administration, 1988). Similar reductions in BP have been reported from experimental protocols when interrupting prolonged sitting in an overweight/obese population when sedentary time was replaced by either light or moderate intensity physical activity (Larsen *et al*., 2014). It is possible that changes in DBP in the present study may have occurred due to the vasodilatory effect of physical activity, whereas changes in systolic BP were not evident, as this is representative of the contraction pressure of the heart and is not likely to change in young participants. Larsen and colleagues concluded that the reduction in BP was likely a result of an interplay of several mechanisms, one of which being exercise-induced hypotension which involves changes in vascular resistance and cardiac output (Fagard, 1995) that

resulted from the displacement of sedentary time with light intensity activity. In the present study, there was a trend of increased time spent in light physical activity and MVPA in the intervention group, which may suggest that sedentary time was displaced by time spent in light or MVPA, however these changes were not significant. In addition, when interrupting prolonged sitting time, Bailey and Locke found no significant differences between continuous sitting versus interruptions with standing or walking for systolic or diastolic blood pressure area under the curve (AUC), however a medium effect size was seen for diastolic (Bailey and Locke, 2015). The authors concluded that more research was needed to further understand the effects of interrupting sedentary time on blood pressure. Our findings suggest that interrupting prolonged bouts of sedentary behaviour, via mobile phone messages, may have potentially beneficial clinical implications for healthy but sedentary individuals at risk of the deleterious effects of a predominantly sedentary workplace lifestyle.

5.2.1 Cardiometabolic health outcomes

Increased sedentary time has previously been shown to be associated with poor metabolic health outcomes which may contribute to the development of metabolic syndrome (Kim *et al.*, 2013; Bankoski *et al.*, 2011). One study investigating the effect of treadmill-workstations on the health of overweight/obese office-workers found that increased standing/stepping time resulted in a reduction of LDL cholesterol and total cholesterol, and had a favorable outcome on participants' overall metabolic profile during the study (Thompson *et al.*, 2011). It is possible that no associations between

activity behaviours and cardiometabolic health variables were found in the present study due to the lack of variation in the markers of cardiometabolic health, as these markers fell within the normal range for a healthy population as mentioned previously.

5.3 The mechanisms of prolonged sedentary time on health

The mechanisms involved in the adverse effects of prolonged sedentary time on metabolic health are unclear, however previous studies have reported associations between high volumes of sedentary time and the deleterious effect on cardiometabolic health (Tremblay *et al.,* 2010; Owen *et al.,* 2010). One of the proposed mechanisms is thought to involve muscle LPL. Lipoprotein lipase is an important enzyme involved in lipid metabolism. It has been demonstrated that muscle LPL is significantly reduced during sedentary activity (Bey & Hamilton, 2003). The association between LPL and sedentary activity in humans is not well documented. The present study however, found no changes in serum LPL from baseline levels after the 10-week intervention. It is probable that changes in LPL concentration can only be detected for a limited duration after a bout of exercise. A previous study noted elevated LPL concentrations for at least 24 hours after exercise (Kantor *et al.,* 1987) however it is possible that these changes can only be detected locally (skeletal muscle tissue) and may not be detectable in the serum particularly after a prolonged period of time. Future studies investigating the effects of long-term changes in skeletal LPL activity may benefit from the use of needle biopsy specimens of skeletal muscle tissue after

bouts of activity. Furthermore, it is possible that activities or exercises that recruit larger muscle groups may elicit detectable changes in serum LPL.

5.4 Limitations

The present study had some limitations that need to be highlighted. Because the first measurement of activity took place after the intervention had started, it is not possible to conclude that sedentary activity was reduced as a result of the intervention. A larger cohort would have been preferable in order to validate associations of sedentary behaviour and overall cardiometabolic health between the control and intervention groups, and would enable us to perform more powerful statistical analyses. The population sample included those who were sedentary, but healthy. Future studies could aim to determine the efficacy of a behavioural modification intervention on cardiometabolic health outcomes in overweight/obese workers with sedentary occupations. The blood biomarkers of metabolic health were analysed externally, and therefore the accuracy of these measurements cannot be confirmed/verified. Pre-intervention measurements of sedentary behaviour and physical activity should have been included to ensure that one of the groups was not naturally less active than the other (due to nature of their occupations). Participant compliance including accelerometer use, and adherence to the intervention, was maintained to the best of my ability through the use of log books and diaries however, because it could not be seen whether the participants interrupted their sitting time, it is difficult to assume that they remained compliant with the intervention. Sleep diaries were inconsistent and sleep times could not be accurately identified.

Participants may need to be contacted or reminded in order to obtain accurate sleep and wake times.

CHAPTER 6 – CONCLUSION

In conclusion, the present study demonstrated a practical intervention protocol that was able to reduce the amount of sitting/sedentary time (as shown using the activPAL) during the day in people with sedentary occupations. In addition, the findings from this study highlight the importance and limitations of activity monitoring equipment in sedentary behaviour epidemiological research. Interrupting prolonged sedentary time via mobile phone messages may be an effective strategy in reducing total sedentary time in the workplace, and may elicit clinically meaningful reductions in DBP in sedentary individuals. Mobile phones are available to most of the South African population which allows for a novel opportunity to utilize these devices for sedentary behaviour modification. The intervention did not yield any changes in anthropometry or blood biomarkers of cardiometabolic health in a sample of healthy participants with sedentary occupations. Nonetheless, it is important for effective interventions to be implemented in order to reduce workplace sitting time. Future research should focus on effective methods to reduce prolonged sedentary behaviour, whereby sedentary workers are able to displace prolonged sitting time with physical activity during workplace hours.

The hypotheses tested in this dissertation are summarised below.

Hypothesis	**Main finding**
Interrupting sedentary behaviour with the aid of messages delivered via a mobile phone is an effective method of reducing time spent sedentary.	Prompts delivered via a mobile phone were effective in reducing sedentary behaviour during the day, measured using the activPAL accelerometer, but not the ActiGraph, and highlights the importance and limitations of activity monitors in sedentary research.
Interrupting sedentary behaviour will have a positive effect on the blood biomarkers of metabolic health.	There were no changes in the markers of cardiometabolic health between baseline and post-intervention follow-up. All participants were healthy, and the markers of metabolic health were within the normal limits.
Participants who spent less time in sedentary behaviour would have better cardiometabolic health.	The present study found no association between sedentary time, and physical activity with cardiometabolic health variables. However, all markers of metabolic health were within normal limits. A larger sample size would be preferable to further evaluate the association between activity behaviours and cardiometabolic health.

CHAPTER 7 – REFERENCES

Altenburg, T.M., Rotteveel, J., Dunstan, D.W., Salmon, J. and Chinapaw, M.J., 2013. The effect of interrupting prolonged sitting time with short, hourly, moderate-intensity cycling bouts on cardiometabolic risk factors in healthy, young adults. *Journal of Applied Physiology*, *115*(12), pp.1751-1756.

American College of Sports Medicine ed., 2013. *ACSM's Health-related Physical Fitness Assessment Manual*. Lippincott Williams & Wilkins.

Astorino, T.A., 2009. Alterations in VO2max and the VO2 plateau with manipulation of sampling interval. *Clinical Physiology and Functional Imaging*, *29*(1), pp.60-67.

Atkin, A.J., Gorely, T., Clemes, S.A., Yates, T., Edwardson, C., Brage, S., Salmon, J., Marshall, S.J. and Biddle, S.J., 2012. Methods of measurement in epidemiology: sedentary behaviour. *International Journal of Epidemiology*, *41*(5), pp.1460-1471.

Arroll, B. and Beaglehole, R., 1992. Does physical activity lower blood pressure: a critical review of the clinical trials. *Journal of Clinical Epidemiology*, *45*(5), pp.439-447.

Bailey, D.P. and Locke, C.D., 2015. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. *Journal of Science and Medicine in Sport*, *18*(3), pp.294-298.

Balkau, B., Mhamdi, L., Oppert, J.M., Nolan, J., Golay, A., Porcellati, F., Laakso, M. and Ferrannini, E., 2008. Physical activity and insulin sensitivity. *Diabetes*, *57*(10), pp.2613-2618.

Bankoski, A., Harris, T.B., McClain, J.J., Brychta, R.J., Caserotti, P., Chen, K.Y., Berrigan, D., Troiano, R.P. and Koster, A., 2011. Sedentary activity associated with metabolic syndrome independent of physical activity. *Diabetes Care, 34*(2), pp.497-503.

Bassett Jr, D.R., Freedson, P. and Kozey, S., 2010. Medical hazards of prolonged sitting. *Exercise and sport sciences reviews, 38*(3), pp.101-102.

Beaglehole, R. and Yach, D., 2003. Globalisation and the prevention and control of non-communicable disease: the neglected chronic diseases of adults. *The Lancet*, *362*(9387), pp.903-908.

BeLue, R., Okoror, T.A., Iwelunmor, J., Taylor, K.D., Degboe, A.N., Agyemang, C. and Ogedegbe, G., 2009. An overview of cardiovascular risk factor burden in sub-Saharan African countries: a socio-cultural perspective. *Globalization and Health, 5*(1), pp.10-22.

Benatti, F.B. and Ried-Larsen, M., 2015. The effects of breaking up prolonged sitting time: a review of experimental studies. *Medicine in Science and Sports and Exercise*, *47*(10), pp.2053-2061.

Bey, L. and Hamilton, M.T., 2003. Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. *The Journal of Physiology*, *551*(2), pp.673-682.

Biddle, S.J., Gorely, T. and Stensel, D.J., 2004. Health-enhancing physical activity and sedentary behaviour in children and adolescents. *Journal of Sports Sciences*, *22*(8), pp.679-701.

Blair, S.N., Kohl, H.W., Paffenbarger, R.S., Clark, D.G., Cooper, K.H. and Gibbons, L.W., 1989. Physical fitness and all-cause mortality: a prospective study of healthy men and women. *Journal of the American Medical Association*, *262*(17), pp.2395-2401.

Bond, D.S., Thomas, J.G., Raynor, H.A., Moon, J., Sieling, J., Trautvetter, J., Leblond, T. and Wing, R.R., 2014. B-MOBILE-A smartphone-based intervention to reduce sedentary time in overweight/obese individuals: a within-subjects experimental trial. *PLoS One*, *9*(6), p.e100821.

Booth, M.L., Ainsworth, B.E., Pratt, M.I.C.H.A.E.L., Ekelund, U., Yngve, A.G.N.E.T.A., Sallis, J.F. and Oja, P.E.K.K.A., 2003. International physical activity questionnaire: 12-country reliability and validity. *Medicine in Science and Sports and Exercise*, *195*(9131/03), pp.3508-1381.

Boulé, N.G., Weisnagel, S.J., Lakka, T.A., Tremblay, A., Bergman, R.N., Rankinen, T., Leon, A.S., Skinner, J.S., Wilmore, J.H., Rao, D.C. and Bouchard, C., 2005. Effects of exercise training on glucose homeostasis. *Diabetes Care*, *28*(1), pp.108-114.

Bradshaw, D., Steyn, K., Levitt, N. and Nojilana, B., Non communicable diseases: a race against time; 2010. *Parow, South Africa: Medical Research Council.*

Brocklebank, L.A., Falconer, C.L., Page, A.S., Perry, R. and Cooper, A.R., 2015. Accelerometer-measured sedentary time and cardiometabolic biomarkers: a systematic review. *Preventive Medicine*, *76*, pp.92-102.

Brozek, J. and Henschel, A., 1961. Techniques for measuring body composition. *In Conference on Techniques for Measuring Body Composition (1959: Natick, Mass.)*. National Academy of Sciences-National Research Council.

Buckley, J.P., Hedge, A., Yates, T., Copeland, R.J., Loosemore, M., Hamer, M., Bradley, G. and Dunstan, D.W., 2015. The sedentary office: a growing case for change towards better health and productivity. Expert statement commissioned by Public Health England and the Active Working Community Interest Company. *British Journal of Sports Medicine*, pp.bjsports-2015.

Buman, M.P., Hekler, E.B., Haskell, W.L., Pruitt, L., Conway, T.L., Cain, K.L., Sallis, J.F., Saelens, B.E., Frank, L.D. and King, A.C., 2010. Objective light-intensity physical activity associations with rated health in older adults. *American Journal of Epidemiology*, *172*(10), pp.1155-1165.

Carson, V. and Janssen, I., 2011. Volume, patterns, and types of sedentary behavior and cardio-metabolic health in children and adolescents: a cross-sectional study. *BMC Public Health*, *11*(1), pp.274-283.

Carson, V., Ridgers, N.D., Howard, B.J., Winkler, E.A., Healy, G.N., Owen, N., Dunstan, D.W. and Salmon, J., 2013. Light-intensity physical activity and cardiometabolic biomarkers in US adolescents. *PloS One*, *8*(8), p.e71417.

Carson, V., Wong, S.L., Winkler, E., Healy, G.N., Colley, R.C. and Tremblay, M.S., 2014. Patterns of sedentary time and cardiometabolic risk among Canadian adults. *Preventive Medicine, 65*, pp.23-27.

Caspersen, C.J., Powell, K.E. and Christenson, G.M., 1985. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public health Reports*, *100*(2), pp.126-131.

Celis-Morales, C.A., Perez-Bravo, F., Ibanez, L., Salas, C., Bailey, M.E. and Gill, J.M., 2012. Objective vs. self-reported physical activity and sedentary time: effects of measurement method on relationships with risk biomarkers. *PloS One*, *7*(5), p.e36345.

Chen, K.Y. and Bassett, D.R., 2005. The technology of accelerometry-based activity monitors: current and future. *Medicine and Science in Sports and Exercise*, *37*(11), pp.S490-S500.

Choi, L., Liu, Z., Matthews, C.E. and Buchowski, M.S., 2011. Validation of accelerometer wear and nonwear time classification algorithm. *Medicine and Science in Sports and Exercise*, *43*(2), pp.357-364.

Church, T.S., Thomas, D.M., Tudor-Locke, C., Katzmarzyk, P.T., Earnest, C.P., Rodarte, R.Q., Martin, C.K., Blair, S.N. and Bouchard, C., 2011. Trends over 5 decades in US occupation-related physical activity and their associations with obesity. *PloS One*, *6*(5), p.e19657.

Cooper, A.R., Sebire, S., Montgomery, A.A., Peters, T.J., Sharp, D.J., Jackson, N., Fitzsimons, K., Dayan, C.M. and Andrews, R.C., 2012. Sedentary time, breaks in sedentary time and metabolic variables in people with newly diagnosed type 2 diabetes. *Diabetologia, 55*(3), pp.589-599.

Corder, K., Ekelund, U., Steele, R.M., Wareham, N.J. and Brage, S., 2008. Assessment of physical activity in youth. *Journal of Applied Physiology, 105*(3), pp.977-987.

Department of Health, Medical Research Council, OrcMacro. (2007). *South Africa Demographic and Health Survey 2003*. Pretoria: Department of Health. ISBN: 978-1-920014-47-6.

de Rezende, L.F.M., Rey-López, J.P., Matsudo, V.K.R. and do Carmo Luiz, O., 2014. Sedentary behavior and health outcomes among older adults: a systematic review. *BMC Public Health*, *14*(1), pp.333-342.

DeSouza, C.A., Shapiro, L.F., Clevenger, C.M., Dinenno, F.A., Monahan, K.D., Tanaka, H. and Seals, D.R., 2000. Regular aerobic exercise prevents and restores age-related declines in endothelium-dependent vasodilation in healthy men. *Circulation, 102*(12), pp.1351-1357.

Dowd, K.P., Harrington, D.M. and Donnelly, A.E., 2012. Criterion and concurrent validity of the activPAL™ professional physical activity monitor in adolescent females. *PloS One, 7*(10), p.e47633.

Dunstan, D.W., Zimmet, P.Z., Welborn, T.A., De Courten, M.P., Cameron, A.J., Sicree, R.A., Dwyer, T., Colagiuri, S., Jolley, D., Knuiman, M. and Atkins, R., 2002. The rising prevalence of diabetes and impaired glucose tolerance: the Australian Diabetes, Obesity and Lifestyle Study. *Diabetes care*, *25*(5), pp.829-834.

Dunstan, D.W., Salmon, J., Healy, G.N., Shaw, J.E., Jolley, D., Zimmet, P.Z. and Owen, N., 2007. Association of television viewing with fasting and 2-h postchallenge plasma glucose levels in adults without diagnosed diabetes. *Diabetes Care*, *30*(3), pp.516-522.

Dunstan, D., Healy, G.N., Sugiyama, T. and Owen, N., 2010. *Too Much Sitting and Metabolic Risk? Has Modern Technology Caught Up with Us*.

Dunstan, D.W., Howard, B., Healy, G.N. and Owen, N., 2012_a. Too much sitting–a health hazard. *Diabetes Research and Clinical Practice*, *97*(3), pp.368-376.

Dunstan, D.W., Kingwell, B.A., Larsen, R., Healy, G.N., Cerin, E., Hamilton, M.T., Shaw, J.E., Bertovic, D.A., Zimmet, P.Z., Salmon, J. and Owen, N., 2012_b. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. *Diabetes Care*, *35*(5), pp.976-983.

Durnin, J.V. and Womersley, J.V.G.A., 1974. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *British Journal of Nutrition*, *32*(01), pp.77-97.

Edwardson, C.L., Gorely, T., Davies, M.J., Gray, L.J., Khunti, K., Wilmot, E.G., Yates, T. and Biddle, S.J., 2012. Association of sedentary behaviour with metabolic syndrome: a meta-analysis. *PloS One*, *7*(4), p.e34916.

Ekblom, Ö., Ekblom-Bak, E., Rosengren, A., Hallsten, M., Bergström, G. and Börjesson, M., 2015. Cardiorespiratory fitness, sedentary behaviour and physical activity are independently associated with the metabolic syndrome, results from the SCAPIS pilot study. *PloS one*, *10*(6), p.e0131586.

Erikssen, G., 2001. Physical fitness and changes in mortality. *Sports Medicine*, *31*(8), pp.571-576.

Evans, R.E., Fawole, H.O., Sheriff, S.A., Dall, P.M., Grant, P.M. and Ryan, C.G., 2012. Point-of-choice prompts to reduce sitting time at work: a randomized trial. *American Journal of Preventive Medicine*, *43*(3), pp.293-297.

Fagard, Robert H. 1995. The role of exercise in blood pressure control: supportive evidence. *Journal of Hypertension*, 13(11), pp.1223-1227.

Ford, E.S. and Caspersen, C.J., 2012. Sedentary behaviour and cardiovascular disease: a review of prospective studies. *International Journal of Epidemiology*, p.dys078.

Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., Nieman, D.C. and Swain, D.P., 2011. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining

cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise, 43*(7), pp.1334-1359.

Grant, P.M., Ryan, C.G., Tigbe, W.W. and Granat, M.H., 2006. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. *British Journal of Sports Medicine, 40(*12), pp.992-997.

Hagströmer, M., Oja, P. and Sjöström, M., 2006. The International Physical Activity Questionnaire (IPAQ): a study of concurrent and construct validity. *Public Health Nutrition*, *9*(06), pp.755-762.

Hagstromer, M., Ainsworth, B.E., Oja, P. and Sjostrom, M., 2010. Comparison of a subjective and an objective measure of physical activity in a population sample. *Journal of Physical Activity and Health, 7*(4), pp.541-550.

Hamilton, M.T., Hamilton, D.G. and Zderic, T.W., 2007. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes*, *56*(11), pp.2655-2667.

Hart, P., Erickson, J. and Benavidez, G., 2016. Meeting Recommended Levels of Physical Activity in Relation to Preventive Health Behavior and Health Status among Adults. *Journal of Preventive Medicine and Public Health*, *50*(1), pp. 10–17

Healy, G.N., Dunstan, D.W., Salmon, J., Cerin, E., Shaw, J.E., Zimmet, P.Z. and Owen, N., 2007. Objectively measured light-intensity physical activity is

independently associated with 2-h plasma glucose. *Diabetes Care, 30*(6), pp.1384-1389.

Healy, G.N., Dunstan, D.W., Salmon, J., Cerin, E., Shaw, J.E., Zimmet, P.Z. and Owen, N., 2008. Breaks in sedentary time. *Diabetes Care, 31*(4), pp.661-666.

Healy, G.N., Wijndaele, K., Dunstan, D.W., Shaw, J.E., Salmon, J., Zimmet, P.Z. and Owen, N., 2008. Objectively measured sedentary time, physical activity, and metabolic risk. *Diabetes Care, 31*(2), pp.369-371.

Healy, G.N., Clark, B.K., Winkler, E.A., Gardiner, P.A., Brown, W.J. and Matthews, C.E., 2011_a. Measurement of adults' sedentary time in population-based studies. *American Journal of Preventive Medicine, 41*(2), pp.216-227.

Healy, G.N., Matthews, C.E., Dunstan, D.W., Winkler, E.A. and Owen, N., 2011_b. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003–06. *European Heart Journal, 32*(5), pp.590-597.

Healy, G.N., Winkler, E.A., Owen, N., Anuradha, S. and Dunstan, D.W., 2015. Replacing sitting time with standing or stepping: associations with cardio-metabolic risk biomarkers. *European Heart Journal, 36*(39), pp.2643-9

Healy, G.N., Winkler, E.A., Eakin, E.G., Owen, N., Lamontagne, A.D., Moodie, M. and Dunstan, D.W., 2017. A Cluster RCT to Reduce Workers' Sitting Time: Impact on Cardiometabolic Biomarkers. *Medicine and science in sports and exercise, 49*(10), pp.2032-2039.

Henson, J., Yates, T., Edwardson, C.L., Khunti, K., Talbot, D., Gray, L.J., Leigh, T.M., Carter, P. and Davies, M.J., 2013. Sedentary time and markers of chronic low-grade inflammation in a high risk population. *PLoS One*, *8*(10), p.e78350.

Holmstrup, M., Fairchild, T., Keslacy, S., Weinstock, R. and Kanaley, J., 2014. Multiple short bouts of exercise over 12-h period reduce glucose excursions more than an energy-matched single bout of exercise. *Metabolism*, *63*(4), pp.510-519.

IPAQ Research Committee, 2005. Guidelines for data processing and analysis of the International Physical Activity Questionnaire (IPAQ)-short and long forms. http://www.ipaq.ki.se/scoring.pdf. Retrieved September 17.

Jans, M.P., Proper, K.I. and Hildebrandt, V.H., 2007. Sedentary behavior in Dutch workers: differences between occupations and business sectors. *American journal of preventive medicine*, *33*(6), pp.450-454.

Janssen, I., Katzmarzyk, P.T. and Ross, R., 2004. Waist circumference and not body mass index explains obesity-related health risk. *The American Journal of Clinical Nutrition*, *79*(3), pp.379-384.

Jette, M., Sidney, K. and Blümchen, G., 1990. Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity. *Clinical Cardiology*, *13*(8), pp.555-565.

John, D., Thompson, D.L., Raynor, H., Bielak, K., Rider, B. and Bassett, D.R., 2011. Treadmill workstations: a worksite physical activity intervention in overweight and obese office workers. *Journal of Physical Activity and Health*, *8*(8), pp.1034-1043.

John, D. and Freedson, P., 2012. ActiGraph and Actical physical activity monitors: a peek under the hood. *Medicine and Science in Sports and Exercise*, *44*(1 Suppl 1), pp.S86-89.

Kantor, M.A., Cullinane, E.M., Sady, S.P., Herbert, P.N. and Thompson, P.D., 1987. Exercise acutely increases high density lipoprotein-cholesterol and lipoprotein lipase activity in trained and untrained men. *Metabolism*, *36*(2), pp.188-192.

Katzmarzyk, P.T., Church, T.S., Craig, C.L. and Bouchard, C., 2009. Sitting time and mortality from all causes, cardiovascular disease, and cancer. *Medicine and Science in Sports and Exercise*, *41*(5), pp.998-1005.

Kay, S.J. and Singh, F., 2006. The influence of physical activity on abdominal fat: a systematic review of the literature. *Obesity Reviews*, *7*(2), pp.183-200.

Kim, Y., Park, I. and Kang, M., 2013. Convergent validity of the international physical activity questionnaire (IPAQ): meta-analysis. *Public Health Nutrition*, *16*(3), pp.440-452.

Kim, J., Tanabe, K., Yokoyama, N., Zempo, H. and Kuno, S., 2013. Objectively measured light-intensity lifestyle activity and sedentary time are independently associated with metabolic syndrome: a cross-sectional study of Japanese

adults. *International Journal of Behavioral Nutrition and Physical Activity, 10*(1), pp.30-36.

Kirk, M.A. and Rhodes, R.E., 2011. Occupation correlates of adults' participation in leisure-time physical activity: a systematic review. *American Journal of Preventive Medicine, 40*(4), pp.476-485.

Kodama, S., Saito, K., Tanaka, S., Maki, M., Yachi, Y., Asumi, M., Sugawara, A., Totsuka, K., Shimano, H., Ohashi, Y. and Yamada, N., 2009. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *Journal of the American Medical Association, 301*(19), pp.2024-2035.

Kozey-Keadle, S., Libertine, A., Lyden, K., Staudenmayer, J. and Freedson, P.S., 2011. Validation of wearable monitors for assessing sedentary behavior. *Medicine and Science in Sports and Exercise, 43*(8), pp.1561-7.

Kruger, H.S., Venter, C.S. and Vorster, H.H., 2001. Obesity in African women in the North West Province, South Africa is associated with an increased risk of non-communicable diseases: the THUSA study. *British Journal of Nutrition, 86*(06), pp.733-740.

Lang, J.J., McNeil, J., Tremblay, M.S. and Saunders, T.J., 2015. Sit less, stand more: a randomized point-of-decision prompt intervention to reduce sedentary time. *Preventive Medicine, 73*, pp.67-69.

Lanningham-Foster, L., Nysse, L.J. and Levine, J.A., 2003. Labor saved, calories lost: the energetic impact of domestic labor-saving devices. *Obesity*, *11*(10), pp.1178-1181.

Larsen, R.N., Kingwell, B.A., Sethi, P., Cerin, E., Owen, N. and Dunstan, D.W., 2014. Breaking up prolonged sitting reduces resting blood pressure in overweight/obese adults. *Nutrition, Metabolism and Cardiovascular Diseases*, *24*(9), pp.976-982.

Lee, P.H., Macfarlane, D.J., Lam, T.H. and Stewart, S.M., 2011. Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), pp.115-125.

Lee, I.M., Shiroma, E.J., Lobelo, F., Puska, P., Blair, S.N., Katzmarzyk, P.T. and Lancet Physical Activity Series Working Group, 2012. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Th Lancet*, *380*(9838), pp.219-229.

León-Latre, M., Moreno-Franco, B., Andrés-Esteban, E.M., Ledesma, M., Laclaustra, M., Alcalde, V., Peñalvo, J.L., Ordovás, J.M. and Casasnovas, J.A., 2014. Sedentary lifestyle and its relation to cardiovascular risk factors, insulin resistance and inflammatory profile. *Revista Española de Cardiología (English Edition)*, *67*(6), pp.449-455.

Levine, B.D., 2008. : what do we know, and what do we still need to know?. *The Journal of physiology*, *586*(1), pp.25-34.

Loprinzi, P.D., 2016. Light-Intensity Physical Activity and Medical Multimorbidity. *Southern Medical Journal*, *109*(3), pp.174-177.

Lyden, K., Keadle, S.K., Staudenmayer, J., Braun, B. and Freedson, P.S., 2015. Discrete features of sedentary behavior impact cardiometabolic risk factors. *Medicine and Science in Sports and Exercise*, *47*(5), pp.1079-1086.

Lyons, E.J., Swartz, M.C., Lewis, Z.H., Martinez, E. and Jennings, K., 2017. Feasibility and Acceptability of a Wearable Technology Physical Activity Intervention With Telephone Counseling for Mid-Aged and Older Adults: A Randomized Controlled Pilot Trial. *JMIR mHealth and uHealth*, *5*(3), p.e28.

Maher, C., Olds, T., Mire, E. and Katzmarzyk, P.T., 2014. Reconsidering the sedentary behaviour paradigm. *PLoS One*, *9*(1), p.e86403.

Matthews, D.R., Hosker, J.P., Rudenski, A.S., Naylor, B.A., Treacher, D.F. and Turner, R.C., 1985. Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia*, *28*(7), pp.412-419.

Matthews, C.E., Chen, K.Y., Freedson, P.S., Buchowski, M.S., Beech, B.M., Pate, R.R. and Troiano, R.P., 2008. Amount of time spent in sedentary behaviors in the United States, 2003–2004. *American Journal of Epidemiology*, *167*(7), pp.875-881.

McVeigh, J.A., Winkler, E.A., Healy, G.N., Slater, J., Eastwood, P.R. and Straker, L.M., 2016. Validity of an automated algorithm to identify waking and in-bed wear time in hip-worn accelerometer data collected with a 24 h wear protocol in young adults. *Physiological Measurement, 37*(10), pp.1636-1652.

Micklesfield, L.K., Pedro, T.M., Kahn, K., Kinsman, J., Pettifor, J.M., Tollman, S. and Norris, S.A., 2014. Physical activity and sedentary behavior among adolescents in rural South Africa: levels, patterns and correlates. *BMC Public Health, 14*(1), pp.40-59.

Ng, S.W. and Popkin, B.M., 2012. Time use and physical activity: a shift away from movement across the globe. *Obesity Reviews, 13*(8), pp.659-680.

Nocon, M., Hiemann, T., Müller-Riemenschneider, F., Thalau, F., Roll, S. and Willich, S.N., 2008. Association of physical activity with all-cause and cardiovascular mortality: a systematic review and meta-analysis. *European Journal of Cardiovascular Prevention & Rehabilitation, 15*(3), pp.239-246.

Oliver, M., Schluter, P.J., Healy, G.N., Tautolo, E.S., Schofield, G. and Rush, E., 2013. Associations between breaks in sedentary time and body size in Pacific mothers and their children: findings from the Pacific Islands Families Study. *Journal of Physical Activity and Health, 10*(8), pp.1166-1174.

Owen, N., Healy, G.N., Matthews, C.E. and Dunstan, D.W., 2010. Too much sitting: the population-health science of sedentary behavior. *Exercise and Sport Sciences Reviews, 38*(3), pp.105-113.

Owen, N., Sparling, P.B., Healy, G.N., Dunstan, D.W. and Matthews, C.E., 2010, December. Sedentary behavior: emerging evidence for a new health risk. *In Mayo Clinic Proceedings*, *85*(12) pp. 1138-1141.

Pate, R.R., Pratt, M., Blair, S.N., Haskell, W.L., Macera, C.A., Bouchard, C., Buchner, D., Ettinger, W., Heath, G.W., King, A.C. and Kriska, A., 1995. Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *Journal of the American Medical Association*, *273*(5), pp.402-407.

Pate, R.R., O'neill, J.R. and Lobelo, F., 2008. The evolving definition of" sedentary". *Exercise and Sport Sciences Reviews*, *36*(4), pp.173-178.

Peddie, M.C., Bone, J.L., Rehrer, N.J., Skeaff, C.M., Gray, A.R. and Perry, T.L., 2013. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. *The American Journal of Clinical Nutrition*, *98*(2), pp.358-366.

Peer, N., Kengne, A.P., Motala, A.A. and Mbanya, J.C., 2014. Diabetes in the Africa Region: an update. *Diabetes research and clinical practice*, *103*(2), pp.197-205.

Pereira, S.M.P., Ki, M. and Power, C., 2012. Sedentary behaviour and biomarkers for cardiovascular disease and diabetes in mid-life: the role of television-viewing and sitting at work. *PloS One*, *7*(2), p.e31132.

Pronk, N.P., 2012. Reducing occupational sitting time and improving worker health: the Take-a-Stand Project, 2011. *Preventing chronic disease, 9*.

Poushter, J. and Oates, R., 2015. CellPhones in Africa: communication lifeline. *Washingston DC: Pew Research Centre*.

Rosenberg, D.E., Norman, G.J., Wagner, N., Patrick, K., Calfas, K.J. and Sallis, J.F., 2010. Reliability and validity of the Sedentary Behavior Questionnaire (SBQ) for adults. *Journal of Physical Activity and Health, 7*(6), pp.697-705.

Ryan, C.G., Grant, P.M., Tigbe, W.W. and Granat, M.H., 2006. The validity and reliability of a novel activity monitor as a measure of walking. *British Journal of Sports Medicine, 40*(9), pp.779-784.

Sardinha, L.B., Santos, D.A., Silva, A.M., Baptista, F. and Owen, N., 2015. Breaking-up sedentary time is associated with physical function in older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 70*(1), pp.119-124.

Sasaki, J.E., John, D. and Freedson, P.S., 2011. Validation and comparison of ActiGraph activity monitors. *Journal of Science and Medicine in Sport, 14*(5), pp.411-416.

Saunders, T.J., Larouche, R., Colley, R.C. and Tremblay, M.S., 2012. Acute sedentary behaviour and markers of cardiometabolic risk: a systematic review of intervention studies. *Journal of Nutrition and Metabolism, 2012*, pp.1-12

Saunders, T.J., Tremblay, M.S., Mathieu, M.È., Henderson, M., O'Loughlin, J., Tremblay, A., Chaput, J.P. and Quality Cohort Research Group, 2013. Associations of sedentary behavior, sedentary bouts and breaks in sedentary time with cardiometabolic risk in children with a family history of obesity. *PloS One*, *8*(11), p.e79143.

Schulz, K.F., Altman, D.G. and Moher, D., 2010. CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. *BMC Medicine*, *8*(1), pp.18-26.

Seip, R.L., Angelopoulos, T.J. and Semenkovich, C.F., 1995. Exercise induces human lipoprotein lipase gene expression in skeletal muscle but not adipose tissue. *American Journal of Physiology-Endocrinology and Metabolism*, *268*(2), pp.E229-E236.

Shisana, O., Labadarios, D., Rehle, T., Simbayi, L., Zuma, K., Dhansay, A., Reddy, P., Parker, W., Hoosain, E., Naidoo, P. and Hongoro, C., 2014. *The South African National Health and Nutrition Examination Survey, 2012: SANHANES-1: the health and nutritional status of the nation*. HSRC press.

Siri, W.E., 1961. Body composition from fluid spaces and density: analysis of methods. *Techniques for Measuring Body Composition*, *61*, pp.223-44.

Statistics South Africa, 2017. *P0309.3 - Mortality and causes of death in South Africa: Findings from Death Notification*. From: 28 February, 2017. http://www.statssa.gov.za/?page_id=1854&PPN=P0309.3&SCH=6987

Steeves, J.A., Bowles, H.R., McClain, J.J., Dodd, K.W., Brychta, R.J., Wang, J. and Chen, K.Y., 2015. Ability of thigh-worn actigraph and activPAL monitors to classify posture and motion. *Medicine and Science in Sports and Exercise, 47*(5), pp.952-9.

Stephens, B.R., Granados, K., Zderic, T.W., Hamilton, M.T. and Braun, B., 2011. Effects of 1 day of inactivity on insulin action in healthy men and women: interaction with energy intake. *Metabolism, 60*(7), pp.941-949.

Straker, L. and Mathiassen, S.E., 2009. Increased physical work loads in modern work–a necessity for better health and performance?. *Ergonomics, 52*(10), pp.1215-1225.

Thompson, P.D., Crouse, S.F., Goodpaster, B.R.E.T.T., Kelley, D., Moyna, N.I.A.L.L. and Pescatello, L.I.N.D.A., 2001. The acute versus the chronic response to exercise. *Medicine and Science in Sports and Exercise*, *33*(6), pp.S438-45.

Thorp, A.A., Healy, G.N., Owen, N., Salmon, J., Ball, K., Shaw, J.E., Zimmet, P.Z. and Dunstan, D.W., 2010. Deleterious associations of sitting time and television viewing time with cardiometabolic risk biomarkers. *Diabetes Care*, *33*(2), pp.327-334.

Thorp, A.A., Kingwell, B.A., Sethi, P., Hammond, L., Owen, N. and Dunstan, D.W., 2014. Alternating bouts of sitting and standing attenuate postprandial glucose responses. *Medicine and Science in Sports and Exercise*, *46*(11), pp.2053-61.

Tremblay, M.S., Colley, R.C., Saunders, T.J., Healy, G.N. and Owen, N., 2010. Physiological and health implications of a sedentary lifestyle. *Applied Physiology, Nutrition, and Metabolism, 35*(6), pp.725-740.

Tremblay, M.S., LeBlanc, A.G., Kho, M.E., Saunders, T.J., Larouche, R., Colley, R.C., Goldfield, G. and Gorber, S.C., 2011. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 8*(1), pp.98-120.

Tremblay, M.S., LeBlanc, A.G., Janssen, I., Kho, M.E., Hicks, A., Murumets, K., Colley, R.C. and Duggan, M., 2011. Canadian sedentary behaviour guidelines for children and youth. *Applied Physiology, Nutrition, and Metabolism, 36*(1), pp.59-64.

Tremblay, M.S., Carson, V., Chaput, J.P., Connor Gorber, S., Dinh, T., Duggan, M., Faulkner, G., Gray, C.E., Gruber, R., Janson, K. and Janssen, I., 2016. Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep 1. *Applied Physiology, Nutrition, and Metabolism, 41*(6), pp.S311-S327.

US Food and Drug Administration. 1988. Clinical Evaluation of Antihypertensive Drugs: Clinical Medical Draft Guidelines. *Bethesda: US Food and Drug Administration*.

Warburton, D.E., Nicol, C.W. and Bredin, S.S., 2006. Health benefits of physical activity: the evidence. *Canadian Medical Association Journal, 174*(6), pp.801-809.

Warren, T.Y., Barry, V., Hooker, S.P., Sui, X., Church, T.S. and Blair, S.N., 2010. Sedentary behaviors increase risk of cardiovascular disease mortality in men. *Medicine and Science in Sports and Exercise*, *42*(5), pp.879.

Wen, C.P., Wai, J.P.M., Tsai, M.K., Yang, Y.C., Cheng, T.Y.D., Lee, M.C., Chan, H.T., Tsao, C.K., Tsai, S.P. and Wu, X., 2011. Minimum amount of physical activity for reduced mortality and extended life expectancy: a prospective cohort study. *The Lancet*, *378*(9798), pp.1244-1253.

Wijndaele, K., Brage, S., Besson, H., Khaw, K.T., Sharp, S.J., Luben, R., Bhaniani, A., Wareham, N.J. and Ekelund, U., 2011. Television viewing and incident cardiovascular disease: prospective associations and mediation analysis in the EPIC Norfolk Study. *PloS One*, *6*(5), p.e20058.

World Health Organization. *World health statistics 2012*. World Health Organization, Geneva; 2012. From http://apps.who.int/iris/bitstream/10665/44844/1/9789241564441_eng.pdf

Yusuf, S., Rangarajan, S., Teo, K., Islam, S., Li, W., Liu, L., Bo, J., Lou, Q., Lu, F., Liu, T. and Yu, L., 2014. Cardiovascular risk and events in 17 low-, middle-, and high-income countries. *New England Journal of Medicine*, *371*(9), pp.818-827.

Zderic, T.W. and Hamilton, M.T., 2006. Physical inactivity amplifies the sensitivity of skeletal muscle to the lipid-induced downregulation of lipoprotein lipase activity. *Journal of Applied Physiology*, *100*(1), pp.249-257.

Zhang, J.Q., Thomas, T.R. and Ball, S.D., 1998. Effect of exercise timing on postprandial lipemia and HDL cholesterol subfractions. *Journal of Applied Physiology*, *85(*4), pp.1516-1522.

APPENDICES

APPENDIX A

PHYSICAL ACTIVITY

1.SPORTING ACTIVITIES/EXERCISE DURING A NORMAL WEEK

1.1 Do you go to gym/sports club or do you participate in any regular physical activity during the week (MONDAY TO FRIDAY)?

Yes=1	No=0

1.2 How often do you go to gym/sports club or do regular exercise? What type of regular exercise do you do in the gym or at the sports club or on your own? How long do you spend doing each exercise?

Type of exercise e.g. running, spinning weights etc.	Times per week					Minutes/ Time	Intensity				
	Mon	Tue	Wed	Thur	Fri		V. low	Low	Med	High	V. high

2.SPORTING ACTIVITIES/EXERCISE DURING A NORMAL WEEKEND

2.1 Do you go to gym/sports club or do you participate in any regular physical activity during the weekend? (SATURDAY AND SUNDAY)?

Yes=1	No=0

2.2 How often do you go to gym during the weekend? What type of regular exercise do you do in the gym or at the sports club or on your own? How long do you spend doing each exercise?

Type of exercise e.g. running, spinning, weights etc.	Times per weekend		Minutes/Time	Intensity				
	Sat	Sun		V. low	Low	Med	High	V. high

2.3 Do you take part in any sporting events on the weekend e.g. cycle race, running race, hiking event etc?

Yes=1	No=0

2.4 What type of sporting events do you take part in? How long do they usually last?

Type of exercise e.g. running, spinning, weights etc.	Times per weekend		Minutes/Time	Intensity				
	Sat	Sun		V. low	Low	Med	High	V. high

3.INFORMAL ACTIVITIES

3.1Do you engage in any physical activity during the day (weekdays and weekend) but NOT in a sports club e.g. cleaning, cooking, ironing, moving furniture, gardening etc? What activities do you engage in, how often & how long?

Type of exercise e.g. running, spinning weights etc.	Times per week							Minutes/ Time	Intensity				
	Mon	Tue	Wed	Thur	Fri	Sat	Sun		V. low	Low	Med	High	V. high

4.SLEEP

1) DURING THE WEEK ON AVERAGE:

What time do you go to bed? _____ Wake up? _____

2) ON THE WEEKEND ON AVERAGE:

What time do you go to bed? _____ Wake up? _____

5. TRANSPORT

How do you get to work and how long does it take to get there and back? Please choose one of the 5 options:

5.1

BY CAR, BUS, TAXI, TRAIN ETC? ☐ Yes ☐ No

How long to get there? _____ minutes How long to get back? _____ minutes

5.2

WALKING? ☐ Yes ☐ No

How long to get there? _____ minutes How long to get back? _____ minutes

When you walk, at what pace (how fast) do you usually walk? Please circle:

At a vigorous pace, that makes me breathe much harder than normal	At a medium pace that makes me breathe somewhat harder than normal	At a slow pace when there is no change in my breathing

5.3

BICYCLE? ☐ Yes ☐ No

How long to get there? _____ minutes How long to get back? _____ minutes

When you cycle, at what pace (how fast) do you usually cycle? Please circle:

At a vigorous pace, that makes me breathe much harder than normal	At a medium pace that makes me breathe somewhat harder than normal	At a slow pace when there is no change in my breathing

5.4

COMBINATION: (E.G. WALKING AND TAXI, BUS AND CYCLE) ☐ Yes ☐ No

How long to get there walking/cycle? _____ minutes

How long to get there vehicle? _____ minutes

How long to get back walking/cycle? _____ minutes

How long to get back vehicle? _____ minutes

When you walk/cycle, at what pace (how fast) do you usually walk/cycle? Please circle:

At a vigorous pace, that makes me breathe much harder than normal	At a medium pace that makes me breathe somewhat harder than normal	At a slow pace when there is no change in my breathing

5.5

OTHER? ☐ Yes ☐ No

Please give details:_____

_____

_____

_____

DO YOU DO ANY OTHER SPORTS?

	No. of times per week	**Minutes / Time**	**Intensity scale 1 – 5. No change in breathing = 1. Breathe harder than normal = 5.**
Athletics (track events)			
Athletics (field events)			
Archery			
Badminton			
Ballet			
Basketball			
Cricket			
Cycling			

Dancing			
Fencing			
Golf			
Gymnastics			
Hockey			
Horse riding			
Judo/Karate			
Netball			
Rowing			
Rugby (Touch)			
Rugby (Contact)			
Road running			
Volleyball			
Soccer			

Squash			
Swimming			
Tennis			
Volleyball			
Waterpolo			
Other sport?			

SEDENTARY BEHAVIOR: Weekday									
On a typical WEEKDAY, how much time do you spend (from when you wake up until you go to bed) doing the following?									
	None	**15 min. or less**	**30 min.**	**1 hr**	**2 hrs**	**3 hrs**	**4 hrs**	**5 hrs**	**6 hrs or more**
1. Watching television (including videos on VCR/DVD).	O	O	O	O	O	O	O	O	O
2. Playing computer or video games.	O	O	O	O	O	O	O	O	O
3. Sitting listening to music on the radio, tapes, or CDs.	O	O	O	O	O	O	O	O	O
4. Sitting and talking on the phone.	O	O	O	O	O	O	O	O	O
5. Doing paperwork or computer work (office work, emails, paying bills, etc.)	O	O	O	O	O	O	O	O	O
6. Sitting reading a book or magazine.	O	O	O	O	O	O	O	O	O
7. Playing a musical instrument.	O	O	O	O	O	O	O	O	O
8. Doing artwork or crafts.	O	O	O	O	O	O	O	O	O
9. Sitting and driving in a car, bus, or train.	O	O	O	O	O	O	O	O	O

SEDENTARY BEHAVIOR: Weekend Day									
On a typical WEEKEND DAY, how much time do you spend (from when you wake up until you go to bed) doing the following?									
	None	**15 min. or less**	**30 min**	**1 hr**	**2 hrs**	**3 hrs**	**4 hrs**	**5 hrs**	**6 hrs or more**
1. Watching television (including videos on VCR/DVD).	O	O	O	O	O	O	O	O	O
2. Playing computer or video games.	O	O	O	O	O	O	O	O	O
3. Sitting listening to music on the radio, tapes, or CDs.	O	O	O	O	O	O	O	O	O
4. Sitting and talking on the phone.	O	O	O	O	O	O	O	O	O
5. Doing paperwork or computer work (office work, emails, paying bills, etc.)	O	O	O	O	O	O	O	O	O
6. Sitting reading a book or magazine.	O	O	O	O	O	O	O	O	O
7. Playing a musical instrument.	O	O	O	O	O	O	O	O	O
8. Doing artwork or crafts.	O	O	O	O	O	O	O	O	O
9. Sitting and driving in a car, bus, or train.	O	O	O	O	O	O	O	O	O

SCREENING GENERAL HEALTH QUESTIONNAIRE

We would like to know about your health. Please answer the questions below as accurately as possible. This questionnaire may be filled out electronically or you can fill it out by hand. If you fill it in electronically, to tick a box, double click the box and under default value select the checked option. Click ok. If you need to type, click in the box provided and write as much as is needed. Thank you very much for your co-operation.

Your date of birth: ☐

1) Compared to other adults your age, how would you rate your health in the last TWO years? Please tick one box.

Better than others	☐	Worse than others	☐
Same as others	☐	Much worse than others	☐

*2) **In the last TWO years:***

a) Have you gone to hospital? Yes ☐ No ☐

*b) If **yes**, what did you go to hospital for?*

c) How long did you stay in hospital for?

d) Have you had any surgical procedures in the last year? Yes ☐ No ☐

If yes, which procedure did you have?

3) Please tick any illnesses that you may have currently or have had in the last SIX months.

Illness		**How long ago?**	**Fully recovered?**
Heart attack, stroke	☐	_____	Yes ☐ No ☐
Diabetes Mellitus Type I	☐	_____	Yes ☐ No ☐
Diabetes Mellitus Type II	☐	_____	Yes ☐ No ☐
Cold	☐	_____	Yes ☐ No ☐
Influenza ('Flu)	☐	_____	Yes ☐ No ☐
High total cholesterol	☐	_____	Yes ☐ No ☐
None	☐		

4) Please write down any medication/treatment that you may be on or have taken in the last SIX months.

5) Do you smoke?

Yes ☐ No ☐

6) Do you own a cell-phone and/or have access to email?

Yes ☐ No ☐

Please tick the box of the items that you own:

☐ Microwave	☐ Telephone – Landline	☐ Cellular telephone
☐ DSTV, Top TV	☐ Car How many?	☐ Formal housing
☐ Washing machine	☐ Fridge	☐ Indoor toilet
☐ Indoor water	☐ Video machine/DVD player	☐ Television
☐ Electricity	☐ Dishwasher	☐ Computer

☐ How many adults (over 18) in your family?

Highest level of education? Please tick the box:

☐ High school
☐ Matric
☐ College
☐ University

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS QUESTIONNAIRE

APPENDIX D

Information Sheet

Sedentary behaviour patterns and the effects of breaking up sedentary time on cardiometabolic health in South African office workers.

Good day,

My name is Jason Dunning and I am a Masters student at the University of the Witwatersrand.

My co-investigators (Dr. Rebecca Meiring and Dr. Joanne McVeigh) and I are interested in determining how sitting for too long influences your health. I would therefore like to invite you to participate in my research project.

If you would be interested in participating in this study, please read the following information carefully before signing the consent form.

We would kindly like to ask you to visit the Exercise Physiology Laboratory at Wits Medical School at a time convenient to you at the start of the study and once again after a 10 week period. At this visit, you will be asked to complete a short general health and physical activity questionnaire which will give us an idea of your recent state of health and activity level. We will also ask you to complete another questionnaire which will give us an indication of how much time you spend sitting during the week. Information from these questionnaires will allow us to determine whether you are eligible to take part in this study. If so, we would then like to measure your height, weight and body fat percentage. We would also like to ask you to take part in a fitness assessment which involves walking on a treadmill, while we increase the incline (at a constant speed), until you are too tired to continue. This assessment will give us an indication of your current physical fitness.

We will also look at the condition of your arteries using a technique which uses ultrasound. The procedure involves lying down for a few minutes while we scan the artery in your upper arm. The procedure also requires an inflated cuff placed over the forearm for 5 minutes. The cuff, when deflated, will create a large increase in blood flow and we will be able to see how well the artery is able to dilate in response to this stress. The information from this scan will allow us to assess the health and function of your arteries. This may be slightly uncomfortable and you may experience a “pins and needles” feeling in your arm but this discomfort is generally considered minimal. If you do not feel comfortable with this procedure you may choose to stop at any time.

If you are willing, we would like to take a small (15ml) blood sample on the morning of your arrival to the lab (after an overnight fast). This sample will be collected by a qualified nurse. From this sample we will determine blood glucose and cholesterol levels as well as other markers of metabolic health.

The entire visit to the lab should last approximately 1.5 hours.

We would also like to ask you to wear a small device on your hip for seven days. This small device which is about the size of a watch will measure your daily activity levels. We will ask you to remove the monitor only when bathing/showering or during swimming activity otherwise we would like you to wear the device for 24 hours a day. The device can be worn discreetly underneath your clothing. I will arrange to collect the activity monitor from you at the end of the seven days.

Once you have come in for the pre-screening measures, we will be allocating you into one of two groups (control or intervention). This allocation will be done randomly and I will not know which group you have been put into. Depending on which group you are put into, for the next 10 weeks during your work day, you may be asked (via SMS, email or computer notification) to try and break up the amount of time you spend sitting. You will be notified every 20 minutes between 08h00 and 17h00 to perform short tasks (for example: stand up when answering phone/reading emails; take a short walk to fetch water; walk to the nearest elevator/window). At some point during the 10 weeks, you will be asked to wear an activity monitor again for seven days, at a time convenient for you. After the 10 week period we will kindly ask you to come back to the lab for a final assessment and repeat the measurements/procedures done at your first visit.

You will receive a report back of your results on conclusion of the study and the findings of the study will be made available to you only, should you be interested.

Please note, you may withdraw your participation at any stage during the study without any prejudice. All results will be kept confidential and will be made available only to the researchers involved in the study and yourself. Anonymity will be ensured throughout. All data will be analysed and the results will be published in a research paper written for the scientific community. We have received approval for this study from the Human Research Ethics Committee of the University of the Witwatersrand.

Thank you for considering participation in this study. Please read the above information before signing the consent form. If you have any questions, please feel free to contact me.

Jason Dunning (investigator) - contact details:

- **Tel: 072 588 8173**
- **Email: Jason-dunning@hotmail.com**

***If you have any doubts to your rights as a participant please feel free to contact Ms Zanele Ndlovu or Mr Langutani Masingi, Medical School, Parktown, Phillip Tobias**

Building, 2nd Floor, Cnr York Road and Princess of Wales Terrace, Mon-Fri 08h00-17h00 Tel: 011-717-1234/1252/2700 or Room SH1005, 10th Floor

PARTICIPANT CONSENT FORM

I, _____(name and surname) consent to participate in the research project entitled: **"Sedentary behaviour patterns and the effects of breaking up sedentary time on cardiometabolic health in South African office workers"**.

The procedures/questionnaires have been explained to me and I understand and appreciate their purpose, any risks involved, and the extent of my involvement. I have read and understand the attached information sheet.

I understand that all experimental procedures have been sanctioned by the Committee for Research on Human participants, University of the Witwatersrand, Johannesburg.

I understand that my participation is voluntary and I am free to withdraw from the project at any time without prejudice.

_____ _____

Participant name and signature Date

_____ _____

Investigator name and signature Date

APPENDIX E

R14/49 Mr Jason Dunning and Mr Tiago Lopes et al

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M170298

NAME: (Principal Investigator)	Mr Jason Dunning and Mr Tiago Lopes et al
DEPARTMENT:	Physiology School of Physiology
PROJECT TITLE:	Sedentary Behaviour Patterns and the Effects of Breaking up of Sedentary Time on Cardiometabolic Health in South African Office Workers
DATE CONSIDERED:	Adhoc
DECISION:	Approved unconditionally
CONDITIONS:	Sub-Study (M130229)
SUPERVISOR:	Dr Rebecca Meiring
APPROVED BY:	Professor P. Cleaton-Jones,Chairperson, HREC (Medical)
DATE OF APPROVAL:	13/03/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004,10th floor, Senate House/2nd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review in February and will therefore be due in the month of February each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

R14/49 Misses A Millen/A Prioreschi

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M130229

NAME: (Principal Investigator)	Misses A Millen/A Prioreschi
DEPARTMENT:	School of Physiology Medical School
PROJECT TITLE:	The Effect of Exercise Participation and Long Term Breaking up of Sedentary Time on Metabolic and Cardiovascular Risk in Sedentary Office Workers
DATE CONSIDERED:	22/02/2013
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Joanne McVeigh
APPROVED BY:	Professor PE Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 08/05/2013

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX F

ACTIGRAPH LOG BOOK		
DATE	TIME	REASON FOR REMOVING MONITOR

APPENDIX G

LOG BOOK - BREAKS IN SEDENTARY TIME						
DAY	**TIME**	**Received [✓] [X]**	**TASK PERFORMED**	**TIME**	**Received [✓] [X]**	**TASK PERFORMED**
Date:	08h20			12h40		
	08h40			13h00		
	09h00			13h20		
	09h20			13h40		
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	11h00			15h20		
	11h20			15h40		
	11h40			16h00		
	12h00			16h20		
	12h20			16h40		
DAY	**TIME**	**Received [✓] [X]**	**TASK PERFORMED**	**TIME**	**Received [✓] [X]**	**TASK PERFORMED**
Date:	08h20			12h40		
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	11h40			16h00		
	12h00			16h20		
	12h20			16h40		
DAY	**TIME**	**Received [✓] [X]**	**TASK PERFORMED**	**TIME**	**Received [✓] [X]**	**TASK PERFORMED**
Date:	08h20			12h40		
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