INTERRELATIONSHIPS AMONG SEDENTARY BEHAVIOUR, SHORT SLEEP, AND THE METABOLIC SYNDROME IN ADULTS

by

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Abstract

Background: Sedentary behaviour is waking activity in a seated or reclined position that involves little energy expenditure. It is gaining attention as an important cardiometabolic risk factor, independent of physical activity. Studies assessing the relationship between sedentary behaviour and cardiometabolic risk have not accounted for sleep duration as a potential covariate, although there is evidence that sleep duration may be related to both sedentary behaviour and cardiometabolic risk.

Objectives: To examine the associations between sleep duration and sedentary behaviour in adults, and determine if sedentary behaviour is related to the metabolic syndrome (MetS) after controlling for sleep duration.

Methods: This cross-sectional study used data from the 2003-2006 National Health and Nutrition Examination Survey, a representative sample of Americans. There were 1371 adults over the age of 20 that were studied. Average daily sedentary time and sleep duration were determined via 7-day accelerometry. Screen time (television, computer) was determined via questionnaire. The MetS was determined using standard criteria. Analysis of variance was used to examine relationships among sedentary time and screen time with sleep duration. Multiple logistic regression was used to examine associations between total sedentary time, screen time, and sleep duration with the MetS after controlling for several covariates.

Results: Sedentary time and screen time did not vary across sleep duration quartiles ($p=0.08$ and $p=0.87$, respectively), and therefore were unrelated to sleep duration. The relative odds of the MetS was significantly higher in participants in the highest quartile of sedentary time than in participants in the lowest quartile (OR=1.60, 95% CI:1.05-2.45).

The relative odds of the MetS was higher in participants in the highest screen time tertile than in participants in the lowest tertile (OR =1.67, 95% CI:1.13-2.48). Short sleep duration was not independently related to the MetS, but was borderline related to waist circumference (OR=1.25, 95% CI:0.85-1.84).

Conclusion: Highly sedentary individuals and individuals with a high screen time are more likely to have the MetS, independent of sleep duration. Future studies in this area would benefit from using more advanced objective measures of sedentary behaviour and sleep duration and a prospective study design.

Co-Authorship

This thesis is the work of Donna Saleh under the supervision of Dr. Ian Janssen. The research question was a collaborative effort between the two authors. Donna Saleh performed data cleaning and reduction of the National Health and Nutrition Examination Survey databases, developed the SAS program to clean the accelerometer data to derive the objective sedentary behaviour and sleep duration variables, performed all statistical analyses, interpreted the results, and wrote all thesis chapters. Dr. Janssen provided guidance on the statistical analysis and interpretation of results and revised the entire thesis and its associated work extensively.

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List of Abbreviations

NHANES: National Health and Nutrition Examination Survey

MEC: mobile exam center

MetS: metabolic syndrome

METS: metabolic equivalents

MVPA: moderate-to-vigorous physical activity

CHD: coronary heart disease

CVD: cardiovascular disease

BMI: body mass index

HDL: high-density lipoprotein

LPL: lipoprotein lipase

SES: socioeconomic status

OR: odds ratio

RR: relative risk

CI: confidence interval

Chapter 1

General Introduction

1.1 Introduction

Over the past few decades, several prospective cohort studies have shown that regular participation in physical activity lowers the risk of developing cardiovascular and metabolic diseases [1]. Therefore, physical activity has been publicized as preventing disease and prolonging life [1]. Research in physical activity epidemiology has generally focused on moderate-to-vigorous-intensity physical activity (MVPA) [2]. This includes activities where the energy being expended is at least three times higher than it is at rest and includes activities like brisk walking, bicycling, jogging, and swimming laps. However, the energy expended in the remaining waking hours of the day, which occupy approximately 95% of the day, have received far less attention [2]. This includes the energy expended in light-intensity spontaneous activities such as doing light chores, walking, and fidgeting. It also includes the minimal energy expended when an individual is sitting or lying down (sedentary behaviour) [2]. Lastly, although time spent in non-waking hours (i.e. sleep) [3] has received more attention with regards to obesity risk, there is limited evidence surrounding the role it plays in conjunction with sedentary behaviour to increase cardiometabolic risk.

Sedentary behaviour and short sleep have each been independently linked to obesity and the metabolic syndrome (MetS) [4,5], a clustering of risk factors related to cardiovascular disease and type 2 diabetes [6]. Some studies suggest there may even be a connection between sedentary behaviour and short sleep [7–9]. However, to date, very

limited research has looked at the sedentary behaviour-cardiometabolic health relationship, while considering short sleep duration as a covariate.

Historically, physical activity researchers believe that excessive sedentary behaviour was akin to not engaging in sufficient MVPA. Research, interventions, and guidelines to optimize health were focused on MVPA. More recently, researchers have discovered that sedentary behaviour is distinct from a lack of MVPA. For example, an individual may accumulate 45 minutes of purposeful exercise (MVPA) every morning, but may remain sedentary for the remainder of the day. The energy expended by this individual would be very different from an individual who accumulated the same amount of purposeful exercise but who also engaged in light intensity activity intermittently throughout the day. As this is a new area of research, limited research exists on the determinants, outcomes and interventions for sedentary behaviour. This thesis has been constructed to address some of the gaps that currently exist in sedentary behaviour research among adults.

1.2 Overview of Thesis

This thesis research project examined whether a relationship exists between sedentary behaviour (screen time and total sedentary behaviour time) and short sleep. Additionally, it determined whether sedentary behaviour is a predictor of the MetS, while controlling for sleep duration and several other covariates that are predictors of the MetS. Metabolic syndrome risk increases with age and is higher among black individuals and those with less than a high school education [14]. Alcohol intake [14], caffeine consumption [15,16], no smoking [17,18] and physical activity [14] are protective of the

metabolic syndrome. The prevalence of the metabolic syndrome is higher in men than in women, particularly abdominal obesity and impaired fasting glucose [19]. However, females of low socioeconomic status (SES) are at a higher risk of the metabolic syndrome than males of low SES [20,21].

The thesis follows a manuscript format (with a single manuscript) and is based on the conceptual framework described in Figure 1.1.

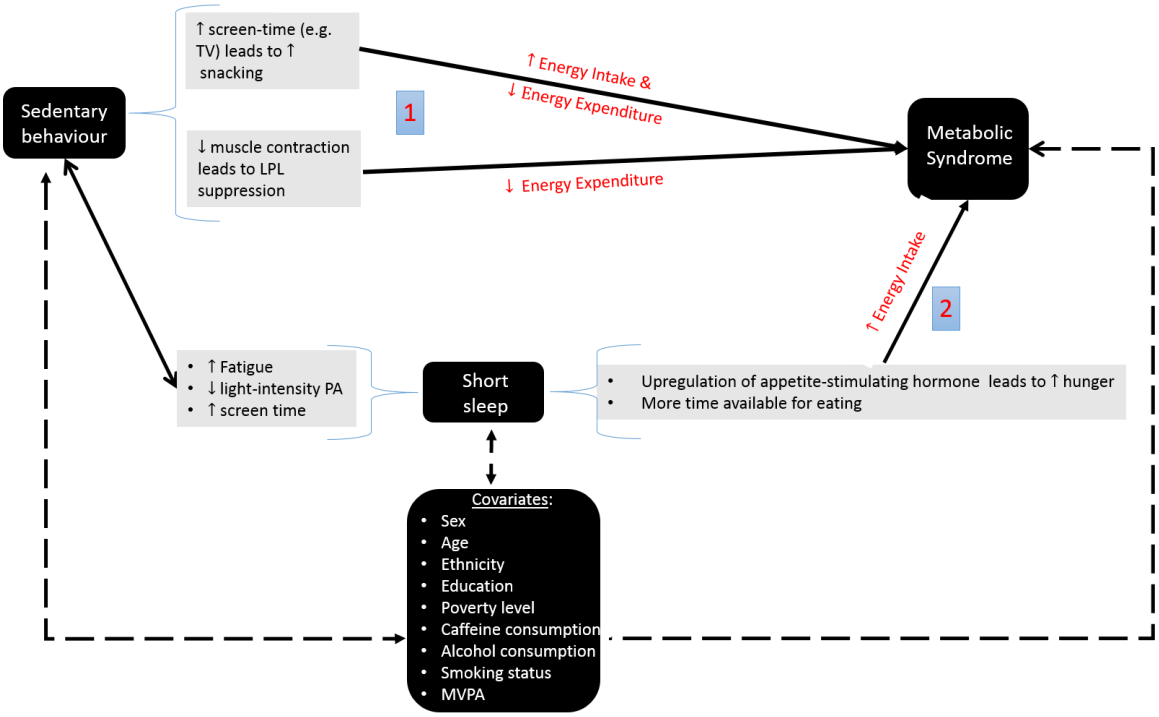

Figure 1.1 Conceptual Framework of Thesis

This manuscript will determine whether a relationship exists between short sleep duration and sedentary behaviour (screen time and total sedentary behaviour time). Additionally, it will determine whether sedentary behaviour is a predictor of the MetS, while controlling for sleep duration and several covariates.

1.3 Objectives and Hypotheses

The objectives and hypotheses of this thesis are:

1. To determine if an association exists between short sleep and sedentary behavior among adults. It was hypothesized that adults with a short sleep duration would be more sedentary than adults who slept regular hours. This was expected since short sleep may cause more tiredness throughout the day, which may unintentionally reduce light intensity physical activity and increase sedentary behaviour.
2. To assess whether an association exists between total sedentary behaviour and screen time with the MetS, and if these associations are independent of sleep duration. It was hypothesized that the relationship between sedentary behavior and the MetS would *not* be independent of sleep duration. Aside from the hypothesized effects of sleep duration on energy expenditure, short sleep is thought to be a strong risk factor for obesity and the MetS among adults.

1.4 Scientific importance

Potential determinants or correlates of sedentary behaviour are not well established [10]. Particularly, the association between sleep duration and sedentary behaviour is not well understood in the adult population. Although sedentary behaviour has been shown to be related to the MetS, previous studies have not considered the role of sleep duration on this relationship. This thesis aims to address some of these issues by 1) using a large national database to conduct a large-scale study among adults and 2) examining the sedentary behaviour-MetS relationship, while controlling for short sleep using multiple logistic modeling.

1.5 Public health importance

Public health recommendations for physical activity have not encompassed all forms of physical activity and have not addressed sedentary behaviour. For example, the American Heart Association states that "the recommended amount of aerobic activity is in addition to routine activities of daily living which are of light intensity, such as self-care, casual walking or grocery shopping…" [11]. Naturally, doing such daily activities would involve reductions in sitting time. However, sitting time is not specifically addressed in the recommendations. As a result, people are unaware the sedentary behaviour may be a risk factor for cardiometabolic health and end up spending a large portion of their day engaging in a variety of sitting activities. Similarly, a growing body of research indicates that short sleep duration increases the risk of weight gain and obesity. Yet, most people seem to think that sleep is a commodity that can be traded for other activities considered more pressing or more important [12].

Therefore, since sedentary behaviour and sleep are both potentially modifiable behaviours that are associated with cardiometabolic health and a slew of other health problems, practical and policy approaches are needed on multiple levels. Firstly, the general public needs to be informed of the negative health outcomes of these behaviours. After that, information campaigns can suggest ways to target these negative behaviours in different settings (e.g. workplace, transport, leisure). Possibly, regulations in workplaces or in the community can be introduced to modify these behaviours [13].

1.6 Thesis layout

This thesis conforms to the guidelines for a manuscript-based thesis as recommended by the Queen's School of Graduate Studies and Research. The first chapter is a general introduction to the main subject area of this thesis. The second chapter reviews current literature surrounding sedentary behaviour, sleep duration, the MetS, and their interrelationships. The third chapter is composed of the manuscript. The fourth chapter summarizes the findings and provides an overall discussion. Finally, several appendices are included at the end of the document. These appendices provide more comprehensive details on some of the research methods and background.

1.7 References

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Chapter 2

Literature Review

2.1 Overview

This literature review aims to (1) summarize descriptive data on short sleep, sedentary behaviour, and the MetS; (2) provide an overview on the measurement of sedentary behaviour and sleep; (3) discuss the existing evidence surrounding potential correlates of sedentary behaviour; (4) examine the negative health outcomes, particularly cardiometabolic outcomes, associated with sedentary time, screen time and short sleep; and (5) review potential biological mechanisms linking short sleep, sedentary behaviour, and the MetS in adults.

2.2 Definition and Conceptualization of Key Terms

2.2.1 Sedentary Behaviour

A formal definition of sedentary behaviour is any waking activity characterized by an energy expenditure of 1.5 metabolic equivalents (METs) or less while in a seated or reclined position [1]. One MET represents resting energy expenditure [2]. Therefore, sedentary behaviour involves minimal body movement and is primarily characterized by time spent sitting [3]. Common sedentary behaviours include screen time activities such as television viewing, computer use, and video game playing as well as motorized transport and reading. Sedentary behaviour can be characterized using the SITT formula, with the acronym corresponding to Sedentary behaviour frequency (number of bouts of a certain duration), Interruptions (e.g. taking a break from sitting), Time (duration or

volume of sitting and lying while awake) and Type (e.g., TV viewing, driving, using a computer) [4].

Traditionally, epidemiologic research investigating relationships between energy expenditure and health benefits have studied MVPA [2]. Early researchers believed that time spent engaging in sedentary behaviour was directly related to time spent in MVPA. Thus, sedentary individuals were classified as those who did not take part in MVPA. Unfortunately, this approach failed to recognize that the amount of MVPA and sedentary behaviour people engage in are poorly correlated if correlated at all [4]. Someone may be physically active (e.g., accumulate 150 minutes/week of MVPA) and still be highly sedentary throughout their day (e.g., have a sedentary job and only use motorized forms of transportation). Figure 2.1 illustrates this (see next page).

The biological, social and environmental pathways leading to sedentary behaviour versus MVPA are different [5]. Additionally, the health outcomes associated with sedentary behaviour and MVPA are thought to be the result of different biological mechanisms [6]. The relationship between purposeful physical activity (i.e. MVPA) and health may mask the importance of other forms of physical activity and their effect on health [7]. In other words, the majority of physical activity energy expenditure is accumulated by engaging in light intensity activities such as doing chores, walking around the home, standing, etc. [8]. Although the energy expenditure of a specific light intensity activity is subtle when considered alone, the cumulative effects of the many activities falling into this category generally make light intensity activity a significant contributor to the total energy expenditure [4]. Therefore, a large proportion of time is

spent in light-intensity activities and sedentary behaviour, which are the inverse of each other and are strongly negatively correlated (r = -0.96) [9] .

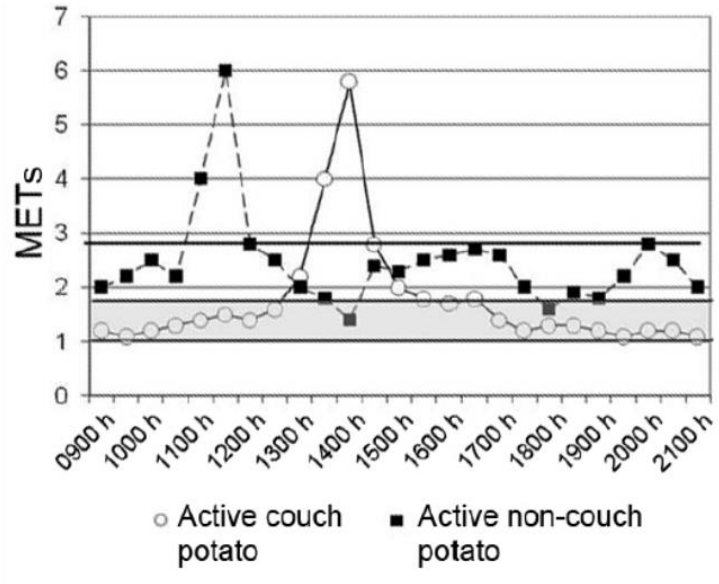

Figure 2.1 Accelerometer Data Portrayal

This illustration of accelerometer data portrays an "active couch potato" (considered physically active according to the guidelines but also highly sedentary) vs. an active non-couch potato**[4]**. The individual represented by the white circles performs a single bout of structured physical activity, but then remains sedentary for the rest of the day. In contrast, the individual represented by the black boxes also accumulates a similar volume of structured physical activity, but accrues much less sedentary time. The x-axis represents time throughout the waking hours of the day. The y-axis represents metabolic equivalents (METs), a measure expressing the energy expenditure of physical activities. 1 MET is equal to resting energy expenditure, while 3 or more METs is equal to the energy expended while engaging in MVPA.

2.2.2 Short sleep duration

There is no formal definition for short sleep duration. Definitions of sleep restriction are inconsistent across the scientific literature. However, the National Sleep Foundation recommends that adults acquire between 7-9 hours of sleep per night, recognizing that the amount of sleep that the human body needs differs among individuals [10]. Several sleep studies suggests that an individual's basal sleep need, the

amount of sleep the body needs for optimal performance, is approximately 8 hours per day in healthy adults [11,12].

2.2.3 The metabolic syndrome and cardiometabolic risk

Cardiovascular disease (CVD) accounts for 1 of every 2.9 deaths in the United States (U.S.) [13] and is the second-leading cause of death in Canada [14]. In the U.S., diabetes was the 7th leading cause of death in 2007, however, it is likely to be underreported [15]. Overall, the risk of death among individuals with diabetes are about twice as high compared to individuals without diabetes of similar age [15]. Cardiometabolic risk is the global risk of CVD and type 2 diabetes resulting from the presence of traditional risk factors (such as age, sex, smoking status, family history of CVD and low-density lipoprotein cholesterol levels) combined with the additional contribution of insulin resistance and abdominal obesity [16]. The current definition of the MetS encompasses a cluster of metabolic abnormalities linked to insulin resistance, which is often associated with abdominal obesity, a high-risk form of overweight/obesity. The MetS has been shown to predict CVD better than individual risk factors alone [17]. These factors include high blood glucose, raised blood pressure, elevated triglyceride levels, low high-density lipoprotein (HDL) cholesterol levels, and obesity (particularly in the abdomen) [17]. Individuals with the MetS are two times more likely to develop CVD within 5-10 years as individuals without the syndrome. They are also five times more likely to develop type-2 diabetes [17].

2.3 Prevalence of sedentary behaviour, short sleep, and the metabolic syndrome

Over the past century, humans have been subject to changes in the physical, economic and social environments in which they sit and move [8]. For example, technological advances in transportation, communication, workplace and domestic tasks, and even leisure have allowed humans to expend less energy and reduce physical labour [8,18]. As a result, humans are spending more time sitting than they were only a decade or two ago. Adults currently spend approximately 55% of their waking hours sedentary [19]. Around the same time that sitting has gone up, obesity and other clinical risk factors for chronic disease have risen. For instance, the prevalence of obesity in Canadian adults increased from 13.8% in 1979 to over 23% in 2004 [20]. Similarly, the prevalence of the MetS amongst Canadian adults has increased to over 25% [21].

Parallel to this rise in sitting time and obesity was an increase in chronic sleep deprivation [22]. As modern civilization has adapted to a 24-hour society with more night-time work and leisure activities, increasingly more people are curtailing their sleep [23]. In 1995, adults accumulated an average of 7 hours of sleep per night, compared to an 8.0-8.9 hour average in 1960, and a 9 hour average in 1910 [24]. Today, more than 30% of adults report sleeping less than 6 hours per night [25].

2.4 Sedentary Behaviour

This next section focuses on sedentary behaviour. I have discussed the existing evidence surrounding the determinants of sedentary behaviour and explained how sedentary behaviour is measured in research studies. Finally, the negative health

outcomes and potential biological mechanisms that explain the association between sedentary behaviour and cardiometabolic health are discussed.

2.4.1 Determinants of sedentary behaviour

Although it has become evident that sedentary behaviour has negative health consequences (as discussed in detail below), there is very limited research among adult populations on effective interventions that could reduce sedentary behaviour [26]. In order for successful interventions to be developed, research on sedentary behaviour determinants is required. When discussing the potential determinants of sedentary behaviour, I have done so using an ecological approach which recognizes that intrapersonal factors (features of the individual), intrapersonal factors (features of the individual's close social connections), and environmental factors at several levels (e.g., neighbourhood, community) may all be relevant.

Intrapersonal factors (including age, sex, race/ethnicity, educational attainment, and occupation) may affect the likelihood of sitting for a prolonged period. Studies that have focused on TV viewing time have generally found that being female, having a low socioeconomic status, low educational attainment, being unemployed, and having a low income predict excessive TV viewing. These results are consistent across Australian, American, and Canadian adults [4]. Based on a national study of Americans, it was reported that females who are 6-29 years old are more sedentary than males of the same age. However, this gender difference reversed when adults reached 60 years of age [19]. Race is also an important predictor of sedentary behaviour. One study found that black adults watch more TV when compared to Hispanic and white individuals (4.1 hr./day vs.

3.2 hr./day and 2.1 hr./day respectively, p=0.01) [27].

An individual's perceived barriers to activity may also contribute to an individual's sedentary behaviour. For example, an early study in large sample of Australian adults found that high levels of TV time were related to perceived barriers of physical activity such as cost ($R^2 = 0.3$, $\beta = 0.06$, $p < .05$) and work commitments ($R^2 = 0.9$, $\beta = -0.11$, $p < .01$) [28]. Similarly, individual choices on light-intensity physical activity (e.g. voluntarily choosing to use the stairs instead of the elevator, standing rather than sitting on public transportation) contributes to an individual's overall sedentary time [18], while leisure-time physical activity does not. Finally, biological attributes such as obesity or a physical disability may affect an individual's comfort or discomfort associated with prolonged sitting [18].

Interpersonal factors (e.g., impact of friends and family) can also influence sedentary behaviour. A recent study found that sitting socializing was the second most common reported leisure-time sedentary behaviour, after TV viewing [28]. They also found that family commitments were associated with a reduced likelihood of high participation in sedentary behaviour (β=-0.12, p<0.01) and TV viewing time (β =-0.09, p<0.01) [28].

Finally, environmental factors such as domestic, occupational, transportation and leisure-time settings may be specific to certain sedentary behaviours [26]. Individuals spend a significant proportion of their day at work, so those who have sedentary occupations generally accrue more sedentary time than those with more active jobs [29]. Also, in leisure settings, it is not always the norm to walk to entertainment destinations or eat and socialize while standing [18], behaviours that would reduce sedentary time.

Additionally, research has shown that women who live in neighbourhoods with poorly connected streets watch more TV (123 minutes/day vs. 96 min/day, $p<0.001$) [30]. With poor street connectivity, the distance required to travel between two points increases, which makes it inconvenient to walk [31]. Similarly, adults who live in suburban areas with limited transit availability and a lower population density have been shown to travel more in their vehicles compared to those who reside in walkable neighbourhoods (i.e. city centers). The residents of the high-walkable neighbourhoods had a 2.9% increase of accelerometer-measured overall sedentary time ($p<0.001$) compared to those living in the low-walkable neighbourhoods [32]. Perceived lack of safety was also related to increased TV viewing time ($R^2=0.3$, $\beta=0.06$, $p<0.05$) [28]. Environmental barriers such as lack of safety discourages individuals from walking and engaging in leisure-time physical activity outside, making sedentary behaviour (e.g. driving, watching TV) the easier, default option [30].

The correlates of sedentary behaviour described above are only a starting point to a wide array of research that needs to be conducted surrounding sedentary behaviour determinants and correlates [26]. One individual-level factor that has not been studied as a possible determinant of sedentary behaviour is sleep, which is discussed in further detail near the end of the literature review.

2.4.2 Measurement of sedentary behaviour

To date, sedentary behaviour has been measured in three ways: in terms of specific behaviours (e.g. TV viewing time); the amount of sedentary time occurring in a specific domain (e.g. work, leisure, domestic, transport) and the overall sedentary time

across the day (using objective measurements). Early research on sedentary behaviour focused primarily on television viewing, as assessed by questionnaire. More recent studies have addressed the changing trends in media usage by expanding TV time to include all "screen time" behaviours such as video gaming, computer time, DVD's and other electronic media [33].

Self-report methods (e.g. questionnaires, diaries) are the most common method of gathering information on sedentary behaviour [34]. The major advantage of measuring sedentary behaviour through self-report methods is that it allows researchers to assess large samples simultaneously, in short periods of time, and with relatively low costs. Eligible samples also feel more inclined to participate since participant burden is low (i.e. not much effort is involved on their part) [34,35]. Self-report methods also provide context to the type of activity/sedentary behaviour performed (e.g. watching TV, using a computer, reading, etc.). This allows researchers to identify which behaviours are most prominent and require distinct interventions. However, there are obvious limitations with self-report methods such as recall bias (e.g. participants may not remember the duration or frequency of sedentary behaviour they accumulate) and social desirability response bias (e.g. participants may under-report sedentary behaviour since it is seen as a negative behaviour). Another disadvantage is that surveys often only capture one type of sedentary behaviour (i.e. TV viewing).

Researchers are moving towards objective measurement of sedentary behaviour to avoid issues with recall biases and to assess total sedentary behaviour. Accelerometers have been the method of choice. Accelerometers are a small electronic devices that research participants usually wear on their hip for 7 consecutive days. They allow

researchers to obtain detailed, minute-by-minute data on the volume, intensity, duration and frequency of most movement between and within days. Accelerometer data can be downloaded to computer databases and used to derive meaningful activity pattern variables [8]. Accelerometers work by using piezoelectric transducers and microprocessors that convert recorded accelerations to a quantifiable digital signal commonly known as "counts" [36]. These counts are recorded over user-specified intervals or epochs (e.g. 15 seconds, 30 seconds, 1 minute), with higher counts representing greater accelerations and more intense movement [34,37]. Laboratory studies are used to determine the accelerometer count cut-points that correspond to different movement intensities (e.g., sedentary behaviour and light, moderate, and vigorous physical activity). Usually, sedentary behaviour is determined by summing up count values that do not cross the 100 counts per minute (cpm) threshold [19,38].

One of the main advantages of accelerometers is that they are able to assess the intensity of physical activity, meaning even light or incidental physical activity can be captured. This is often impossible to capture when self-report methods are used. Therefore, accelerometers have the ability to characterize patterns of sedentary time. For example, the same volume of sedentary time may exhibit different patterns in two individuals. While one person may be a "prolonger" (i.e. remain sedentary for long periods of time), another may be a "breaker" (i.e. interrupt sedentarism by moving around briefly during seated activities) [4]. Secondly, accelerometers (unlike pedometers) do not provide real-time information for participants, which may limit their motivation to be physically active, providing a true measure of effect by not introducing social desirability bias.

A disadvantage of accelerometers is that they cannot detect upper body movement. Also, they cannot differentiate between postural changes, meaning that they cannot detect differences between sitting, lying, and standing still. This is problematic because recent research indicates that standing positively influences cardiometabolic risk factors [6]. Additionally, accelerometers are unable to provide context regarding the type of sedentary behaviour performed such as watching television, driving, reading, etc. [4,34,39]. Finally, most accelerometers are not water proof, so they must be taken off during showers or swimming.

In addition to limitations of the actual device, there are methodological issues regarding accelerometer data collection, data reduction, and data analysis that can result in inaccurate measures of sedentary behaviour [34,40]. Firstly, a minimum wear time (i.e. hours/day and number of days) is required to ensure that sedentary behaviour is accurately represented. For optimal results, it is recommended that minimum wear time should be 10 hours/day for at least 4 days including at least one weekend day [41,42]. Secondly, wear time must be defined. This is difficult because zero counts can either mean that the participant is not moving or that they are not wearing their accelerometer [42]. In population-based studies, wear time is usually defined by algorithms that remove long periods of consecutive zero counts (i.e. 10-60 minutes). However, doing this may underestimate sedentary time since it is highly possible that an individual remain sedentary for long periods of time. Another problem is that participants often remove their accelerometers in the evening while engaging in sedentary behaviours [43].

2.4.3 Sedentary Behaviour among Adults and Cardiometabolic Risk

The first indication that sedentary behaviour could increase coronary heart disease (CHD) risk was found in a study conducted in 1949-1950. This was a prospective study that used 31,000 employees aged 35-64 years, who worked at the London Transport Executive. When compared with bus drivers, conductors had half the rate of fatal CHD, but a similar rate of non-fatal CHD [44]. Similar results were found in subsequent prospective studies that examined whether drivers in the transportation industry had an increased risk of CVD [45]. More recently, several prospective cohort studies have reported inverse relationships between sitting time and CVD risk. For instance, among women from the Women's Health Initiative Observational Study, the relative risk of incident CVD over 5.9 years of follow-up was 1.68 (95% CI:1.07-2.64) for women who sat for more than 16 hours per day compared to women who sat for less than 4 hours per day [46]. Self-reported sitting time is also detrimentally associated with waist circumference, body mass index (BMI), systolic blood pressure, fasting triglycerides, HDL-cholesterol, 2 hour plasma glucose, and fasting insulin [47].

Adults in most Western countries spend large amounts of their days engaging in sedentary activities, particularly those who are employed in sedentary occupations [29]. Low movement at work is a significant risk factor for abdominal obesity in adults [48]. Data from the National Human Activity Pattern Survey showed that common sedentary activities, when ranked by percentage of waking hours, were driving a car (10.9%), office work (9.2%), performing various activities while sitting quietly (5.8%) and eating (5.3%) [45]. A limited amount of research has explored differences between different types of sedentary behaviour on health. In one study, interactive sedentary behavior (driving and

computer use), but not non-interactive sedentary behavior (television viewing) was associated with a higher risk of hypertension [49].

To date, the most widely studied sedentary behaviour in relation to cardiometabolic risk has been self-reported time spent watching television [45]. In the Nurses' Health Study, a prospective cohort study of over 60,000 women, television watching was associated with significantly elevated risk of obesity and type 2 diabetes after 6 years of follow-up [50]. The relative risk of obesity was almost double (RR=1.94, 95% CI:1.51-2.49) and the risk of type 2 diabetes was 70% higher in those watching more than 40 hours of TV per week, compared to those who watched less than 1 hour per week. Within the Australian Diabetes study, television viewing was associated with waist circumference, systolic blood pressure, and 2 hour plasma glucose in a dose-response pattern [51]. In a large study assessing weight loss maintenance, weight loss was highly associated with avoidance of television viewing, independent of MVPA [52]. A recent systematic review of longitudinal studies reported that self-reported sedentary behaviour was associated with weight gain from childhood to adulthood, but that findings were mixed for associations of weight gain and cardiometabolic risk during adulthood [53].

Although screen-time behaviour provides a convenient measure of a specific sedentary behaviour, it does not capture total sedentary time [4,54]. This was demonstrated in a recent study conducted by Clark et al. who found that even though screen time was positively associated with objectively measured total sedentary behaviour as assessed by accelerometer, the correlations were weak (r=0.22) [35]. The first study to objectively measure sedentary behaviour was done in 1967 using gravity-

activated stop watches that were attached to the legs of subjects. It was found that lean individuals stood 3.5 hours per day more than obese individuals [55]. Accelerometer-collected sedentary time has also been shown to be associated with 2 hour plasma glucose, waist circumference and MetS in middle-aged Australian adults [56]. In a 3 year study among ~500 subjects, sedentary time, as measured by accelerometers, was found to be an independent determinant of carotid wall thickness, a result of inflammation of the heart's arterial wall [57]. A meta-analysis including 10 cross-sectional studies that used both subjective and objective measurements of sedentary time found that greater time spent sedentary increased the odds of the MetS by 73% (OR=1.73, 95% CI:1.55-1.94) [58]. This meta-analysis included results from the first population-representative findings from a large national study that used accelerometer data which reported detrimental, linear associations of total sedentary time with all the individual components of the MetS and C-reactive protein, an inflammatory marker [38].

There is a lack of prospective studies that assess cardiometabolic health using objective measures of sedentary time [53]. Only three studies have used device measures when investigating prospective relationships with health outcomes [53]. The first study used accelerometry and found no relationship between sedentary time and insulin resistance after 1 year of follow-up [59]. The second study used heart rate monitoring and found that sedentary time predicted higher levels of fasting insulin [60] after 5.6 years of follow-up. The third study also used heart rate monitoring and found that BMI, fat mass, and waist circumference predicted sedentary time but that sedentary time did not predict future obesity [61].

Aside from the effects of total sedentary time, the manner in which it is accumulated, or the patterns of sedentary behaviour may also be important. Although groups may exhibit similar duration of sedentary time, their patterns of sedentary behaviour are different [62]. Independent of MVPA, a higher number of "breaks" in sedentary time (as distinct from overall volume of sedentary time) were found to be beneficially associated with factors suggesting risk for MetS and cardiovascular disease including, waist circumference (OR=0.85, 95% CI:0.73-0.98), body mass index (OR=0.83, 95% CI:0.70-0.98), triglycerides (OR=0.84, 95% CI:0.71-0.98), and 2-hour plasma glucose (OR=0.84, 95% CI:0.71-0.98) [38,63].

Several pathways may explain the relationship between sedentary behaviour and cardiometabolic risk factors. The most obvious explanation is that sedentary behaviour reduces energy expenditure, which in turn is related to weight gain. However, sedentary behaviour may also induce energy intake stimulated by TV viewing. TV viewing is negatively associated with fruit consumption and positively associated with the consumption of energy-dense snacks, fast food, and energy-dense drinks among adults [64].

Recent research has studied the biological mechanism through which sedentary behaviour leads to cardiometabolic risk. Loss of contractile stimulation induced through sitting leads to suppression of muscle lipoprotein lipase (LPL) activity and reduced glucose uptake [6,65]. LPL is necessary for triglyceride uptake and beneficial high-density lipoprotein (HDL) cholesterol production. This evidence came from a study that was conducted among rats when sedentary behaviour was induced. When rats were suspended by their tail to prevent them from bearing weight on their lower limbs,

intracellular LPL activity in lower-limb skeletal muscle was reduced by more than 25% after just six hours, and continued to decrease with a 75% reduction in LPL activity after 18 hours. The study also found that the concentration of plasma HDL cholesterol decreased dramatically and lasted over many days [65]. A similar study conducted by Hamburg et al. examined the effects of 5 days of complete bed rest on metabolic health in 22 healthy adult volunteers. Participants remained in bed for over 23.5 hours per day, rising only for matters of personal hygiene. Although participants did not experience changes in body weight, they experienced significant changes in total cholesterol, plasma triglycerides, and glucose and insulin resistance [66]. These results support the finding that LPL is suppressed when muscles are not stimulated. It also proves that physiologically, unique effects have been observed between prolonged sedentary time and too little physical activity [6].

One area of sedentary behaviour research that is currently lacking is the effect of sleep duration on the sedentary behaviour-cardiometabolic risk relationship. Sleep duration and sedentary behaviour are usually studied separately, although literature suggests they may be related [33] and may together influence obesity [67,68]. This is an important limitation given that some studies among children and adolescents point towards screen-time as being a potential effect modifier for the sleep-obesity relationship and indicate that there is biological evidence for the sleep-sedentary behaviour relationship [33]. Other studies that assessed TV viewing have found that the sleep-obesity relationship could not be explained by it [69]. Regardless, a common behaviour that accompanies night-time TV viewing is high-energy snack and beverage consumption [33]. Therefore, being awake at night may predict several unhealthy behaviours which

warrant further study. The evidence on this topic is limited, and has mainly been conducted in a younger population. Future studies would benefit from examining the simultaneous effects of sleep duration and sedentary behaviour on cardiometabolic risk in adults.

2.5 Sleep duration as it relates to sedentary behaviour

This section will focus on the relationship between sedentary behaviour and sleep duration. It begins by discussing how sleep duration has been measured in the past, and outline the gaps that currently exist in its measurement. It then examines the cardiometabolic outcomes associated with insufficient sleep, and how sedentary behaviour may be involved through various mechanisms. Other potential biological mechanisms that may influence sleep's effect on cardiometabolic health are also covered.

2.5.1 Measurement of sleep duration

Sleep duration is most commonly measured through subjective measures such as self-report questionnaires or sleep diaries [70]. Although there is evidence that individuals with sleep disorders have difficulty assessing their own sleep patterns, the gold standard of sleep measurement is not always practical since it requires individuals to sleep in research laboratories. This gold standard is called polysomnography (PSG), [70] which is a test used to diagnose sleep disorders by recording brain waves, oxygen levels, heart rate, breathing and movement during sleep [71].

Wrist actigraphy, or wrist-worn accelerometers, are another commonly used method of assessing sleep duration, and are feasible for large populations since they are

lower-cost and minimally invasive. Wrist actigraphy can assess sleep-wake states through wrist movement, and allows participants to record the time they went to sleep, and the time they got out of bed each morning. The wrist actigraph then calculates an actual "sleep start" and "sleep end" time to determine the actual sleep time determined by the sleep algorithm within the device [72]. It also provides sleep and wake bout information which can be useful for determining how many times the individual woke up during the night. A limitation of wrist actigraphy is that it cannot distinguish sleep from inactivity or night-time restlessness during sleep from night-time awakening [70]. One study measured sleep using 3 days of wrist actigraphy, a sleep log and a questionnaire about sleep duration. They found that on average, subjects over reported their sleep by 0.80 hours. The overall correlation between self-report and objective sleep duration was modest with a correlation coefficient of 0.45 [73].

Finally, a less commonly used method to assess sleep duration is accelerometry [74]. Although accelerometry is not the ideal method, it is less sensitive to limb movements [75]. To my knowledge, only two other studies have assessed sleep duration using a uniaxial waist accelerometer. One study determined sleep duration by recording accelerometry counts between 8 p.m. to 8 a.m. among adolescent girls. [74]. The other recorded the longest period of nonwear time in a 24-hour period between two valid days among children [76].

2.5.2 Interrelationships among sleep, sedentary behaviour, and cardiometabolic risk

The notion that loss of sleep influences waking behaviours (e.g. food intake, sedentary behaviour, and MVPA) that ultimately lead to metabolic risk is currently under

much debate [77]. One might expect shorter sleep duration to be associated with higher energy expenditures, resulting in lower weight status. However, evidence suggests an inverse relationship among both adolescents and adults.

The first indication that sleep curtailment had negative effects on metabolic function was from a study conducted on 11 young men after their time in bed was restricted to 4 hours per night for 6 consecutive nights. The rate of glucose clearance after injection was 40% slower in this sleep-debt period compared to the previous 3 night sleep-sufficient period (8 hours of sleep) [24]. In a cross-sectional study of 1,214 adult participants, the odds for having the MetS increased by 45% in short sleepers compared with those sleeping 7-8 hours per night [78]. A meta-analysis including 604,509 adults from around the world found a pooled odds ratio of 1.55 (95% CI:1.43-1.68) for the sleep-obesity relationship and that a reduction of one hour of sleep per day would be associated with a 0.35 kg/m^2 increase in the BMI [79]. This is equivalent to 3 pounds in a person of average height.

Very few prospective cohort studies have assessed the sleep-obesity relationship. Two of these studies reported that the relationship weakened with increasing age [22]. One longitudinal study in adults found that short sleep contributed more to obesity than did other well known risk factors such as MVPA and high dietary fat intake [80]. They also found that insufficient sleep combined with high disinhibition eating behaviour and low dietary calcium intake contributed more to the risk of obesity (OR=6.05, 95% CI:4.26-7.88) than did high fat intake and non-participation in high-intensity physical activity (OR=2.95, 95% CI:2.18-3.73) [67]. Another longitudinal study found associations between short sleep duration (≤5 hours/night) and increased risk of

hypertension (HR 2.10, 95% CI=1.58-2.79), and controlling for confounders only attenuated the relationship [81].

Short sleep is thought to alter bodily mechanisms that ultimately lead to obesity by reducing energy expenditure [82]. Firstly, sleep restriction may impact energy expenditure by leading to feelings of fatigue, thereby reducing the amount of voluntary MVPA [82]. Secondly, short sleep can cause tiredness throughout waking hours, which may lead to more screen-time behaviours or overall sedentary behaviour, ultimately leading to increased weight or obesity [22]. This explanation has been proven more in pediatric and adolescent studies. In children under 13 years, parent-reported sleep duration was highly negatively correlated with screen time (r=-0.144, p=0.011) [83]. However, another study found sleep decreased as hours of computer use, and not TV use, increased. Students who used the computer for 3 hours per night had a lower odds of sufficient sleep (OR=0.55, 95% CI =0.42-0.72) compared to those who did not use the computer [84].

Only a few controlled experiments have tested the effect of short sleep on the amount and intensity of everyday activity [77]. A crossover randomized trial including 15 healthy, normal-weight men, were exposed to 2 nights of regular sleep (8 hours) followed by 2 nights of restricted sleep (4 hours). Their total physical activity was assessed through accelerometry. Activity counts were distinctly lower after the 4-hour sleep than after the 8 hour sleep (p=0.02) [85]. However, a similar crossover study found opposite results, with activity counts being higher after sleep restriction, and food intake increasing [86]. An interventional study among healthy adults with an immediate family history of type 2 diabetes measured sleep objectively through wrist actigraphy instead of

accelerometry. Participants were enrolled in a randomized crossover experiment. Those who slept 5.5 hours/night vs. 8.5 hours/night were on average 21 minutes more sedentary per day (p=0.02). Additionally, total activity counts were 31% lower (p=0.02) in the short sleep group. This decrease in daily activity counts was most prominent in participants who exercised regularly [87]. This study informs the need for more interventional research using objective measures on the relationship between sleep and activity, and suggests the need to look at MVPA as an effect modifier. However, a review paper summarizing the sleep-weight associations stated that none of the studies that assessed physical activity found differences in activity could explain the sleep-weight association. Interpreting these studies is difficult because they did not fully take place under free-living conditions. Having sleep monitored in a laboratory environment is seen as artificial and may not truly represent an individual's sleep patterns and behaviours.

One naturalistic study that assessed the sleep-sedentary behaviour relationship did so using wrist actigraphy and waist accelerometry while following participants' normal lifestyle at home [72]. In these adults with parental history of type 2 diabetes, those who slept less than 6 hours per night had 27% fewer daily activity counts and accumulated 69 minutes per day more sedentary time (p=0.026) [72]. Therefore, the cross-sectional evidence on this topic is inconsistent and warrants further research.

A longitudinal study using an objective measure of sleep, involving 612 participants who were assessed at baseline and a 5 year follow-up period using wrist actigraphy [88], found that sleep duration was unrelated to future weight gain. These longitudinal results suggest that assumptions about the direction of the sleep-obesity

relationship cannot be confirmed until further research using longitudinal objective measures has been conducted.

Although sleep duration may affect energy expenditure, most of the available evidence suggests that its effect is much stronger on energy intake. Several review papers have summarized studies that assessed energy intake as a possible mechanism for the sleep-obesity relationship [69,77,89–91]. The most obvious explanation for this relationship is that shorts sleepers have increased time and more frequent opportunities to eat, simply because they are awake for longer hours. This may be especially true if those extra hours are used to watch TV, which encourages passive overconsumption of high-energy foods [68]. One cross-over study found that within a 2 week period, the sleep-restricted condition caused participants not to consume more calories during meals, but rather to increase snacking at night when they would be sleeping in the regular-sleep condition [92]. Short sleep may also increase the risk of weight gain and obesity through appetite up-regulation. In some studies, insufficient sleep has been reported to decrease leptin (satiety hormone released primarily from adipocytes or fat cells) levels and increase ghrelin (hunger hormone released primarily from the stomach) levels, and alter glucose metabolism. In the Quebec Family Study, the sleep-weight association disappeared after adjusting for leptin, indicating that leptin may be on the causal pathway [93].

Finally, studies assessing sleep patterns have generally focused on sleep duration. However, recent evidence points to sleep timing as being just as important. Cross-sectional studies have shown that children and young adults who go to bed early and wake up early (also known as morningness) tend to have lower BMIs than children

who sleep late and wake up late [94,95]. A possible explanation of this is that morningness is positively associated with dietary restraint and negatively association with perceived hunger [95]. In adults, late sleepers (as measured by wrist actigraphy) consumed on average 248 more calories per day when compared to normal sleepers, with the majority of those calories being consumed after dinner time [96].

2.6 Thesis Rationale

Sedentary behaviour is gaining significant attention as a valid area of study in physical activity epidemiology. Naturally, engaging in more light-intensity activity (domestic tasks, casual walking) would reduce sedentary time, however, sedentary behaviours have not been addressed specifically in Canadian and American recommendations in the adult population [8]. Like sedentary behaviours, sleep is an activity characterized by a prolonged period of reduced energy expenditure. Yet, it seems to have protective effects on cardiometabolic health. These differences suggest that, from a public health standpoint, if an individual is going to spend time engaging in screen time behaviours, they are better off taking a nap [97].

Previous studies assessing the sedentary behaviour-disease relationship in adults have typically controlled for age, gender, ethnicity, education, employment status and physical activity [98]. However, to my knowledge, none have controlled for sleep duration. The goal of this thesis is to use objective measurements of sleep duration and sedentary time to determine whether they are related and if both, one or none are associated with the MetS.

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Chapter 3

Interrelationships among sedentary behaviour, short sleep and the metabolic syndrome in adults

ABSTRACT

Introduction: Sedentary behaviour is gaining attention as an important cardiometabolic risk factor. Studies of sedentary behaviour and cardiometabolic risk have not considered sleep duration, although there is evidence that sleep duration may be related to both sedentary behaviour and cardiometabolic risk. The purpose of this study is to determine if sedentary behaviour is related to the metabolic syndrome (MetS) while controlling for sleep duration.

Methods: This cross-sectional study is based on the 2003-2006 National Health and Nutrition Examination Survey. A sample of 1371 adults over the age of 20 were studied. Average daily sedentary time and sleep duration were determined via 7-day accelerometry. Screen time was determined via questionnaire. The MetS was determined using standard criteria. Analysis of variance was used to examine relationships among sedentary time and screen time with sleep duration. Multiple logistic regression was used to examine associations between total sedentary time, screen time, and sleep duration with the MetS after controlling for several covariates.

Results: Sedentary time and screen time did not vary across the sleep quartiles (p=0.08 and p=0.87, respectively). Participants in the highest quartile of sedentary time were significantly more likely to have the MetS than participants in the lowest quartile (odds ratio=1.60, 95% CI:1.05-2.45). The odds of the MetS was higher in participants in the highest screen time tertile as compared to the lowest tertile (odds ratio=1.67, 95% CI:1.13-2.48). Sleep duration was not independently related to the MetS.

Conclusion: Highly sedentary individuals and individuals with a high screen time are more likely to have the MetS.

INTRODUCTION

Sedentary behaviour, or time spent sitting or lying while awake, is gaining increased attention as an important determinant of health [1–3], independent of moderate-to-vigorous physical activity (MVPA). The first population-representative findings on the negative associations of prolonged sedentary time with biomarkers of cardiometabolic health came from a study that used an objective measure of sedentary time in a large sample of U.S. participants [4]. The results of that study indicated that sedentary time is associated with waist circumference, HDL-cholesterol, C-reactive protein, triglycerides, and insulin [4]. As reviewed elsewhere, several other studies have confirmed these observations [5].

Research on the determinants and correlates of sedentary behaviour is still in its infancy, particularly in the adult population. Among adolescents, several studies have shown that sedentary behaviours such as T.V. watching and computer use are associated with short sleep duration [6–8]. Furthermore, consistent evidence indicates that short sleep duration is positively associated with weight gain and obesity among children, while this evidence is more mixed among adults [9]. Based on these findings, sleep duration may be related to both sedentary behaviour and the metabolic syndrome (MetS), making it a variable worth controlling for in analyses exploring the association between sedentary behaviour and cardiometabolic risk. However, to date sedentary behaviour research has not considered sleep duration. Therefore, the purpose of this study is to examine the interrelationships among sedentary behaviour, short sleep, and the MetS.

METHODS

Overview of Study Design and Measures

Study data are from the 2003-2004 and 2005-2006 cycles of the U.S. National Health and Nutrition Examination Survey (NHANES). NHANES was conducted by the National Centre for Health Statistics of the Centers for Disease Control and Prevention. NHANES is a nationally representative cross-sectional study that assesses the health of adults and children. It combines interviews, physical examinations and laboratory tests that take place in a home interview and mobile examination center (MEC) visit. NHANES uses a complex, multistage probability sampling design to select participants representative of the civilian U.S. population. Essentially, the NHANES sampling procedure consists of four stages. Firstly, primary sampling units are selected, usually counties or groups of small counties. Counties are then divided into segments, households and individuals which are randomly selected [10]. Sampling weights were applied from the NHANES MEC weights to reflect the unequal probability of participation among certain demographic groups. These sample weights were used to produce an unbiased national estimate. Appendix D provides more detail on the NHANES study design and methods.

The NHANES study was approved by the U.S. National Center for Health Statistics Research Ethics Review Board and participants provided informed consent. Ethics approval for the secondary analysis conducted for this thesis was obtained from the Queen's University Health Sciences Research Ethics Board (Appendix A).

Participants

The present study was limited to non-pregnant adult (aged ≥20 years) participants without chronic disease (cancer, diabetes, coronary heart disease, stroke, chronic bronchitis and emphysema) who comprised the morning fasting subsample. Of the 3373 participants who met these eligibility criteria, 191 were excluded because they were missing one or more components of the MetS, 1462 were excluded because they did not have valid accelerometer data for the sedentary behaviour and sleep duration measures, and 349 were excluded because they were missing one or more of the covariates. Thus, the final sample consisted of 1371 participants. Figure 3.1 displays how participants were lost in the study. Although many participants were lost in the study because they failed to meet the eligibility criteria, only 6% of participants who were in the morning subsample were lost because they did not have sufficient outcome (MetS) information. Therefore, since less than 10% of the data for the main outcome variable was missing, it was acceptable to continue the analysis without further evaluation or adjustment [11]. Participants who were excluded from this study were similar in age (51 vs. 49 years) and ethnicity (52% vs. 54% non-Hispanic white) to those who were included. However, more females than males were excluded (56% vs. 50% male), which is partly explained by the fact that 330 pregnant women were excluded.

Sedentary behaviour duration

Sedentary behaviour was measured using raw data provided by the uniaxial Actigraph AM-7164 accelerometers. Accelerometers are small electronic devices generally worn on the hip which allow detailed, minute-by-minute data on the volume, intensity, duration and frequency of most movement between and within days, which

may be downloaded to computer databases and used to derive meaningful activity pattern variables [12]. Accelerometers provide a reliable and valid measure of sedentary behaviour. When assessed against the activePAL, a waterproof triaxial inclinometer that can differentiate between sitting and standing, correlations of sedentary time were relatively high (r=0.76) [13].

Participants were given the accelerometer at the MEC visit and instructed to wear it for the following 7 days over their right hip using the elastic belt provided, and to remove the monitor before going to bed and during showers, bathing, and swimming. The accelerometers were programmed to record activity at 12:01 a.m. the day after the MEC visit and provided 10,080 consecutive minute-by-minute movement data points (e.g., one data point for each minute of the week). Accelerometers were returned by mail in postage-paid padded envelopes that were provided. Participants received $40 remuneration after their monitors were returned [14].

The first stage of accelerometer data cleaning was conducted by NHANES survey collaborators who removed outliers or biologically implausible values. The remaining data cleaning and reduction was completed by the authors using criteria published in the literature [15]. Initially, periods of nonwear time were removed. Nonwear time was defined as an interval of at least 60 consecutive minutes of zero activity intensity counts, with allowance for 1–2 min of counts above 0 [15]. In the next step, days that were invalid were removed. A valid day was defined as a day with more than 10 hours of wear time [15,16]. The next step was to remove participants with an insufficient amount of days with valid data. Only those who had ≥4 valid days were included in the analysis [15,16].

Next, each minute of accelerometer data was defined as being sedentary or of a light or moderate-to-vigorous intensity using established cut-points. A given minute was considered "sedentary" if the accelerometer count value did not exceed the 100 counts per minute (cpm) threshold [4,17]. Counts ranging from 100-2020 were classified as light-intensity activity and counts of 2020 or higher were considered moderate-to-vigorous intensity [15]. Total sedentary time and time spend in light and MVPA were calculated for each valid day by summing the number of minutes, and then averaged across all valid days. Wear time was calculated by subtracting nonwear time from 24 hours. The proportion of total wear time that was sedentary was then determined. Sedentary time was expressed relative to wear time because although two individuals may have the same number of sedentary hours in a day, one individual might have worn the accelerometer for a longer period of time. There are no guidelines or recommendations indicating the quantity of total sedentary behaviour that is likely to confer a health risk. Therefore, the proportion of total wear time that was sedentary was divided into quartiles as following: Q1= 21.0-48.1%, Q2=48.2-56.5%, Q3=56.5-63.9%, Q4=64.0-90.7%. More detail on the accelerometry protocol and data cleaning is provided in Appendix E.

Screen time

The second exposure variable measured total screen time (including T.V., video, and computer use) using the interview questions, "Over the past 30 days, on average how many hours per day did you sit and watch TV or videos?" and "Over the past 30 days, on average how many hours per day did you use a computer or play computer games?" There were 7 response options for each question: 0 hours, less than 1 hour, 1 hour, 2

hours, 3 hours, 4 hours, and 5 or more hours. TV and computer time were summed to create an overall screen time score. Screen time was then divided into tertiles. Tertiles were chosen instead of quartiles since a large proportion (approx. 46%) of participants reported 2 hours of screen time per day. The range of screen time (hours/day) for each tertile is as follows: T1= 0-1, T2=2, T3=3-6. Questionnaires measuring T.V. usage, such as the NHANES questionnaire, are moderately correlated with T.V. time measured by a detailed log (r=0.47) [18].

Sleep Duration

While studies have typically used self-report questionnaires to gather sleep duration data, recent evidence suggests that self-report data and sleep actigraphy are poorly correlated and are systematically biased [19,20]. A possible explanation for this is that people cannot accurately report how much they sleep on a single night and/or that an individual's sleep patterns vary from night to night [20]. Therefore, in this study sleep duration was estimated using an objective proxy measure. Using data gathered from accelerometry, the longest period of nonwear time in the 24-hour period between 12:00 noon on two valid days was used as a proxy for sleep duration. The same criteria as explained above under sedentary behaviour were used to define nonwear time periods and valid days. Only those who had ≥2 valid sleep night periods were included in the analysis. The criteria for having ≥ 2 valid sleep nights was determined by examining the correlation between the sleep duration proxy measures from participants who had complete (6 nights) sleep data. These analyses revealed the flowing correlations with the average sleep duration obtained over 6 nights: r=0.77 for one randomly chosen night, r=0.84 for two randomly chosen nights, r=0.93 for three randomly chosen nights, r=0.95

for four randomly chosen nights, and r=0.98 for 5 randomly chosen nights. Because the correlation for 2 nights (r = 0.84) is considered "very strong" according to the standard correlation criteria [21], and because there was a large drop in sample size with ≥2 nights of valid data vs. ≥3 nights of valid data (n=1371 vs. n=984), ≥2 nights was chosen as the criteria.

The average proxy sleep duration was calculated by averaging the sleep duration across the number of nights with valid data and then divided into quartiles as follows: Q1= 3.0-7.2 hours/night, Q2=7.2-8.6 hours/night, Q3=8.6-9.7 hours/night, Q4=9.7-11.8 hours/night. Extreme sleep duration observations (below 2nd and above 98th percentile) were deleted since they were numerically distant from the rest of the data (causing an abnormal distribution), and were thought to inaccurately represent sleep duration as they were outside the physiological range of sleep duration times. These values could have resulted from participants removing their accelerometer before bed or a temporary error with the accelerometer device that can cause high count values to sporadically occur [22].

Metabolic syndrome

Participants were classified as having the MetS using standard criteria [23] based on having three or more of the following five risk factors: high waist circumference (≥94 cm in men, ≥80 cm in women), high triglycerides (≥150 mg/dL), low HDL-cholesterol (<40 mg/dL in men, <50 mg/dL in women), high blood pressure (systolic ≥130 mmHg or diastolic ≥85 mmHg or medication use), and high blood glucose (≥100 mg/dL or presences of diabetes or medication use).

All MetS data were taken by trained technicians during the MEC visit. Waist circumference was obtained to the closest 0.1 cm using a flexible tape at the level of the

iliac crest while the participants were standing. Prior to measuring blood pressure, participants rested quietly in a seated position for 5 minutes. Then, four consecutive manual blood pressure readings were obtained from the right arm using a manual mercury sphygmomanometer. Blood pressure measurements were averaged for each participant. Blood was drawn from an antecubital vein of the left arm following an overnight fast [24]. HDL-cholesterol was measured through a direct HDL immunoassay method (Roche/Boehringer-Mannheim Diagnostics) [25], glucose was measured through the hexokinase-mediated reaction using the Roche Cobas Mira analyzer in 2003-2004 and the Roche/Hitachi 911 analyzer in 2005-2006, and triglycerides were measured enzymatically in serum using a series of coupled reactions using the Beckman Synchron LX20 analyzer in 2003-2004 and the Hitachi 717/912 analyzers in 2005-2006 [25]. The presence of physician diagnosed diabetes (other than gestational diabetes) and medication use for diabetes and hypertension were assessed in the interview.

Covariates

Age, gender, ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, other), education level (less than high school, high school graduate, college graduate), socioeconomic status (SES), smoking status (never, former or current), alcohol consumption, caffeine consumption, and physical activity were considered as covariates. SES was assessed using the poverty-to-income ratio, as provided within the NHANES dataset, which is a ratio between family income and the poverty threshold [26]. Caffeine consumption was assessed using a 24-hour food recall. The food recall was assessed in a dietary interview room of the MEC which contained a set of measuring guides. These tools were used to help participants recall the volume and dimensions of food and drink

consumed (i.e. estimate portion size) [27]. The recall data was analyzed using the Food and Nutrient Database for Dietary studies, which contains the weight, in grams, for common portions of food and drink and converts them into nutrient values [27]. Those who consumed more than 250 mg/day of caffeine were considered high caffeine users [28]. Alcohol consumption was assessed by asking participants how many drinks they consume per week. Females who consumed more than 7 drinks per week and males who consumed more than 14 drinks per week were considered excessive alcohol users [29]. Finally, MVPA was assessed by accelerometry as previously described. Mean duration of MVPA per day accumulated in bouts of at least 10 minutes was calculated for all participants and three categorical groups were created: no bouts of MVPA, some MVPA (up to 75 minutes/week), and at least 75 minutes/week of MVPA. These cut points are based on half of the minimum physical activity requirements set by the CDC [30]. A summary of the NHANES variables used in the thesis are provided in Appendix B. The specific NHANES questionnaire items used in the thesis are provided in Appendix C.

Statistical Analysis

All data were analyzed using the SAS 9.2 Software (SAS Inc., Cary, NC) and took into consideration the complex survey design and sample weights. There was sufficient power to detect a meaningful effect in this study. These calculations are provided in Appendix F. Descriptive statistics were used to determine baseline characteristics of the study population. PROC UNIVARIATE for continuous variables and PROC FREQ for categorical variables were used to determine differences in descriptive statistics. Relations between sedentary behaviour and sleep variables were determined using Pearson correlations. ANOVA using the PROC GLM and GLIMMIX

procedures were used to explore the relationship between sleep duration with the proportion of total wear time that was sedentary and screen time. Multiple logistic regression, using PROC LOGISTIC, was performed to examine the relationship between sleep duration and the sedentary behaviour variables with the MetS and its individual components. To adjust for potential covariates, the backward deletion according to change in estimate criteria approach was used [31]. Therefore, after starting with a full model of all covariates, potential confounders that did not change the risk estimate for the MetS by more than 5% were removed in a stepwise fashion. Two regression models (the proportion of total wear time that was sedentary, and screen time as the independent variables; the MetS as the dependent variables) were run for each analysis, with sleep duration consistently being included in each model. The first model was a univariate model. The second model that was run adjusted for all the covariates discussed above (bivariate). The use of interaction terms assessed whether sleep had a moderating effect on the sedentary behaviour-MetS relationship, in order to determine if this relationship was stronger in any of the sleep duration groups.

RESULTS

Descriptive characteristics

Participant characteristics are in Table 3.1. Of the 1371 participants, approximately 56% were male and the mean age was 48.7 years. Overall, 56.2% of total accelerometry wear time was spent in sedentary behaviour. The proxy sleep duration was 8.34 hours per night. Participants watched 2.24 hours/day of television and used the computer for 43.5 minutes/day, for a total of 2.29 hours/day of screen time. The cross

tabulation frequency of each covariate measure was presented according to the three exposures (screen time, sedentary time and sleep duration). These results are in Table 3.2.

Relationships between sedentary behaviour and sleep duration variables

Total sedentary time and screen time were poorly correlated (r=0.18). Sedentary time and screen time were poorly correlated to sleep duration (r=0.04 and r=0.004, respectively). As shown in Table 3.3, sedentary time and screen time means did not vary across the sleep duration quartiles (p=0.08 and p=0.87, respectively).

Relationship between sedentary behaviour and sleep duration with the MetS

Of those participants who accrued the most screen time, 44.1% had the MetS. Conversely, only 29.3% in the lowest screen time tertile had the MetS. Of the most sedentary participants, 45.9% had the MetS; only 32.4% in the lowest sedentary behaviour quartile had the MetS. There was no trend in the prevalence of the MetS across sleep duration groups (Table 3.4).

After adjusting for relevant confounders (age, education level, MVPA) and sleep duration, the relative odds of the MetS was higher in participants in the highest sedentary behaviour quartile by comparison to participants in the lowest quartile (odds ratio (OR)=1.60, 95% confidence interval (CI): 1.05-2.45). A positive relationship was also observed with screen time such that the odds ratio of the MetS was higher in participants in the highest screen time tertile as compared to the lowest tertile (OR=1.67, 95% CI:1.13-2.48). Sleep duration was not related to the MetS in the bivariate or multivariate logistic regression models. There were no significant sedentary behaviour X sleep duration interactions in any of the models.

Relationship between sedentary behaviour and sleep duration with the MetS components

As shown in Table 3.5, sedentary behaviour and screen time were significantly associated with a high waist circumference, high triglycerides, and a low HLD-cholesterol (sedentary time only). The associations between sleep duration and the MetS components were weak and non-significant. There were no significant sedentary behaviour X sleep duration interactions in any of the models.

DISCUSSION

This study examined associations between objective measures of sedentary time and sleep duration with the MetS in adults. There were moderate associations between sedentary time and screen time with the MetS; however, sleep duration was not associated with the MetS.

Results from this study indicate that the average adult spends over half of their waking hours being sedentary. Adults who spend between 65-90% of their day sedentary were more likely (OR=1.60, 95% CI:1.05-2.45) to have the MetS than those who spent less than 48% of their day sedentary. This result is consistent with a previous study that used the NHANES dataset [4], and with several other cross-sectional studies that report moderate associations [5]. Additionally, the strongest associations with sedentary time were observed for waist circumference and triglycerides, rather than for blood pressure and plasma glucose, which is consistent with previous evidence [4]. The strong

associations with waist circumference could be explained through an energy expenditure pathway. Since skeletal muscle eliminates triglycerides and does not contract during sedentary behaviour, this could explain the strong associations with triglycerides [1].

Adults who spent more than 3 hours per day in front of TV and computer screens were at increased odds (OR=1.67, 95% CI:1.13-2.48) for having the MetS compared to those who spent less than 1 hour per day, which is also consistent with previous literature reporting moderate associations [32]. These findings are important because they provide context to the type of sedentary behaviour that is likely to confer a health risk. Futures studies would benefit from examining other types of sedentary behaviour outside of screen time since little is known about the health impact of non-screen based sedentary behaviour and because different sedentary behaviours may require distinct interventions.

Sleep duration was unrelated to sedentary time, screen time, and the MetS. However, there was a borderline positive association with sleep duration and waist circumference, which is consistent with recent evidence indicating that short sleep is associated with abdominal adiposity [33] and that the relationship wanes with age [9]. Although previous studies examining this relationship found stronger associations with sleep duration and obesity, most of them have relied on self-report methods to capture sleep duration. If the misclassification associated with self-reported sleep duration measures is differential, that could explain the different results. Future studies should considering control for obstructive sleep apnea (OSA), which may be a significant confounder, and should explore relationships with sleep onset timing rather than sleep duration, since timing is a factor that is related to unhealthy eating behaviours [34], circadian rhythm disruption, and melatonin suppression [35].

Although it is still unclear how much sedentary time leads to an increased health risk, this study has shown a monotonic relationship, with more sedentary time leading to an increased odds of the MetS. Therefore, time spent engaging in sedentary behaviour is significant, even if the only plausible explanation is that it displaces time spent in light-intensity physical activity, leading to a reduction in overall energy expenditure [12]. Even substituting 2 hours/day of sedentary behaviour (1.5 METS) by very light-intensity activity (2.5 METs) would be the equivalent of a 30 minute brisk walk [12]. A recent randomized control study showed the significant impact of making this simple substitution. Adults who participated in a TV commercial stepping program (replaced sitting screen-time with light-intensity physical activity) had significant decreases in their percent body fat and waist circumference over a 6 month period [36]. Altogether, this evidence has important implications for future public health initiatives and interventions. A next step would be to identify what factors lead to excessive sedentary behaviour, as the determinants of sedentary behaviour have not been studied extensively [37].

An important strength of this study is that sedentary behaviour and sleep was measured objectively. Additionally, we used waist circumference, which has been shown to explain obesity-related health risk to a greater extent than BMI [38]. Our study has several limitations. Firstly, temporal associations could not be determined due to the cross-sectional nature of this study. Also, measurement bias may have been present because of the use of self-reported data for many of the covariates and screen time. For example, residual confounding could have resulted from the inaccurate measurement of certain covariates (e.g. alcohol consumption was measured through questionnaire, which

may have not provided an accurate measure of true consumption). Also, the self-reported screen time exposure data may have led to non-differential or differential misclassification, and over- or under-estimating the true effect. There is also the possibility of misclassification on the basis of sleep duration and sedentary behaviour because of accelerometer device limitations. For example, if an individual were to remove the accelerometer while sedentary or delay their accelerometer wear after waking up, this could bias our results.

CONCLUSION

Time spent sedentary is related to cardiometabolic risk, independent of sleep duration, although prospective evidence is needed to confirm the direction of the relationship. Additionally, more prospective research using objective measures of sleep duration, timing, and quality are needed to explore the relationship between sleep and cardiometabolic risk.

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Figure 3.1 Exclusion flow chart

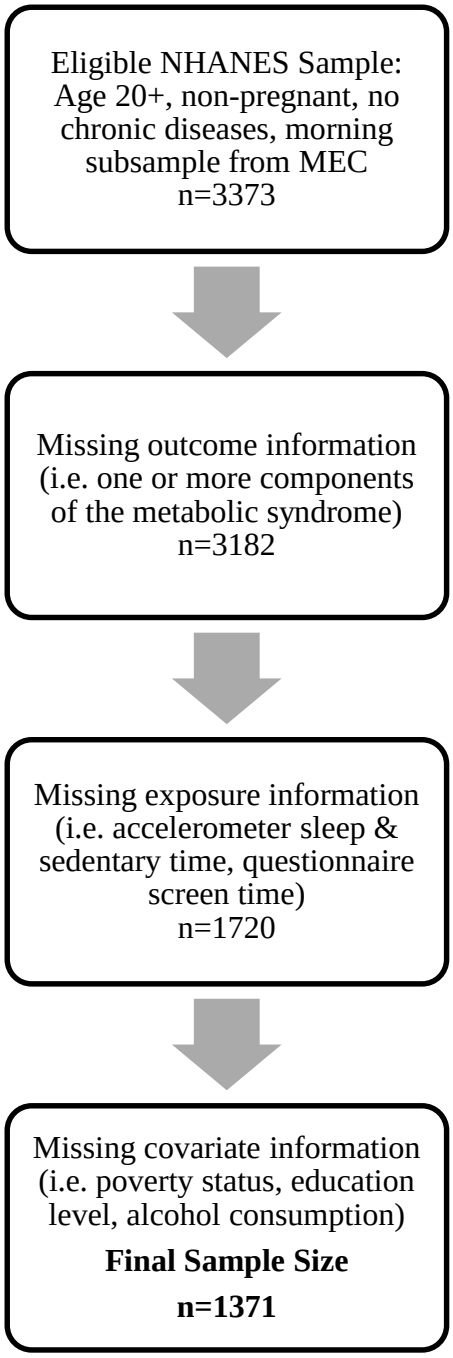

Table 3.1 Baseline characteristics of study sample

Characteristic	N=1371	Prevalence (%)	Mean (SD)
Demographic Factors			
Sex, Male	770	56.2	-
Age (years)			
20-39	451	32.9	-
40-59	523	38.2	
60+	397	29.0	
Ethnicity			-
Non-Hispanic white	738	53.8	
Non-Hispanic black	245	17.9	
Hispanic	334	24.4	
Other	54	3.9	
Education			-
< High school	313	22.8	
High school graduate	742	54.1	
College graduate	316	23.1	
Poverty level, below poverty	153	11.2	-
Behavioural Factors			
Caffeine consumption, >=250 mg/day	284	20.7	-
Smoking status			-
Never	669	48.8	
Former	404	29.5	
Current	298	21.7	
Alcohol consumption (drinks/week)			-
None	312	22.8	
Some	1040	75.9	
Excessive (7+ women, 14+ men)	19	1.4	
Sedentary Behaviour	-	-	
Screen time (hours/day)			2.3 (1.0)
% of total wear time that is sedentary			56.2 (11.3)
Sleep duration proxy (hours/day)			8.3 (1.9)
Moderate-to-vigorous physical activity (min/day)	-	-	7.0 (12.5)
Metabolic syndrome Factors			
Metabolic syndrome , yes	512	37.4	-
Waist circumference (cm), high	987	72.0	97 (14)
HDL cholesterol (mg/dL), high	418	30.5	55 (16)
Triglycerides (mg/dL), high	416	30.3	140 (113)
Glucose (mg/dL), high	521	38.0	99 (17)
Systolic blood pressure (mmHg), high	518	37.8	124 (17)
Diastolic blood pressure (mmHg), high	214	15.6	71 (11)

Table 3.2 Cross tabulation frequencies of covariates according to each exposure

	Screen time tertile				Sedentary Time Quartile					Sleep duration Quartile				
Characteristic	***T1***	***T2***	***T3***	***p-value***	***Q1***	***Q2***	***Q3***	***Q4***	***p-value***	***Q1***	***Q2***	***Q3***	***Q4***	***p-value***
Demographic Factors														
Sex														
Male	18.7	44.9	36.4	0.57	27.7	24.6	23.1	24.7	0.05	28.8	26.8	23.4	20.9	<0.0001
Female	18.2	47.7	34.2		21.6	25.6	27.5	25.3		19.5	22.7	27.2	30.6	
Age (years)														
20-39	17.1	47.2	35.7	0.13	32.8	23.1	25.5	18.6	<0.0001	29.0	25.9	24.6	20.6	0.01
40-59	20.5	47.6	31.9		29.6	28.1	22.0	20.3		24.1	26.9	26.4	22.6	
60+	17.5	42.8	39.8		10.1	23.2	28.5	38.3		21.7	22.0	23.6	32.7	
Ethnicity														
Non-Hispanic White	17.5	46.5	36.0	<0.0001	20.3	24.8	25.9	29.0	<0.0001	21.9	25.8	26.1	26.3	0.006
Non-Hispanic Black	14.7	37.1	48.2		20.8	27.8	26.1	25.3		35.0	25.8	18.8	20.4	
Hispanic	23.1	51.5	25.5		39.8	24.3	21.0	15.0		22.3	21.8	28.8	27.1	
Other	20.4	48.2	31.5		16.7	20.4	33.3	29.6		35.7	31.0	16.7	16.7	
Education														
< High school	25.1	38.6	36.3	0.0004	37.7	23.3	20.8	18.2	<0.0001	26.8	19.6	27.2	26.3	0.01
High school graduate	15.2	47.4	37.3		25.7	28.7	22.6	22.9		26.2	26.9	20.9	26.0	
College graduate	19.6	50.3	30.1		10.8	18.0	34.8	36.4		20.5	26.0	31.8	21.7	

Poverty level														
Below	24.2	37.3	38.6	0.04	32.0	27.5	16.3	24.2	0.03	28.3	19.8	24.3	27.0	0.50
Above	17.8	47.2	35.0		24.1	24.7	26.1	25.0		24.4	25.7	25.1	24.8	
Behavioural Factors														
Caffeine consumption														
<250 mg/day	19.2	45.8	35.0	0.43	25.9	24.9	24.6	24.6	0.47	24.0	24.7	25.3	26.0	0.37
>=250 mg/day	15.9	47.2	37.0		21.5	25.4	26.8	26.4		28.4	26.5	23.7	21.3	
Smoking status														
Never	20.8	47.9	31.3	0.0004	25.1	21.8	27.2	25.9	0.03	21.3	25.0	26.8	26.8	0.0002
Former	18.9	46.2	35.0		22.5	27.0	24.0	26.5		21.4	27.6	27.0	24.0	
Current	12.8	42.0	45.3		28.2	29.5	21.5	20.8		37.3	21.9	18.4	22.4	
Alcohol consumption														
None	20.3	45.0	34.7	0.5	19.6	31.4	20.5	28.5	0.003	26.7	16.8	26.3	30.2	0.02
Some	18.1	46.6	35.3		26.9	23.0	26.4	23.8		24.5	27.7	24.4	23.4	
Excessive	10.5	36.8	52.6		10.5	31.6	26.3	31.6		15.4	15.4	38.5	30.8	
MVPA														
None	17.2	43.1	39.8	0.004	19.0	24.7	26.2	30.2	<0.0001	22.6	23.0	25.5	29.0	0.08
Some	19.6	49.1	31.3		31.0	25.6	23.8	19.6		27.1	27.3	24.6	21.0	
Moderate	42.9	57.1	0		57.1	0	28.6	14.3		40.0	20.0	20.0	20.0	

Table 3.3 Means and adjusted means*of sleep duration groups according to sedentary behaviour variables

Sleep Duration Quartile	Screen time (hours/day)		% of total wear time that is sedentary	
	Mean (SD)	***Adjusted Mean* (SD)***	***Mean (SD)***	***Adjusted Mean *(SD)***
Q1 (shortest sleep)	2.35 (1.05)	2.40 (2.22)	56.05 (11.01)	57.72 (22.77)
Q2	2.30 (0.92)	2.41 (2.22)	58.13 (10.76)	57.36 (23.51)
Q3	2.30 (0.97)	2.47 (2.22)	57.59 (10.94)	56.57 (23.14)
Q4 (longest sleep)	2.35 (0.90)	2.50 (2.22)	57.91 (10.65)	56.23 (23.51)
p-value	0.87	0.87	0.13	0.08

*Adjusted for all sex, age, ethnicity, education, poverty level, caffeine consumption, alcohol consumption and MVPA

Table 3.4 Prevalence, ORs and 95% CI of Metabolic syndrome according to groups of sedentary behaviour and sleep duration

Exposure or Covariate	Prevalence, %	Univariate Model	Multivariate Model 1*	Multivariate Model 2**
Exposures				N/A
Screen time				
T1 (least screen time)	29.3	1.00 (ref)	1.00 (ref)	
T2	35.3	1.32 (0.96-1.81)	1.18 (0.81-1.72)	
T3 (most screen time)	44.1	1.91 (1.38-2.64)	1.67 (1.13-2.48)	
Sedentary time			N/A	
Q1 (least sedentary)	32.4	1.00 (ref)		1.00 (ref)
Q2	34.1	1.18 (0.80-1.76)		1.00 (0.66-1.51)
Q3	37.0	1.44 (0.98-2.1)		1.25 (0.83-1.89)
Q4 (most sedentary)	45.9	2.10 (1.44-3.06)		1.60 (1.05-2.45)
Sleep duration				
Q1 (shortest sleep)	34.1	0.86 (0.60-1.23)	0.90 (0.62-1.32)	0.91 (0.62-1.33)
Q2	37.4	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q3	35.6	0.93 (0.65-1.33)	0.89 (0.61-1.30)	0.89 (0.61-1.29)
Q4 (longest sleep)	39.8	1.12 (0.78-1.60)	0.97 (0.67-1.41)	0.95 (0.66-1.39)
¡ Confounders				
Age				
20-39 y	23.3	1.00 (ref)	1.00 (ref)	1.00 (ref)
40-59 y	37.1	2.24 (1.60-3.13)	2.29 (1.63-3.22)	2.23 (1.58-3.13)
60+ y	53.7	4.00 (2.82-5.67)	4.00 (2.81-5.71)	3.13 (2.16-4.54)
Ethnicity				N/A
Non-Hispanic white	39.2	1.00 (ref)	1.00 (ref)	
Non-Hispanic black	29.8	0.60 (0.42-0.87)	0.60 (0.41-0.88)	
Hispanic	38.0	0.96 (0.70-1.31)	1.10 (0.79-1.54)	
Other	42.6	1.45 (0.77-2.71)	1.55 (0.80-3.00)	
Education			N/A	
Less than high school	44.4	1.00 (ref)		1.00 (ref)
High school graduate	37.3	0.78 (0.56-1.07)		0.86 (0.61-1.21)
College graduate	30.4	0.61 (0.42-0.89)		0.69 (0.45-1.03)

Moderate-to-vigorous physical activity			N/A	
None	44.3	1.00 (ref)		1.00 (ref)
Some	34.7	0.54 (0.39-0.74)		0.70 (0.49-0.98)
Moderate	25.8	0.46 (0.33-0.64)		0.58 (0.41-0.81)
Remaining Covariates				
			N/A	N/A
Sex				
Male	40.5	1.00 (ref)		
Female	33.3	0.75 (0.58-0.97)		
Poverty level				
Below	43.8	1.36 (0.91-2.03)		
Above	36.5	1.00 (ref)		
Caffeine				
<250 mg/day	36.7	1.00 (ref)		
>=250 mg/day	39.8	1.18 (0.87-1.61)		
Smoking Status				
Never	35.1	1.00 (ref)		
Former	42.8	1.45 (1.08-1.95)		
Current	34.9	0.93 (0.67-1.30)		
Alcohol consumption				
None	45.2	1.52 (1.13-2.05)		
Some	35.1	1.00 (ref)		
Excessive	31.6	0.57 (0.16-2.08)		

*Model 1 includes screen time and sleep duration as the main predictors
**Model 2 includes sedentary time and sleep duration as the main predictors
¡ The backward deletion according the change in estimate approach was used to identify confounders. Covariates that changed the odds ratio for the main predictors and outcome by more than 5% were kept in the model

Table 3.5 ORs and 95% CI of metabolic syndrome components according to sleep duration and sedentary behaviour

Exposure	High Triglycerides[1]	High Plasma Glucose[2]	High Waist Circumference[3]	High Blood Pressure[4]	Low HDL-Cholesterol[5]
Sleep duration					
Q1 (shortest sleep)	0.90 (0.61-1.33)	1.08 (0.74-1.59)	1.25 (0.85-1.84)	1.12 (0.76-1.65)	1.20 (0.78-1.85)
Q2	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q3	1.26 (0.86-1.84)	1.03 (0.70-1.50)	1.07 (0.72-1.57)	0.89 (0.60-1.31)	0.89 (0.59-1.34)
Q4 (longest sleep)	1.13 (0.77-1.66)	0.96 (0.66-1.41)	1.26 (0.84-1.87)	1.15 (0.78-1.70)	1..23 (0.80-1.89)
Screen time					
T1 (least screen time)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
T2	1.56 (1.03-2.37)	0.94 (0.64-1.38)	1.38 (0.93-2.04)	1.02 (0.68-1.52)	0.79 (0.50-1.23)
T3 (most screen time)	1.71 (1.11-2.63)	0.76 (0.51-1.13)	1.53 (1.09-2.32)	1.43 (0.94-2.17)	0.65 (0.41-1.03)
Sedentary time					
Q1 (least sedentary)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2	1.23 (0.78-1.93)	1.46 (0.97-2.22)	1.48 (0.97-2.26)	0.87 (0.57-1.34)	0.64 (0.40-1.04)
Q3	1.85 (1.18-2.88)	1.07 (0.71-1.61)	1.83 (1.19-2.81)	1.15 (0.75-1.77)	0.90 (0.55-1.48)
Q4 (most sedentary)	1.81 (1.15-2.85)	0.86 (0.57-1.31)	1.81 (1.16-2.83)	0.94 (0.59-1.47)	0.56 (0.35-0.92)

[1] Alcohol consumption was the only significant confounder
[2] No significant confounders
[3] Significant confounders include gender, ethnicity, and smoking status
[4] Age was the only significant confounder
[5] Smoking was the only significant confounder

Chapter 4

General Discussion

4.1 Summary of Key Findings

The objectives of this thesis were to: 1) determine if an association exists between short sleep and sedentary behavior among adults, and 2) assess whether an association exists between total sedentary behaviour and screen time with the (MetS), and if these associations are independent of sleep duration. This study made use of a large a representative cross-sectional survey of American adults. Sleep duration and sedentary behaviour were measured objectively using accelerometers.

The key findings of this study are that 1) sleep duration is unrelated to sedentary time and screen time, 2) adults who spend between 65-90% of their waking hours sedentary are more likely to have the MetS than those who spend less than 48% of their waking hours sedentary, and 3) adults who spend 3 or more hours per day in front of T.V. and computer screens are more likely to have the MetS than those who accumulate less than 1 hour per day of screen time.

This study found that individuals who are highly sedentary and use screens for long periods of time are at an increased odds of having the MetS. The associations found were moderate in strength. The strongest associations with sedentary time were observed for triglycerides, rather than for blood pressure and plasma glucose [1], which is consistent with other studies.

Although sleep duration was unrelated to the MetS, it was positively associated with waist circumference (borderline significant), which is consistent with current evidence that

insufficient sleep is related to obesity. Had the sample size been larger, this association may have been significant.

4.2 Strengths of the Thesis

To my knowledge, this is the first study to account for the effects of sleep duration on the sedentary behaviour-MetS relationship. Also, based on a recently developed approach [2], I used 7-day accelerometry data to estimate sleep duration, rather than a self-report method, which has typically been used in other large observational studies. Previous studies have found systematically biased, poor to moderate correlations between self-reported and objectively-measured sleep duration [3]. One study found that below 6 hours of sleep duration, the mean self-reported sleep duration was one hour greater than the objective mean, but after 6 hours of sleep, the self-reported sleep duration was half an hour greater than the objective mean [3]. If similar systematic errors were to occur in every sleep study, the strength of associations would be weakened among the short sleep group.

Another strength of the study was the use of an objective measurement of sedentary behavior, in addition to self-reported screen time measure. Previous studies typically assess one domain of sedentary behaviour (e.g. TV viewing time, occupational sitting time, etc.). Instead of capturing one aspect of sedentary behaviour, I measured total sedentary time throughout the day.

Also, the participants involved in the NHANES were sampled from many areas across the U.S. using a complex, multistage, probability sampling design [4]. The demographic characteristics of those in the study population are similar to the characteristics of the general U.S. population. Therefore, the results are generalizable to the U.S. national population, and possibly to Canadian adults.

4.3 Limitations of this Thesis

4.3.1 Internal Validity

There are several ways in which the internal validity of a study can be compromised due to systematic errors such as selection bias, measurement bias, and confounding. Selection bias is error that results from the method of choosing participants, leading to an under- or over-estimation of the true relationship. If the characteristics of the participants selected for the study differ systematically from those in the target population, then selection bias can occur. Due to the incentives of participating in the MEC portion of the survey, volunteer bias, a type of selection bias, may be present. For example, participants are offered free physical examinations and additional health information not typically provided by their physician. They also receive monetary reimbursement of up to $125 to cover transportation expenses and participation. These remunerations provide participants an incentive to participate. However, since my research examined a biologic relationship (i.e. how sedentary behaviour influences the MetS), a volunteer bias is unlikely to have affected the observed relationships. Instead, it was more likely to have affected the prevalence of the exposures, outcome, and covariates (e.g. if those who have a lower SES were more likely to participate than those with a high SES).

Measurement bias may have also been problematic in this study because of the use of self-reported data for the screen time exposure and many of the covariates. This may have led to misclassification, and subsequently over- or under-estimating the true associations. This misclassification may be due to recall bias (participants may experience problems remembering behaviours in the last month) or a social desirability response bias. For example, people tend to under-report negative behaviours such as alcohol consumption [5], smoking status [6] , and

screen time behaviours [7]. Also, because the NHANES screen time question did not distinguish between days, the validity of the screen time measure may have been affected since screen time has been shown to differ between weekdays and weekend days [8]. There is also the possibility of misclassification on the basis of sleep duration and sedentary behaviour because of the accelerometer device limitations. For example, if an individual were to remove their accelerometer while engaging in sedentary behaviour, this may underestimate sedentary time. On the other hand, if an individual were engaging in heavy exercise while sitting (e.g. lifting weights), sedentary time would be overestimated since the accelerometer would not have detected upper body movement. Furthermore, if an individual were to delay their accelerometer wear after waking up, this may over-estimate sleep duration. In these situations, it is unclear if the misclassification was differential or non-differential, and therefore unknown whether the observed associations were underestimated or overestimated.

There is a potential for the associations to be confounded by variables not accounted for in this study (e.g. obstructive sleep apnea). Also, there is a possibility of residual confounding due to the possibly of misclassification of the covariates (e.g. self-report measures of smoking status or alcohol consumption may be biased).

4.3.2 External Validity

External validity refers to the degree which results of a study are generalizable to populations outside of the sample that was studied. This manuscript examined associations in a large national sample using NHANES, which is assumed to be nationally representative survey. However, there may have been sampling bias in the beginning stages of participant selection. Sampling bias is a type of selection bias that affects the external validity of a study. The

NHANES dataset contained data from certain populations that were oversampled. This could have created selection bias, however, NHANES adjusted for this using weighted samples so that the sample was representative of the non-institutionalized U.S. population.

4.3.3 Causation

A central and essential theme that surrounds all etiological epidemiologic studies is causation. A commonly used method of assessing causation is to use Hill's criteria of causation [9], which is discussed in this section.

Temporality is a necessary component of causation. The NHANES data used in this study are by nature cross-sectional. Therefore, it is not possible to assume that sedentary behaviour or screen time leads to the MetS in this study. Although mechanisms have been postulated that prove this temporal relationship, there is not enough prospective evidence to conclude so. Furthermore, it is possible that individuals who develop the MetS become more sedentary and watch more TV than those without the syndrome.

Strength of association is a criteria that states that stronger associations are more likely to be causal [9]. We determined strength using multiple logistic regression. Moderately strong and statistically significant relationships were observed with the MetS outcome for both the sedentary time and screen time exposures. Therefore, the observed associations are less likely to be due to an extraneous variable.

Consistency is a criteria that refers to finding similar results in different populations across different settings [9]. The study methods differed from previous studies, which could explain the inconsistent results with regards to sleep. However, the results were consistent with the large majority of studies assessing the relationship between sedentary behaviour, screen time,

and the MetS. With regards to internal consistency, there were no significant interactions of sedentary behaviour or sleep with age, gender, and ethnicity, indicating that the associations were consistent across these groups.

With respect to biological plausibility, there is reason to believe that sedentary behaviour is a risk factor for the MetS. This may be through behavioural mechanisms such as reduced energy expenditure and increased energy intake [10] or via a biological mechanism (suppression of LPL, which is responsible for triglyceride uptake, as described in Chapter 1) [11,12].

In this study, no dose-response relationships were found for sleep duration and the MetS, although several studies in the past have found a U-shaped relationship, indicating that short and long sleepers are at equal and increased risk for obesity [13]. For sedentary behaviour, a more monotonic relationship existed in this study, with more sedentary behaviour and screen time leading to higher odds.

4.4 Future Research Directions

Although this study looked at the association of each individual component of the MetS with our exposure variables, one limitation of my research is that I characterized the collection of multiple outcomes (individual components of the MetS) into a single, one-dimensional outcome using a pooling strategy that resulted in a single score of the MetS. Since the individual components of the MetS are not measured on the same scale (noncommensurate outcomes), it is not ideal to combine them into one outcome [25]. However, the use of multivariate regression analysis to evaluate noncommensurate outcomes still lacks a complete theoretical framework and appropriate methodology for model selection [25]. Furthermore, based on the Framingham risk score, which estimates the 10-year cardiovascular risk of an individual, the MetS predicted CVD

and diabetes more than its individual components [26,27]. Therefore, using the MetS as a single outcome may provide a clearer understanding of an individual's overall risk of CVD and diabetes. Futures studies may benefit from exploring new methods of analyzing noncommensurate outcomes [25].

Another limitation of my research is that I did not adjust for sleep disorders such as obstructive sleep apnea (OSA). OSA is a condition in which the upper airway collapses during sleep, resulting in increased respiratory effort [14]. Although previous studies have found that an association between short sleep and obesity exists independent of sleep apnea [15], OSA is highly associated with obesity, the MetS, and sleep interruption and this may lead to poor sleep quality and an insufficient amount of sleep. Therefore, future studies ought to assess OSA using more objective measures such as polysomnography, instead of the typical questionnaire measures which were used in NHANES.

Although objective measures provide abundant information on the duration and frequency of sedentary behaviour, they do not provide context to the type of sedentary behaviour performed. Given this, it would be difficult to design interventions that target sedentary behaviour, since sedentary behaviour is related to several daily activities besides screen-time (e.g. auto commuting, occupational sitting, social events, and eating). Future studies would benefit from using a daily log alongside accelerometer wear. However, a first step would be to determine the duration of sedentary time that is likely to confer a health risk, and use that as a public health guideline.

Future studies assessing the sleep-MetS relationship should also assess sleep quality alongside sleep duration. In a cross-sectional study involving a cohort of 612 middle-aged adults, sleep fragmentation (a measure of sleep quality), as assessed by wrist actigraphy, was strongly

associated with a higher BMI [16]. Although longitudinal analysis of the same study showed no longitudinal associations, sleep fragmentation predicted higher blood pressure levels and adverse changes in blood pressure [17].

Future studies would also benefit from examining sleep timing vs. sleep duration. According to one study, a significant proportion of the population (8.3%) report a sleep onset time of 3:00 A.M. or later [18]. Individuals who are part of this late-sleep population are more likely to consume unhealthy calories later at night, leading to weight gain [18]. This consumption of calories later at night is thought to be due to circadian rhythm disruption. Also, melatonin suppression is thought to be another pathway by which late sleepers may become obese [19]. Therefore, future studies would benefit from examining the effects of sleep duration vs. sleep timing.

Another area of future exploration is the determinants of sleep duration. Common causes of short sleep include voluntary curtailment in order to spend time on other activities (e.g. work, recreation, childcare), insomnia, and feeling fully rested with a small amount of sleep [15]. The biological effects of insufficient sleep in these three groups may be very different, thereby making future interventions group-specific [15]. For example, early studies found that a significant proportion of individuals experiencing insomnia also have a psychiatric comorbidity [20]. Since insomnia is treatable, it would make sense to conduct interventional studies using individuals with and without insomnia, comparing their future obesity risk.

4.5 Public Health and Policy Implications

Some of the findings from this manuscript have important public health implications. Firstly, the finding that sedentary behaviour was associated with the MetS, while controlling for

MVPA, indicates that distinct approaches for sedentary behaviour and MVPA need to be considered for future initiatives targeting the reduction of the MetS and obesity. Ultimately, public health messages should try to induce people to shift a proportion of their sedentary time to increased time spent in light-intensity physical activity [21]. In order to do this, researchers should understand the particular settings that are likely to influence sedentary time [21]. For example, decreasing time spend watching TV and decreasing motorized transportation would require distinct interventions (e.g. exercise/fitness breaks during TV commercials vs. using active transportation). Secondly, short sleep may be related to abdominal obesity, a risk factor for a host of cardiometabolic diseases [22]. Since insufficient sleep is such a prevalent problem in society [23], the general public and health care providers need to be informed of the consequences of sleep loss. Many people do not realize the many risks associated with insufficient sleep [24]. An increased understanding may lead to better sleep behaviours among society [24]. Furthermore, groups who are prone to insufficient sleep (e.g. shift workers, students) should be identified so that campaigns can be targeted directly towards them.

4.6 Conclusion

Individuals who are more sedentary and spend more time using screens are at higher odds of developing the MetS, independent of MVPA and sleep duration. The finding from this study make an important contribution to the field of research surrounding cardiometabolic health. It is hoped that this finding will help inform individuals from the public health sector, the scientific community, and the general public on the importance of reducing sedentary behaviour.

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Appendix A

Ethics Approval Document

QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS RESEARCH ETHICS BOARD-DELEGATED REVIEW
December 07, 2012

Dr. Ian Janssen
Department of Community Health and Epidemiology
Queen's University

Dear Dr. Janssen
Study Title: EPID-404-12 Interrelationships among short sleep, sedentary behaviour,and the metabolic syndrome in adults
File # 6007574
Co-Investigators: Ms. D. Saleh

I am writing to acknowledge receipt of your recent ethics submission. We have examined the protocol and appendices for your project (as stated above) and consider it to be ethically acceptable. This approval is valid for one year from the date of the Chair's signature below. This approval will be reported to the Research Ethics Board. Please attend carefully to the following listing of ethics requirements you must fulfill over the course of your study:

Reporting of Amendments: If there are any changes to your study (e.g. consent, protocol, study procedures, etc.), you must submit an amendment to the Research Ethics Board for approval. Please use event form: HSREB Multi-Use Amendment/Full Board Renewal Form associated with your post review file # **6007574** in your Researcher Portal (https://eservices.queensu.ca/romeo_researcher/)

Reporting of Serious Adverse Events: Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information. Serious Adverse Event forms are located with your post-review file **6007574** in your Researcher Portal (https://eservices.queensu.ca/romeo_researcher/)

Reporting of Complaints: Any complaints made by participants or persons acting on behalf of participants must be reported to the Research Ethics Board within 7 days of becoming aware of the complaint. Note: All documents supplied to participants must have the contact information for the Research Ethics Board.

Annual Renewal: Prior to the expiration of your approval (which is one year from the date of the Chair's signature below), you will be reminded to submit your renewal form along with any new changes or amendments you wish to make to your study. If there have been no major changes to your protocol, your approval may be renewed for another year.

Yours sincerely,

Albert L. Clark.

Chair, Research Ethics Board
December 07, 2012

Investigators please note that if your trial is registered by the sponsor, you must take responsibility to ensure that the registration information is accurate and complete

Appendix B

Summary of Key Study Variables

Study Construct	Variables Employed to Measure Construct	NHANES Data Source
Exposures		
Short sleep	**Sleep duration** - how much sleep an individual gets per night (hours)	**Physical Activity Monitor Data**
Sedentary behaviour	**Sedentary behaviour during waking hours** -proportion of total wear hours to sedentary hours **Screen time** -average duration of a screen time per day	**Physical Activity Monitor Data** **Physical Activity Questionnaire**
Covariates		
Sociodemographic Factors	**Age in years** **Sex** **Race/ethnicity** **SES** -poverty income ratio	**Demographic Information Questionnaire**
Behavioural risk factors	**Smoking** -current vs. former vs. never	**Cigarette Use Questionnaire**
	Alcohol -number of alcohol drinks consumed per week	**Alcohol use Questionnaire**
	Caffeine Consumption -total caffeine (mg) intake on 2 separate days	**24-hour recall interview**
Outcome		
Metabolic Syndrome	**Three or more of the following risk factors:** -high waist circumference -high triglycerides -low HDL-cholesterol -high blood pressure -high blood glucose	**-Body measurements examination files** **-Serum Triglyceride levels laboratory files** **-Serum HDL-cholesterol levels laboratory files** **-Blood pressure examination files** **-Plasma fasting glucose laboratory files**

Appendix C

NHANES Questionnaire Key Questions

Screen Time

1. Over the past 30 days, on average about how many hours per day did you sit and watch TV or videos?

Code	Description
0	Less than 1 hour
1	1 hour
2	2 hours
3	3 hours
4	4 hours
5	5 hours or more
6	None

2. Over the past 30 days, on average about how many hours per day did you use a computer or play computer games?

Code	Description
0	Less than 1 hour
1	1 hour
2	2 hours
3	3 hours
4	4 hours
5	5 hours or more
6	None

Sociodemographic covariates

3. Race/Ethnicity

Code	Description
1	Mexican American
2	Other Hispanic
3	Non-Hispanic White
4	Non-Hispanic Black
5	Other race

4. Education

Code	Description
1	Less than 9^{th} grade
2	9-11^{th} grade
3	High school Grad
4	Some College
5	College Graduate
7	Refused
9	Don't know

Behavioural covariates

5. Have you smoked at least 100 cigarettes in your entire life?

Code	Description
1	Yes
2	No
7	Refused
9	Don't know

6. Do you now smoke cigarettes?

Code	Description
1	Everyday
2	Some days
3	Not at all
9	Don't know

7. In your entire life, have you had at least 12 drinks of any type of alcoholic beverage?

Value	Description
1	Yes
2	No
7	Refused
9	Don’t know
.	Missing

8. Do you drink on a weekly, monthly or yearly basis?

Value	Description
1	Week
2	Month
3	Year

9. In the past 12 months, how many times per week/month/year do you drink any type of alcoholic beverage? PROBE: Question 6

Value	Description	
0 to 365	Range of values	
777	Refused	
999	Don’t know	

Appendix D
NHANES Study Design

Background

The National Health and Nutrition Examination Survey (NHANES) is large, continuous survey that assesses the health and nutritional status of adults and children in the United States to meet emerging health needs [1]. It is a major program of the National Center for Health Statistics (NCHS) which is responsible for producing health statistics for the United States [1]. The NCHS is part of the Centers for Disease Control and Prevention (CDC) [1]. From the early 1960s to 1999, the survey was conducted periodically and focused on certain populations groups or different health topics [1]. After 1999, the survey became continuous and assessed a variety of health indicators [1]. Several epidemiological studies have used NHANES to determine the prevalence of disease, assess risk factors for disease, and develop public health policy [1]. The manuscript within this thesis was based on NHANES 2003/04 and 2005/06.

Study Design

The sample selected for the survey is meant to represent the U.S. population. However, individuals residing in nursing homes, members of the armed forces, and institutionalized persons are excluded [2]. NHANES over-samples individuals over the age of 60, adolescents (12-19 years), low income White Americans, African Americans, Asians, and Hispanics [2]. The NHANES sampling procedure consists of 4 stages [2]. Firstly, primary sampling units are selected, usually counties or groups of small counties [2]. Counties are then divided into segments [2]. Within each segment, households are listed and randomly selected [2]. From each household, individuals are chosen at random to participate in NHANES from a list of all individuals residing in the selected household [2]. On average, 1.6 persons are selected per household [2]. To produce

unbiased national estimates, a sampling weight is assigned to each participant [2]. A sample weight is a measure of the number of people in the population that the participant represents [2]. This weight reflects the unequal probability of selection and nonresponse [2]. Separate sample weights are applied depending on which part of the survey the researcher is analyzing [2].

What is unique about the survey is that it combines interviews with physical examinations and laboratory testing [2]. The interviews are conducted in participants' homes and use computer-assisted personal interview (CAPI) technology [2]. An interviewer is present to guide the respondent if needed [2]. The home interview collects participant's demographic information (e.g. education level, ethnicity), health behaviour information (e.g. smoking, alcohol use) and dietary habits/intake (i.e. 24 hour recall of food and beverages consumed) and medical history [2]. Health measurements are performed in the mobile exam centers (MEC) which travels throughout the country [2]. Every participant is examined by a physician, dentist, and medical health technicians [2]. The examination involves physiological measurements (e.g. blood pressure, BMI) and laboratory testing (e.g. blood and urine samples) [2]. Additionally, participants are given an accelerometer to wear for 7 days, with detailed instructions for use [2]. The health technologists ensure monitor placement is correct on the participant's waist [2]. After the 7 day period, they are asked to return it by mail in a postage paid envelope [2].

NHANES is designed to encourage and maximize participation [2]. Transportation is available to and from the MEC [2]. Participants who are examined receive additional health information about themselves that are not commonly performed in a routine physical exam conducted by their doctor [2]. They are then mailed all of their results and a cash payment of up to $125 to cover transportation expenses, and to thank them for their time [2]. All information collected on participants is kept confidential [2]. Participants are provided informed consent forms, agreeing to participate in the household interview and MEC portions of the survey [2]. If

the participant was under the age of 18, parental consent was obtained [2]. They are also informed that their specimens are stored for future research [3].

Appendix E

Accelerometry Protocol

List of measured Variables

- Mean wear hours per day
- Sedentary behaviour (duration and intensity)
- Proportion of total wear time that is sedentary
- Light intensity physical activity (duration and intensity)
- Moderate to vigorous physical activity (duration and intensity)
- Nonwear hours per day
- Sleep duration (hours)

Exclusions [4]

- If the participant is too large to accommodate the belt
- If the participant is in a wheelchair
- If the participant had recent abdominal surgery

Measurement Device

- Actigraph 7164

Measurement Procedure [4]

- The health technologist initializes the monitor (e.g. ensures it has enough battery life, etc.)
- Accelerometer is given to the participant after the MEC visit

- Participant is shown how to wear the accelerometer (under or against clothing on the right hip during waking hours only) using a removable elastic belt with a Velcro closure
- Participant is instructed to wear it for 7 consecutive days, except for when in contact with water (e.g. swimming, showering)
- The health technologist attaches a label sticker on their device with their name to minimize confusion if multiple household members are taking part in the survey
- Accelerometer starts recording counts at 12 a.m. (e.g. if they receive it at 6 p.m., it starts recording 6 hours later)
- An information brochure and a toll-free number is provided for participants if questions or problems arise
- After the 7-day period, participants receive a postcard reminder to return their accelerometer in a postage-paid envelope
- Upon receipt of the accelerometer, a $40 cheque is mailed to the participant
- Data is transferred from the monitor to a download application
- Monitor is calibrated

Retrieving data [5]

1. Download raw data from the NHANES Examination webpage (Physical activity Monitor) and save in a folder on the computer
2. Extract the data files using SAS (LIBNAME)
3. Ensure the data has the correct number of observation and variables (PROC CONTENTS)

4. Sort the data by participant ID (PROC SORT)
5. Only include participants who have 10080 observations (24 hours x 7 days x 60 minutes)
6. Append the raw data from both years (2003/04 and 2005/06)
7. Append the demographic datasets from both years (2003/04 and 2005/06)
8. Merge the accelerometry data to the demographic data
9. Run the provided "nw" macro that defines the duration of monitor nonwear periods
    a. A nonwear period starts with an intensity count of zero
    b. The nonwear period ends when any of the following conditions is met:
        i. One minute with a missing count
        ii. 3 consecutive minutes with intensity counts above 0
        iii. Last minute of the day is reached
    c. The macro then creates summary variables of wear time and nonwear time for each participant in two different data sets
    d. The number of minutes of zero intensity that define a nonwear period is set to 60 minutes
10. Classify intensity counts for each minute as sedentary (0 cpm), light intensity (100 cpm), moderate intensity (2020 cpm), and vigorous intensity (5999 cpm) based on the Troiano et al. thresholds [6].
    a. An activity bout starts at a minute with an intensity count greater than or equal to the threshold and stops when any of the following conditions are met:

i. one minute with intensity < threshold

ii. one minute with a missing intensity count

iii. the last minute of the day

11. Run the provided "bouts" macro which sets a bout length of 1 minute so that it accumulates all minutes of a given intensity
    a. The activity bout stops when any of the following conditions are met:
        i. one minute with intensity < threshold
        ii. one minute with a missing intensity count
        iii. the last minute of the day
12. Run the provided "%bouts_8of10" macro which calculates 10-minute bouts with an allowance for 2 minutes below the threshold. These bouts are used for MVPA intensities
    a. The bout stops when any of the following conditions are met:
        i. 3 consecutive minutes with intensity less than the threshold
        ii. 1 minute with a missing intensity count, or last minute of the day
13. Summarize the data into one record per person
14. Eliminate invalid days (less than 10 hours of wear)
15. Eliminate invalid persons (less than 4 valid days of data)
16. Save the data set permanently
17. To create the sleep variable, repeat steps 1-9 but instead of beginning the day at 12 a.m., begin the day at 12 p.m.

18. Merge the nonwear data set with the wear time and eliminate invalid days (less than 10 hours of wear) and invalid persons (less than 2 days of data). Each valid person must have at least 2 valid day of data with 1 valid night in between
19. Create 6 separate data sets, one for each sleep night. Each data set contains nonwear periods in a 24 hour period from 12 p.m. to 12 p.m. the following day
20. Find the longest nonwear period in each dataset. That will be the sleep duration for that night
21. Average the sleep durations from every night to get a weekly average
22. Remove outliers (below the 2^{nd} and above the 98^{th} percentile)

Appendix F

Power Calculations

Power = $\Phi Z_{(1-\beta)} = \Phi \{d [(nr)/p(1-p)(1+r)]^{1/2} - Z_{\alpha/2}\}$

Estimated power for detecting sedentary behaviour-Metabolic syndrome associations

$N_{adjusted}$	% exposed	$N_{exposed}$	r	RR*	p	p0	p1	d	za/2	Z(1-b)	Power
1371	0.25	343	4	1.33 OR=1.60	0.37	0.34709	0.46163	0.1145	1.96	5.89	100%

$N_{adjusted}$ is the adjusted sample size
$N_{exposed}$ is the number of adults exposed (highly sedentary)
r is the ratio of unexposed to exposed
RR is the detectable relative risk
p is the proportion of adults who have the outcome (have the Metabolic Syndrome)
p_0 is the prevalence of metabolic syndrome *in those who are <u>not</u> highly sedentary*
p_1 is the prevalence of metabolic syndrome *in those who are highly sedentary*
d is the difference between p_1 and p_0
$z_{\alpha/2}$ is the level of significance
* RR = OR / [(1 – Po) + (OR x Po)]

Estimated power for detecting sedentary behaviour-Metabolic syndrome association while accounting for the moderating effect of sleep †

$N_{adjusted}$	% ↑SB, ↓sleep*	% ↑SB, ↑sleep	% ↓SB, ↑sleep	%↓SB, ↓sleep	p_1 ↑SB, ↓sleep	p_2 ↑SB, ↑sleep	OR_1 ↑SB, ↓sleep	OR_2 ↑SB, ↑sleep	Power
1371	0.25	0.25	0.25	0.25	0.45	0.34	2.0	1.20	60%

$N_{adjusted}$ is the adjusted sample size
* % exposed (frequencies) in each sedentary behaviour (SB) and sleep group
p_1 is the probability of getting the metabolic syndrome *in those who are highly sedentary and have short sleep*
p_2 is the probability of getting the metabolic syndrome *in those who are highly sedentary and have normal sleep*
OR_1 is the odds ratio of sedentary behaviour and the metabolic syndrome in those with short sleep
OR_2 is the odds ratio of sedentary behaviour and the metabolic syndrome in those with normal sleep [7]

† $N = (q(1-a/2)+q(1-b))^2 * S\,[1/f_{ij}*(p_{ij}*(1-p_{ij}))]/D^2$
Where $D=log(o_1/o_2)$

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