DESCRIPTION OF SPORADIC PHYSICAL ACTIVITY AND THE RELATIONSHIP BETWEEN NON-BOUTED PHYSICAL ACTIVITY INTENSITY AND THE METABOLIC SYNDROME IN AMERICAN ADULTS

by

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Abstract

Less than 15% of North American adults currently met the physical activity guidelines. These guidelines recommend that adults accumulate at least 150 minutes per week of moderate-to-vigorous physical activity (MVPA) in bouts of 10 minutes or more. Emerging evidence suggests that accumulating sporadic MVPA (i.e. physical activity performed in periods of less than 10 consecutive minutes) also has health benefits. Little is known about how much sporadic physical activity (SPA) adults get. Furthermore, it is not known if SPA needs to be of at least moderate intensity to convey health benefits. The purpose of this thesis was twofold: 1) to describe SPA levels and intensity patterns in adults, and 2) to investigate the relationship between various intensities of SPA and the metabolic syndrome. The metabolic syndrome is a clustering of risk factors for cardiovascular disease and diabetes.

Data for the thesis research came from the National Health and Nutrition Examination Survey, a representative cross-sectional sample of adults from the United States. Physical activity was measured over 7 days using accelerometers, which are small electronic sensors worn on the hip. The metabolic syndrome was determined from direct body measurements and blood samples.

Results of this thesis indicate that the typical American adult accumulates 103 minutes/day of SPA, which represented 27% of their total daily physical activity. Of these 103 minutes/day, only 2 minutes/day were of moderate-to-vigorous intensity. However, adults accumulated 16 minutes/day of MVPA that was embedded within bouts of primarily light intensity activity – this activity did not meet the MVPA bout criteria but it was not truly sporadic since it occurred within bouts of primarily light intensity activity. Accumulation of this
embedded MVPA was as strongly related to the MetS as bouted MVPA. Conversely, sporadic light intensity physical activity was weakly associated with the metabolic syndrome. Together, these results suggest MVPA is commonly accumulated outside of the current recommended bout length and that this type of activity is strongly associated with the metabolic syndrome.
Co-Authorship

This thesis presents the work of Jordan Robson in collaboration with his supervisor, Dr. Ian Janssen.

**Manuscript 1: A Description of the Volume and Intensity of Sporadic Physical Activity among Adults** has been submitted to Applied Physiology, Nutrition and Metabolism and is presented in adherence with the journal guidelines. Jordan Robson was responsible for conducting the literature review to identify specific research needs related to the description of sporadic physical activity, developing and conducting the data reduction and processing procedures for the raw accelerometer data, carrying out all of the statistical analyses, writing the first draft of the manuscript and revising the manuscript based on comments received from Dr. Janssen. In addition to providing comments for the manuscript, Dr. Janssen provided insight and feedback on analyzing the data, developing the data reduction and processing program, interpreting the results of the statistical analyses and the presentation of the information.

**Manuscript 2: Intensity of Sporadic and Bouted Physical Activity and the Metabolic Syndrome in Adults** has been prepared for submission to Applied Physiology, Nutrition and Metabolism and is presented in adherence with journal guidelines. Contributions for both authors (Jordan Robson and Ian Janssen) are similar in nature as to what was explained above for manuscript 1. The remaining chapters of this thesis (i.e. Introduction, Literature Review, General Discussion and Appendices) were the work of Jordan Robson with input and comments from Dr. Janssen.
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Last but not least, I would like to extend many thanks to my brothers and sisters in arms at the physical activity epidemiology lab and at SKHS. Specifically Andrei, Brenton, Rachel, Asha, and Tom, without you guys around the lab almost every day I may have lost my mind. The motivation, feedback and companionship you have all provided me have been invaluable.
# Table of Contents

Abstract ................................................................................................................................. ii

Co-Authorship ........................................................................................................................ iv

Acknowledgments ...................................................................................................................... v

List of Tables ........................................................................................................................... ix

List of Figures .......................................................................................................................... x

List of Acronyms ....................................................................................................................... xi

Chapter 1 Introduction .............................................................................................................. 1

1.1 Overview ............................................................................................................................ 1

1.2 Scientific and public health significance .......................................................................... 2

1.3 Thesis objectives and hypotheses ..................................................................................... 3

1.4 Thesis organization ............................................................................................................ 4

1.5 References ......................................................................................................................... 5

Chapter 2 Literature Review ................................................................................................... 8

2.1 Overview and outline ......................................................................................................... 8

2.2 Key definitions .................................................................................................................. 9

2.2.1 Physical activity and physical inactivity ....................................................................... 9

2.2.2 Physical activity guidelines ......................................................................................... 10

2.2.3 Measuring physical activity levels ................................................................................. 11

2.2.4 Metabolic syndrome .................................................................................................... 13

2.3 Public health burden of physical inactivity in adults ....................................................... 14
2.4 Physical activity and health in adults ................................................................. 17

2.4.1 Physical activity bout duration and health .................................................. 17

2.4.2 Physical activity intensity and health .......................................................... 22

2.5 Summary and conclusions ............................................................................. 26

2.6 References ........................................................................................................ 28

Chapter 3 A Description of the Volume and Intensity of Sporadic Physical Activity among Adults ............................................................................................................. 35

3.1 Abstract .............................................................................................................. 36

3.2 Introduction ....................................................................................................... 37

3.3 Methods ............................................................................................................ 38

3.4 Results .............................................................................................................. 41

3.5 Discussion ........................................................................................................ 48

3.6 References ........................................................................................................ 51

Chapter 4 Intensity of Sporadic and Bouted Physical Activity and the Metabolic Syndrome in Adults ........................................................................................................... 55

4.1 Abstract .............................................................................................................. 56

4.2 Introduction ....................................................................................................... 57

4.3 Methods ............................................................................................................ 58

4.4 Results .............................................................................................................. 63

4.5 Discussion ........................................................................................................ 69

4.6 References ........................................................................................................ 72
Chapter 5 General Discussion ................................................................. 77

5.1 Summary of key findings .................................................................. 77
5.2 Strengths of this thesis .................................................................. 80
5.3 Limitations of this thesis ............................................................... 81
5.4 Public health implications .............................................................. 83
5.5 Future research directions ............................................................. 84
5.6 Summary of MSc research experiences .......................................... 85
5.7 Conclusions ................................................................................. 86
5.8 References .................................................................................. 87

Appendix A Ethics Approval ................................................................. 91
Appendix B NHANES Study Design ..................................................... 93
Appendix C Accelerometer Protocol .................................................... 97
Appendix D Sample Reweighting .......................................................... 101
List of Tables

Table 3.1 Characteristics of the study sample.................................................................42
Table 3.2 Median (interquartile range) daily time spent in sporadic physical activity of different intensities, in minutes per day and as a fraction of total of sporadic physical activity, within the total sample and according to sex, age, race/ethnicity, and body mass index..........................44
Table 3.3 Median (interquartile range) daily time spent in sporadic physical activity of different intensities, in minutes per day and as a fraction of total of sporadic physical activity, within men and according to sex, age, race/ethnicity, and body mass index.............................................45
Table 3.4 Median (interquartile range) daily time spent in sporadic physical activity of different intensities, in minutes per day and as a fraction of total of sporadic physical activity, within women and according to sex, age, race/ethnicity, and body mass index....................................................46
Table 3.5 Median (interquartile range) minutes per day spent in moderate-to-vigorous intensity physical activity embedded within bouts of light intensity physical activity within the total sample and according to sex, age, race/ethnicity, and body mass index...................................47
Table 4.1 Descriptive characteristics of the study sample..................................................65
Table 4.2 Associations between physical activity variables and the metabolic syndrome..........66
Table 4.3 Associations between physical activity variables and the metabolic syndrome components............................................................................................................68
List of Figures

Figure 2.1 Example of collected minute-by-minute accelerometer data over the course of 1 day .................................................................................................................................................................................................................. 13

Figure 3.1 Classification of physical activity data from 95 minutes of accelerometer data obtained on a 24-year-old man ....................................................................................................................................................................................................... 40

Figure 4.1 Odds ratios for the metabolic syndrome per daily minute of physical activity. Values are plotted from 0 minutes/day to the value that corresponds to the 98th percentile of the physical activity variable within the study sample. MVPA, moderate-to-vigorous physical activity; LIPA, light intensity physical activity ............................................................................................................................................................................. 66
**List of Acronyms**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>BMI</td>
<td>body mass index</td>
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<tr>
<td>BPA</td>
<td>bouted physical activity</td>
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<tr>
<td>CI</td>
<td>confidence interval</td>
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<tr>
<td>CPM</td>
<td>counts per minute</td>
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<tr>
<td>HDL</td>
<td>high density lipoprotein</td>
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<tr>
<td>LIPA</td>
<td>light intensity physical activity</td>
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<tr>
<td>LPL</td>
<td>lipoprotein lipase</td>
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<tr>
<td>LTPA</td>
<td>leisure time physical activity</td>
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<tr>
<td>MET</td>
<td>metabolic equivalent</td>
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<tr>
<td>MetS</td>
<td>metabolic syndrome</td>
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<tr>
<td>MVPA</td>
<td>moderate-to-vigorous intensity physical activity</td>
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<tr>
<td>NHANES</td>
<td>National Health and Nutrition Examination Survey</td>
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<tr>
<td>OR</td>
<td>odds ratio</td>
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<tr>
<td>PPS</td>
<td>probability proportional to a measure of size</td>
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<tr>
<td>RR</td>
<td>relative risk</td>
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<tr>
<td>SPA</td>
<td>sporadic physical activity</td>
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</table>
Chapter 1
Introduction

1.1 Overview

The landscape for chronic diseases has shifted in response to changing lifestyles promoted by modern day society. A major component of this shift is the lack of sufficient physical activity. Public health guidelines for physical activity state that adults should accumulate 150 minutes per week of moderate-to-vigorous intensity physical activity (MVPA) in bouts of 10 minutes or more. This guideline is met by less than 15% of North American adults. Insufficient physical activity is associated with a myriad of health outcomes including the metabolic syndrome (MetS), a clustering of cardiovascular disease risk factors that affects an estimated 19.1% of Canadian adults. Individuals who have the metabolic syndrome have been found to be at a greater risk of several adverse health outcomes including cardiovascular disease (relative risk (RR) = 2.35) and all-cause mortality (RR = 1.58).

Given the low levels of physical activity in the population, it is important to explore ways to make physical activity more accessible and appealing to the general public. One way this could be accomplished is by encouraging sporadic physical activity (SPA). SPA is defined as activity occurring in periods shorter than the recommended 10 minute bout duration. Recent research suggests that SPA is associated with cardiometabolic risk factors independent of bouted physical activity (BPA), and that associations between SPA and cardiometabolic risk factors are as strong as associations with BPA. Despite this, SPA is currently not addressed in
any major physical activity guidelines. Additionally, very little descriptive research has investigated how much SPA people accumulate and at what intensity.

There is also a lack of information concerning the health effects of intensity for SPA. Intensity represents another important aspect of physical activity that could be modified to make physical activity more desirable. Engaging in vigorous intensity physical activity compared to moderate intensity activity can reduce the amount of time required to observe health benefits. Also, some evidence suggests energy expenditure from vigorous physical activity may provide greater benefits than equivalent energy expenditure from moderate intensity activity. While the role of intensity is relatively well researched for bouted and total activity, there is uncertainty about the role of intensity for SPA. Some evidence suggests that sporadic light intensity physical activity (LIPA) has health effects that may be comparable to moderate intensity SPA, while other evidence suggests an intensity dependent relationship for SPA. More evidence is needed to establish whether intensity has similar effects as it does in bouted and total activity, or if there is also potential for an alternative pathway for SPA involving disruption of prolonged sedentary behaviour periods that may be independent of activity intensity.

1.2 Scientific and public health significance

It has been estimated that physical inactivity is responsible for 3.2 million deaths each year around the world, and 3.7% of healthcare spending in Canada. As such, formal physical activity recommendations have been developed and issued by many countries and the World Health Organization. These guidelines encourage adults to accumulate 150 minutes of bouted
MVPA a week. Although these guidelines do not recognize SPA at present, if enough evidence is accumulated future revisions to the guidelines may be made to incorporate SPA.

Research on SPA is in its infancy and there are several notable research gaps. Of interest to this thesis is developing a better understanding of how much SPA adults accumulate and the role of SPA intensity on health. From a public health perspective, this information can help to identify how much of daily activity in adults is represented by SPA. If it is found that SPA represents a meaningful proportion of daily physical activity, then it may establish SPA as an interventional opportunity to improve physical activity accumulation and reduce sedentary time. Additionally, information about the role of SPA intensity will help inform the nature of future interventions involving SPA; specifically, as to whether SPA interventions should be recommended at any intensity as a means of interrupting prolonged periods of sedentary time or as an alternate means of accumulating minutes of MVPA.

1.3 Thesis objectives and hypotheses

The purpose of this thesis was to investigate SPA patterns and tendencies in adults and whether SPA intensity is important. The thesis research was divided into two manuscripts. The objective of Manuscript 1 was to describe how much daily SPA adults accumulated, the intensity at which it was accumulated, the contribution of SPA to total daily physical activity and whether differences in these characteristics existed between sociodemographic groups. The objective of Manuscript 2 was to investigate the relationship between SPA intensity and the MetS. It was hypothesized that for an equivalent amount of minutes/day of SPA of vigorous intensity, there would be greater reductions in the odds of having the MetS compared to moderate intensity SPA, and even greater reductions when compared to light intensity SPA.
Both manuscripts used data from the National Health and Examination Nutrition Survey (NHANES); a representative cross-sectional survey of Americans. Physical activity was measured objectively over 7 days using accelerometers. Data for each of the components of the MetS were collected through direct physical measurements and fasting blood samples.

1.4 Thesis organization

This thesis adheres to the regulations stated in the Queen’s School of Graduate Studies and Research “General forms of theses”. Chapter 2 includes an overview of the literature concerning the individual properties of physical activity and inactivity, as well as the relationship between physical activity and health. The latter part focuses on the relationships of physical activity bout length and intensity with health. Chapter 3 includes the first manuscript entitled “A Description of the Volume and Intensity of Sporadic Physical Activity among Adults”. This manuscript has been submitted to Applied Physiology, Nutrition and Metabolism and is formatted in adherence to the requirements of the journal. Chapter 4 includes the second manuscript entitled “Intensity of Sporadic and Bouted Physical Activity and the Metabolic Syndrome in Adults”. This manuscript has been prepared for submission to Applied Physiology, Nutrition and Metabolism and is formatted in adherence to the requirements of the journal. Lastly, Chapter 5 includes a general discussion of the key findings, literature context, strengths and limitations, public health implications, future directions and overall conclusions of the thesis.
1.5 References


Chapter 2

Literature Review

2.1 Overview and outline

Physical inactivity is becoming increasingly common in the modern Western lifestyle\textsuperscript{1} and is a risk factor for several chronic diseases.\textsuperscript{2} It is estimated that physical inactivity is responsible for 3.2 million deaths annually worldwide.\textsuperscript{3} In order to reverse this trend, it is important to understand all of the aspects of physical activity and the associated health benefits. For example, are the health effects different for the same amount of physical activity happening a few minutes at a time versus in larger chunks, or for equivalent energy expenditure from shorter duration high intensity activity versus longer duration moderate intensity activity? This may lead to finding more accessible options for accumulating meaningful physical activity time to recommend to the 85\% of Canadian adults who do not meet the current physical activity guidelines.\textsuperscript{4}

This literature review begins with definitions of the key terms and concepts used in this thesis. The next section provides a brief overview of the public health burden of physical inactivity. This is followed by a section that discusses the associations between physical activity and health, with an emphasis placed on bout duration and intensity. Finally, there will be a summary with general conclusions and future directions.
2.2 Key definitions

2.2.1 Physical activity and physical inactivity

Physical activity is broadly defined as bodily movement produced by skeletal muscles resulting in energy expenditure. Physical activity is described and measured through five main aspects, including: frequency, intensity, time, type and domain. Frequency corresponds to the number of physical activity sessions, typically counted only if they occur in a period lasting 10 minutes or longer. Intensity refers to the energy expenditure of the activity, and is often measured using the metabolic equivalent (MET) scale that compares the energy expenditure of an activity to that of a resting state, which is equal to 1 MET. Intensity is commonly categorized as sedentary (1.0-1.5 METs), light (1.6-2.9 METs), moderate (3.0-5.9 METs) or vigorous (≥6.0 METs). Time can refer to the duration of a physical activity session, often dichotomized as sporadic (<10 minutes) or bouted (>10 minutes), or the amount of physical activity performed over a given reference period, often a day or week. Type refers to the modality of the physical activity, namely whether it occurs through walking, running, biking, dancing, etc. Type can also refer to categorization of physical activity into 3 main types based on its physiological response and energy demand. These 3 types are: aerobic activities (i.e. jogging or cycling), resistance training activities (i.e. weight lifting) and flexibility activities (i.e. stretching, yoga). Lastly, domain specifies the context in which the physical activity happens, such as leisure time, occupational, household and transportation activities.

Physical inactivity as used in this thesis refers to not meeting the physical activity recommendations for good health (detailed below).
2.2.2 Physical activity guidelines

Due to overwhelming evidence supporting the role of physical activity in the prevention of several chronic diseases, public health recommendations for physical activity have been developed. The first major iteration of these recommendations was published in 1995 in the United States through a joint effort between the Centres for Disease Control and Prevention and the American College of Sports Medicine. Here it was recommended that adults spend 30 minutes or more engaging in moderate-intensity physical activity on most, if not all, days of the week. These recommendations also noted the importance of increasing physical activity levels in those who are largely inactive, as there are greater health benefits to be gained in this population compared to those who are already sufficiently active.

The recommendations in place today have changed in some ways, but remain largely consistent with the 1995 recommendations. Current recommendations for Canadian adults and American adults, as well as recommendations from the World Health Organization, suggest a minimum of 150 minutes of moderate-intensity activity per week accumulated in bouts of at least 10 minutes. Current recommendations also acknowledge that energy expended during 1 minute of vigorous intensity activity is equivalent to 2 minutes of moderate intensity activity. This allows the accumulation of the recommended 150 minutes per week to be accomplished via 150 minutes of moderate intensity activity, 75 minutes of vigorous intensity activity or an equivalent combination of moderate and vigorous intensity physical activity.
2.2.3 Measuring physical activity levels

Measuring physical activity levels at an individual or population level represents a challenging and dynamic task. There are three main types of physical activity measurement techniques: criterion standards, subjective measures and objective measures. Criterion standards are often used for evaluating the energy expenditure or intensity associated with certain types of physical activity. They are not typically used to assess physical activity levels in large samples or over prolonged periods, but rather as cross-validation for subjective and objective measures. Examples of this type of technique include direct observation, doubly labelled water and indirect calorimetry.

Subjective measures represent the most common form of physical activity measurement and often rely on the use of questionnaires. Questionnaires are generally the most practical and cost-effective method of collecting data about physical activity levels, especially in larger samples as they do not require expensive equipment or a large time commitment from the participants. Questionnaires in general are subject to several important biases. Recall bias is a major concern, as participants may not remember specific details about their activity in the past. Questionnaires are also prone to social desirability bias, as participants often over-report their physical activity and under-report their sedentary time to appear healthier.

Specifically, short or incidental bouts of physical activity and physical activity intensity can be difficult to assess via questionnaire. Short or incidental bouts of physical activity are commonly not captured by questionnaires or not captured well. This is likely due to the high cognitive demand associated with remembering such brief periods of activity. To assess
physical activity intensity, questionnaires often rely on the participant’s perceptions of the intensity of the physical activity accumulated, which can vary from person to person depending on their cardiorespiratory fitness. Additionally, reported time spent in an activity of a given intensity may not fully reflect whether that intensity was maintained the entire duration or varied (e.g. 40 minutes of jogging at 10 kilometers/hour reported but contained 10 minutes of walking throughout).

Objective measures of physical activity, primarily obtained using accelerometers, have become a staple in physical activity epidemiology research. Accelerometers are small electronic sensors most commonly placed on the hip that record movement intensity over a period of time specified by the user (often 1 minute intervals obtained continuously over 7 days). This movement intensity, in the form of counts per minute (CPM), can be used to objectively assess physical activity time, intensity and bout length over the given wear period. Given that recorded accelerometer data is quite unrefined (7 days of activity with 1 minute intervals for 1 person results in 10,080 data points), several data processing, reduction and quality control procedures are necessary before meaningful information can be attained. An example of an accelerometer output is shown in Figure 2.1.

The use of accelerometers has become cost effective enough for incorporation into several national surveillance programs, including the Canadian Health Measures Survey and the National Health and Nutrition Examination Survey (NHANES) in the United States. Accelerometers address key limitations that are inherent to questionnaire measures of physical activity. Namely, by directly measuring physical activity with electronic sensors, they remove response biases and eliminate the need to remember specific details of past physical activity.
durations or intensity. However, accelerometers are not without limitations. Primarily, they are not able to capture movement that is not step-based (i.e. cycling or strength training)\(^{23}\) and they do not provide qualitative information regarding the type or domain of physical activity.

![Figure 2.1 Example of collected minute-by-minute accelerometer data over the course of 1 day](image)

**2.2.4 Metabolic syndrome**

The metabolic syndrome (MetS) is a clustering of cardiometabolic risk factors that is estimated to be present in 19% of Canadian adults\(^ {24}\) and 34% of American adults.\(^ {25}\) An individual is considered to have the metabolic syndrome when at least 3 of the 5 following criteria are above the predefined threshold: high waist circumference (men ≥102 cm, women ≥88 cm), high triglycerides (≥150 mg/dL), low HDL-cholesterol (men <40 mg/dL, women <50 mg/dL), high blood pressure (systolic ≥130 mmHg or diastolic ≥85 mmHg or hypertension medication use) and high fasting glucose (≥ 100 mg/dL or diagnosed diabetes or insulin use or glucose medication use).\(^ {26}\) Those who have the MetS have a moderately increased risk of
cardiovascular disease (relative risk (RR) = 2.35; 95% Confidence Interval (CI): 2.02-2.73), all-cause mortality (RR = 1.58; 95% CI: 1.39-1.78), and an increased risk of type 2 diabetes mellitus (RR = 2.99; 95% CI: 1.96-4.57). It is, however, unclear whether this effect is due to the clustering of the components or the individual components themselves. Overall, MetS has been identified as an important target for secondary prevention of mortality and morbidity and because of its high prevalence in the population, represents an important public health burden.

2.3 Public health burden of physical inactivity in adults

A recent report on global inactivity in 2012 places the prevalence of self-reported physical inactivity in adults at 31%, representing nearly double the prevalence reported in 2002. Notable disparities for physical inactivity have also been reported, as women are found to be more inactive than men, older age groups to be more inactive than younger age groups, and high-income countries to have more inactivity than low-income countries. This high prevalence of physical inactivity is estimated to be responsible for 5.3 million deaths globally that could have been prevented if people had been sufficiently active, placing physical inactivity as the fourth leading cause of mortality worldwide.

Physical inactivity during leisure time appears to have decreased over the last few decades in Canada. Self-reported physical activity data from the Canadian Fitness Survey and Physical Activity Monitor survey collected between 1981 and 2000 at various time points shows a general decrease in physical inactivity when defined as averaging <3.0 MET-hours a day of leisure time physical activity (LTPA). In 1981, 79.4% of adults 18 years of age and older were considered physically inactive compared to 48% in 2000. Additionally, self-reported LTPA data
from National Population Health Surveys (1994-1998) and Canadian Community Health Surveys (2001-2007) shows that physical inactivity levels decreased from 46% in 1994-1995 to 35% in 2007. This study used a weekly activity target for MVPA in order to be considered sufficiently active, which may account for some of the differences in the overlapping years with the study by Craig et al. These observed decreases in physical inactivity (an increase in physical activity) may be the result of true temporal changes; however, it is not possible to rule out differences in both the definitions of physical inactivity and variations in the questions and methods used to capture the self-reported data.

Self-reported physical inactivity in Canada compares favourably to the United States and the global estimates. Using self-reported data from the American Behaviour Risk Factor Surveillance System, Brownson et al. observed declines in physical activity from 1990 to 2000. This is primarily attributable to the declining rates of occupational and transportation physical activity overshadowing a minor increase (<10%) in LTPA. The observed increase in physical activity for Canadian adults runs opposite the current American and global trends. This is likely due to the exclusive use of LTPA compared to use of all domains of activity in the American and global estimates. As occupational and transportation activity rates decrease, a corresponding increase in LTPA is likely. If people are required to be less active in their occupations and transportation methods, they may make a greater effort to be more active in their leisure time.

Recent surveillance efforts for physical activity and inactivity have incorporated objective accelerometer assessment, and have painted a different picture for inactivity levels in Canada. Data from the 2007-2009 Canadian Health Measures survey suggests that 84.6% of
Canadian adults are not sufficiently active based on the current 150 minutes/week of MVPA recommendation. This number climbs to 95.2% when considering the old recommendations of 30 minutes/day of MVPA on at least 5 days a week. In the United States, using accelerometer data from the 2005-2006 NHANES, it is estimated that 90.4% of adults accumulate less than 150 minutes/week of MVPA. It is worth noting that accelerometer data does not distinguish between occupational, transportation and leisure-time physical activity. As such, these findings suggest that 85% of Canadian adults and 90% of American adults do not accumulate 150 minutes/week of MVPA even when considering all 3 domains.

Insufficient physical activity is associated with a myriad of chronic diseases, including cardiovascular disease, diabetes, cancer, and depression, and also with premature death. A recent article calculated population attributable fractions (PAF) for physical inactivity, defined as not meeting the 150 minutes/week of MVPA recommendation, and several chronic diseases as well as all-cause mortality. A PAF represents the percent of cases for a given outcome in the population that would not happen if the risk factor of interest, physical inactivity, was not present. Globally, PAF estimates for physical inactivity are 6% for coronary heart disease, 7% for type II diabetes, 10% for breast and colon cancer, and 10% for all-cause mortality. In Canada, estimates based on objectively measured physical inactivity suggest even higher PAF values, at approximately 23% for hypertension, 26% for coronary artery disease, 25% for stroke, 24% for colon cancer, 32% for osteoporosis, and 38% for type 2 diabetes in men. Similar estimates were observed for women in addition to a PAF of 15% for breast cancer.

The direct (i.e. medical-care expenditures) and indirect (i.e. lost economic output due to illness, work-related disability and premature death) costs of physical inactivity also represent a
measure of burden. The Canadian economic burden of physical inactivity in adults is currently estimated at 2.4 billion dollars in direct costs and 4.3 billion dollars in indirect costs, for a total of 6.8 billion dollars.\textsuperscript{38} This represents nearly 4\% of overall healthcare spending in Canada.\textsuperscript{38}

2.4 Physical activity and health in adults

The association between physical activity and health has been well established. A recent systematic review evaluated the evidence for a dose-response effect of physical activity on seven major chronic diseases and all-cause mortality.\textsuperscript{36} The authors concluded that regular physical activity, or meeting the current public health recommendations, is an effective method of primary prevention for premature mortality, cardiovascular disease, stroke, hypertension, colon and breast cancer, type 2 diabetes and osteoporosis. Risk reductions for these 7 outcomes (excluding osteoporosis) were found to range between 20 to 44\% when comparing those who were the most active to those who were the least active.

Despite clear evidence that physical activity has a meaningful impact on health, very few people are reaching what is currently recommended as the weekly dose. This raises the question of whether the recommendations are too difficult for people to meet and whether alternatives should be investigated. The following two sections critically review potential alternatives to the currently recommended 150 weekly minutes of bout MVPA, namely sporadic physical activity and high intensity physical activity.

2.4.1 Physical activity bout duration and health

Physical activity occurring in periods of less than 10 minutes has been termed sporadic physical activity (SPA). While SPA is acknowledged to be important in children and youth,\textsuperscript{39} it is
often neglected in adults. Before physical activity guidelines for health were published, guidelines for cardiorespiratory fitness suggested a 30 minute minimum bout length.\textsuperscript{40} Later, in 1995, a landmark publication about physical activity recommendations for good health in adults\textsuperscript{9} lowered this bout restriction length to reflect emerging evidence that three 10 minute daily sessions of physical activity were as beneficial to fitness and cardiometabolic risk factors as a single 30 minute session.\textsuperscript{41,42} This 10 minute minimum bout length restriction for adults still remains in the Canadian physical activity guidelines;\textsuperscript{10} however, recent epidemiologic evidence suggests that the 10 minute minimum bout length restriction may not be necessary.\textsuperscript{43-45}

Evidence on SPA has become more feasible in the last decade with the rise of accelerometers, which allow researchers to objectively measure physical activity on a minute-by-minute basis over an extended period (e.g. over 7 days). Several estimates of the proportion of total MVPA that is sporadic have been recently published. In adults, evidence from a representative sample of Canadians\textsuperscript{45} and the Third Generation Cohort of the Framingham Heart Study\textsuperscript{44} suggests that SPA represents between 53\% and 68\% of total MVPA respectively. Estimates from a representative sample of youth\textsuperscript{46} and a small convenience sample of older adults\textsuperscript{47} also found a similar proportion of 66\% of total MVPA time. If these estimates approximate the true nature of physical activity, then SPA represents a major portion of physical activity. Detailed descriptive information about the amount of SPA that people accumulate is still lacking, specifically in terms of the relative time spent engaging in light, moderate and vigorous intensity SPA and how SPA differs by age, sex, race, and other characteristics.
While descriptive information on SPA in adults is sparse, research supporting the associated health benefits in adults compared to more traditional bouted physical activity is more available. One of the initial etiological papers investigating SPA examined the association between physical activity accumulated in bouts and sporadically and measures of obesity. This paper was based on data from over 3200 adults from the 2003-2004 cycle of the NHANES; a representative cross-sectional survey of Americans. The authors found that MVPA accumulated in bouts shorter than 10 minutes was a weak but statistically significant predictor of BMI ($\beta = -0.07$, $p=0.005$) and waist circumference ($\beta = -0.23$, $p < 0.001$). MVPA accumulated in bouts was shown to have a slightly stronger association with these two obesity measures than MVPA in sporadic sessions ($\beta = -0.15$ and $\beta = -0.36$); however, this may have been due to the higher average intensity of the bouted activity versus the sporadic activity (2370 versus 1420 accelerometer counts per minute).

Ross and McGuire investigated SPA and cardiovascular fitness in a sample of 135 abdominally obese adults who did not accumulate bouted MVPA. They found that cardiorespiratory fitness was positively associated with sporadic MVPA ($\beta = 1.36$, 95% CI = 0.61-2.10), independently of BMI and gender; although, this association was weak ($r^2 = 0.20$). In a similar sample, McGuire and Ross found that sporadic MVPA was negatively associated with visceral adipose tissue ($r^2 = 0.03$, $p = 0.04$). However, in both studies the participants did not accumulate enough vigorous physical activity to be able to assess the full spectrum of intensity for SPA, and the use of a small sample with specific characteristics limits the generalizability of their findings.
Glazer et al.\textsuperscript{44} examined the impact of bout duration on cardiovascular disease risk factors in a cross-sectional analysis of 2109 adults from the Framingham Heart Study. Here the authors found that MVPA accrued sporadically had statistically similar associations to health outcomes as to MVPA accrued in bouts: waist circumference ($\beta = -0.86, \beta = -1.17$, $p$ for comparison = 0.36), BMI ($\beta = -0.30, \beta = -0.46$, $p = 0.27$), triglycerides ($\beta = -4.42, \beta = -3.17$, $p = 0.48$), and higher levels of HDL cholesterol ($\beta = 0.87, \beta = 1.45$, $p = 0.17$). It was also found that meeting the physical activity guidelines with exclusively bouted MVPA resulted in non-significant odds ratio reductions for hypertension (Odds Ratio (OR) = 0.96, 95% CI = 0.66-1.40) and impaired fasting glucose (OR = 0.98, 95% CI = 0.69-1.38) compared to significant odds ratios (OR = 0.78, 95% CI = 0.61-0.99; OR = 0.69, 95% CI = 0.55-0.86 respectively) in individuals who met the MVPA guidelines while incorporating both bouted and sporadic MVPA. While their study had some weaknesses, including a homogenous sample population (73% Caucasian) and an inability to control for important confounding variables (i.e. diet factors), these findings provide some evidence that sporadic MVPA provides health benefits.

Most recently, Clarke and Janssen\textsuperscript{45} investigated the associations between sporadic activity and the MetS in 1129 Canadian adults using data collected within the Canadian Health Measures Survey. The authors found a 9% reduction (OR = 0.91, 95% CI = 0.86-0.96) in the odds of having the MetS for each MET hour/week of bouted MVPA versus a 13% reduction (OR = 0.87, 95% CI = 0.81-0.92) for each MET hour/week of sporadic MVPA. This indicates that an additional MET hour/week of either activity type resulted in a similar reduction in the likelihood that an individual had the MetS. Strengths of this study include a strongly representative
sample population and the presence of confounding information not available in prior studies. The primary limitation was the cross-sectional nature of the study.

The relationship between sporadic physical activity and health outcomes has also been approached from a different angle not related to energy expenditure. Healy et al.\textsuperscript{50} investigated the importance of breaks in sedentary time, a measurement of how often periods of sedentary behaviour were interrupted by physical activity over 1.5 METs, on metabolic risk. Using a sample of 168 Australian adults, the authors found that an increased number of breaks in sedentary time was weakly associated with lower waist circumference ($\beta = -0.16; \text{95\% CI} = -0.31$ to -0.02), BMI ($\beta = -0.19; \text{95\% CI} = -0.35$ to -0.02), triglycerides ($\beta = -0.18; \text{95\% CI} = -0.34$ to -0.02) and 2-h plasma glucose ($\beta = -0.18; \text{95\% CI} = -0.34$ to -0.02) independent of total sedentary time and time spent in bouted MVPA. While this finding was in a small sample, similar associations between cardiometabolic health and sedentary breaks have since been reported in representative samples of American\textsuperscript{51} and Canadian adults.\textsuperscript{52} Sedentary breaks represent an avenue not involving bouts of physical activity as evidence suggests the average break in sedentary time lasts approximately 4.5 minutes.\textsuperscript{50}

The potential health benefits of breaking up sedentary time with sporadic physical activity is further supported by experimental evidence that shows incorporating regular SPA breaks during a prolonged period of sedentary time reduced postprandial glucose response when compared to a condition involving uninterrupted sedentary time.\textsuperscript{53-55} In a randomized crossover trial in 70 inactive but otherwise healthy adults, Peddie et al.\textsuperscript{54} found that incorporating ~2 minute physical activity breaks every 30 minutes during a 9 hour sedentary period resulted in reductions in insulin levels and plasma glucose levels compared to an
uninterrupted 9 hour sitting condition. Furthermore, the observed reduction in the breaks condition was also greater than a condition involving 15 minutes of sitting, 30 minutes of bouted activity, then 8 hours and 15 minutes of sitting. Bailey and Locke\textsuperscript{55} found similar reductions in plasma glucose in a sample of 10 non-obese adults using a 5 hour protocol with 2 minute breaks of light intensity walking compared to uninterrupted sitting and standing break conditions. However, there are still questions surrounding this area of literature. Evidence for short-term cardiometabolic health benefits are not well supported for components of cardiometabolic health outside of postprandial glucose responses.\textsuperscript{54,55} Additionally, it has yet to be demonstrated whether these acute changes observed in glucose during one laboratory session translate into long-term health benefits.

Overall, literature on the positive health effects of SPA is growing, and in many circumstances showing equivalent results to that of bouted physical activity. However, there is little descriptive information on SPA in adult populations. Greater knowledge about the tendencies and practices surrounding SPA in adults will provide evidence that may be used to inform future public health interventions. Furthermore, SPA has not yet been investigated when incorporating all 3 of the major intensity categories. Previous studies have only investigated SPA relationships with moderate and vigorous intensity activities grouped together.

2.4.2 Physical activity intensity and health

Specification of a minimum intensity requirement for physical activity in adult physical activity guidelines dates back to the 1995 recommendations\textsuperscript{9} in the United States, where it was recommended that 30 minutes of physical activity should be accumulated, on most or all days
of the week, of moderate-to-vigorous intensity. Recently, this recommendation has been modified to account for the difference in energy expenditure between moderate and vigorous intensity activities, accepting that the energy expended during 1 minute of vigorous intensity physical activity is equivalent to that expended during 2 minutes of moderate intensity physical activity.\textsuperscript{11} Thus, most current guidelines recommend 150 minutes per week of moderate activity or 75 minutes per week of vigorous activity or an equivalent combination of the two intensities.

Some evidence\textsuperscript{56-58} suggests that there may be greater relative health benefits for equivalent energy expenditure from vigorous intensity activity versus moderate intensity activity. Initial evidence for a greater positive health effect of energy expenditure from vigorous physical activity can be found in an article by Lee et al.\textsuperscript{56} Using a sample of over 13,000 participants from the Harvard Alumni Health Study assessing physical activity using self-report, the authors examined the association between various intensities of physical activity and all-cause mortality. Compared to equivalent energy expenditure from light and moderate physical activity, energy expenditure from vigorous physical activity was the strongest predictor (p, trend < 0.001) of mortality risk. This means that increasing energy expenditure from vigorous activity was more closely related with lower mortality rates than increasing energy expenditure from the other intensities. These findings are limited by the self-report nature of the physical activity assessment and reduced measurement precision for light and moderate intensity activity. Additionally, activity was only assessed once during the 15 year study period, which likely resulted in some misclassification resulting from changing exercise habits throughout those 15 years.
More recent epidemiologic evidence involving the use of accelerometers to capture physical activity data was published by Janssen and Ross. Using data collected from the 2003-2004 and 2005-2006 cycles of NHANES, the authors investigated the relationship between equivalent weekly energy expenditure from moderate and vigorous intensity physical activity and the MetS. In the sample of 1841 adults, the estimated prevalence of the MetS for those with 500 MET minutes/week from moderate intensity physical activity decreased by 15.5% compared to those with 0 weekly minutes, while the estimated prevalence for adults with 500 MET minutes/week of vigorous intensity physical activity decreased by 37.1% comparatively. This finding illustrates that matched energy expenditure from vigorous intensity physical activity leads to a lower likelihood of having the MetS than energy expenditure from moderate intensity physical activity. While this article provides compelling cross-sectional evidence, physical activity was measured without consideration of bout length, limiting the ability to comment on the impact of increased intensity for either sporadic or bouted physical activity specifically. Intensity data derived from accelerometers is also prone to potential misclassification, as an accelerometer count of 1952 (i.e. moderate threshold) may represent a different relative intensity between any two people depending on the cardiorespiratory fitness of the individual (e.g. a 20 year old athlete versus a 60 year old).

Regarding the relationship between SPA and the various intensities, little work has been published. A small study involving 42 Japanese women by Ayabe et al. reported a significant negative correlation for fasting glucose and the frequency of 1 minute periods of vigorous intensity activity (r = -0.328, p < 0.05) but not with the frequency of 1 minute periods of either light or moderate intensity. This negative correlation represents a weak effect size, in that it
indicates that the number of 1 minute periods of vigorous intensity activity explains 11% of the variation in fasting glucose levels observed. Additionally, two studies in obese adults observed significant reductions in visceral adipose tissue\textsuperscript{49} and a positive association with cardiorespiratory fitness ($r^2 = 0.20$, $p < 0.001$)\textsuperscript{48} for sporadic MVPA but not sporadic light intensity physical activity (LIPA). Together, these findings provide some preliminary evidence to suggest that an intensity dependent relationship for SPA and cardiometabolic health may exist.

In contrast to the results discussed above, evidence from a small crossover trial of 19 overweight and obese adults building on the sedentary interruptions aspect of SPA suggests intensity may not be important. Dunstan et al.\textsuperscript{53} investigated the impact of light or moderate sporadic physical activity breaks during a sedentary period versus no physical activity breaks on plasma glucose and insulin response. Each participant attended three separate sessions at least 6 days apart, completing three trial conditions in a randomized order. The 3 conditions involved uninterrupted sitting, sitting interrupted every 20 minutes by 2 minute light intensity activity breaks, and sitting interrupted every 20 minutes by 2 minute moderate intensity breaks; each for a 5 hour period. The authors found similarly lower mean net postprandial glucose for the light intensity breaks condition (M =5.2 mmol/L; 95% CI = 4.1-6.6) and the moderate intensity breaks condition (M =4.9 mmol/L; 95% CI = 3.8-6.1) by comparison to the uninterrupted sitting condition (M =6.9 mmol/L; 95% CI = 5.5-8.7). However, no differences between the light and moderate intensity conditions were observed. These findings indicate that there is an acute benefit to breaking up sedentary time with sporadic activity on glucose levels, but that the intensity level of that sporadic activity is not important, at least between light and moderate intensities.
Evidence suggesting the importance of physical activity intensity for health is more established in total and bouted physical activity compared to SPA. Evidence for an intensity-dependent relationship between SPA and health outcomes is currently restricted to small experimental studies in overweight and obese individuals or studies that only evaluate SPA intensity for acute responses in glucose through sedentary interruptions. There is a clear need for observational evidence in larger and more representative samples in order to better understand the relationship between SPA intensity and more chronic health outcomes. This type of observational evidence may also be able to elucidate the role of SPA, as to whether it is associated primarily through interrupting sedentary periods or through the expenditure of energy.

2.5 Summary and conclusions

This literature review presents key research demonstrating the importance of physical activity for the prevention of a myriad of health outcomes and also that physical activity levels are declining throughout most of the world despite prominent published public health recommendations. This illustrates the need for finding ways to make accumulating meaningful physical activity more accessible, as evidence suggests the risks for many health outcomes decrease even with small increases in physical activity. In the past, physical activity research primarily focused on bouted physical activity of moderate intensity and above due to measurement limitations. As such, the current public health recommendations primarily are based on research with this type of activity. Now, accelerometers have been incorporated into many intervention and population studies, increasing the feasibility of studying specific aspects of physical activity such as SPA and more intensity categories.
Current literature surrounding the health benefits of SPA and of increased exercise intensity is built on evidence from trials and cross-sectional studies. Longer-term prospective studies are lacking in these areas, and due to feasibility issues surrounding the nature of exposure collection and adherence, this gap will likely persist. Also, despite several papers investigating SPA and the associated health benefits, little descriptive information surrounding SPA practices in adults and the individual characteristics that influence those practices exists. Finally, while the importance of higher intensity BPA is supported, information about the interplay between SPA and the various exercise intensities is lacking, as is information regarding the pathway through which SPA influences health outcomes.
2.6 References


Chapter 3

A Description of the Volume and Intensity of Sporadic Physical Activity among Adults
3.1 Abstract

**Background:** Emerging evidence indicates that accumulating physical activity in periods of less than 10 minutes, termed sporadic physical activity (SPA), has similar effects on health as the similar volume of bouted physical activity (BPA). The purpose of this study was to describe the volume and intensity of SPA in adults.

**Methods:** Participants consisted of a representative sample of 6,040 adults aged 20 years and older from the 2003-2006 U.S. National Health and Examination Nutrition Survey. Physical activity was measured over 7 days using Actigraph AM-7164 accelerometers. Each minute of accelerometer data was initially categorized by intensity (sedentary, light, moderate-to-vigorous), and then non-sedentary time was categorized as following a BPA or SPA pattern (≥ or < 10 consecutive minutes).

**Results:** American adults accumulated 103 minutes/day of SPA of an intensity, which represented 27% of their total daily physical activity. Only 2 minutes/day of the SPA were of moderate-to-vigorous intensity; however, participants accumulated 16 minutes/day of moderate-to-vigorous activity embedded within light intensity BPA. This embedded moderate-to-vigorous activity represented 85% of total daily moderate-to-vigorous activity.

**Conclusions:** SPA accounted for about a quarter of total daily physical activity. While the amount of moderate-to-vigorous SPA was minimal, a significant amount of moderate-to-vigorous activity was accumulated within bouts of primarily light intensity activity.

**Key Words:** motor activity; health surveys; adult
3.2 Introduction

Physical inactivity is common in the modern Western lifestyle,¹ where it plays a role in the development of several chronic diseases.² Public health guidelines for physical activity are that adults accumulate 150 minutes per week of moderate-to-vigorous intensity physical activity (MVPA) in bouts of 10 minutes or more.³⁻⁵ This guideline is met by less than 15% of North American adults.⁶,⁷ While sporadic physical activity (SPA), or physical activity occurring in periods of less than 10 minutes, is not recognized as providing health benefits within the current physical activity guidelines, a growing body of evidence suggests otherwise.

Specifically, SPA is associated with cardiometabolic risk factors independent of bouted physical activity (BPA),⁸⁻¹⁰ and the associations between SPA and cardiometabolic risk factors are as strong as they are for BPA.¹⁰ Notable barriers to physical activity participation, including a lack of time and self-efficacy,¹¹⁻¹³ may be less relevant for SPA than BPA.

Very little is known about the amount of SPA that people accumulate. Data from a representative sample of adolescents¹⁴ and a small convenience sample of older adults¹⁵ suggest that approximately 66% of total MVPA occurs sporadically. However, the relative time spent engaging in moderate or vigorous intensity SPA is unknown. Additionally, no descriptive information exists regarding the amount of time spent engaging in light intensity SPA. Therefore, the purpose of this study is to describe SPA in adults. Specifically, this study describes how much daily SPA adults accumulate, the intensity at which it is accumulated, the contribution of SPA to total physical activity, and whether these characteristics vary by sociodemographic factors. These results will provide foundational knowledge that can be used to help design SPA interventions.
3.3 Methods

Study Design and Participants

Participants were from the 2003-2004 and 2005-2006 cycles of the U.S. National Health and Nutrition Examination Survey (NHANES); a nationally representative cross-sectional survey.\textsuperscript{16} NHANES collects data through home interviews and physical examinations in mobile exam centres. All participants gave informed consent and NHANES was approved by the National Center for Health Statistics.

The current study was limited to NHANES participants aged 20 years of age and older, non-pregnant women, and those who completed both the home interview and mobile exam centre visit. This left an eligible sample of 9451. We excluded 3411 participants with missing or invalid physical activity accelerometer data (explained below), leaving a final sample of 6040.

Potential selection bias arising from the lack of valid physical activity accelerometer data in 36% of eligible participants was assessed by comparing several characteristics (sex, age, ethnicity, obesity) between the 6040 participants with valid data to the 3411 without. Differences were observed between the two samples for age, sex, and ethnicity but not for obesity. The age, sex, and racial differences were used to derive new sample weights to account for the selection bias.

Sociodemographic Variables

Sociodemographic variables included sex, age (20-39 years old, 40-59 years old or 60+ years old), race/ethnicity (non-Hispanic white, non-Hispanic black, Mexican American or other) and body mass index (BMI) status\textsuperscript{17} (underweight <18.5 kg/m\textsuperscript{2}, normal weight 18.5-24.9 kg/m\textsuperscript{2},
overweight 25-29.9 kg/m², or obese ≥30 kg/m²). BMI values were calculated from measured heights and weights.

**Physical Activity**

SPA and BPA were assessed using Actigraph AM-7164 uniaxial accelerometers (Actigraph, Ft. Pensacola, FL). These accelerometers recorded average movement intensity, measured by counts in 1 minute intervals or epochs. Participants were given accelerometers at their mobile examination centre visit and asked to wear them on an elasticized belt on their right hip for the 7 days after the visit. Participants were instructed to only remove the accelerometer when sleeping or when the accelerometer would get wet (e.g. bathing or swimming). After the 7 day measurement period was completed, participants mailed the accelerometers back to the NHANES researchers. The accelerometers were then tested to ensure calibration, the data were downloaded, and implausible count values were removed.

Further data reduction was carried out by the authors based on existing protocols.\textsuperscript{10,18-22} Initially, we removed non-wear periods and calculated the wear time for each day. Non-wear periods were defined as periods with ≥ 90 minutes of zero counts, with an allowance for 2 minutes of counts between 0 and 100.\textsuperscript{20} Next, each day was coded as valid or invalid and invalid days were removed from the dataset. Days were considered valid if the participant had ≥ 10 hours of wear time.\textsuperscript{18,19,22} We then removed participants with 3 or fewer valid days.\textsuperscript{18,19,21,22}

After removing invalid days and participants with an insufficient number of valid days, each minute of physical activity data was categorized into one of four intensities based on established cut-points for the Actigraph AM-7164 accelerometer.\textsuperscript{18,23} Specifically, values between 0-99 counts per minute were classified as sedentary, values between 100-2019 were
classified as light intensity, values between 2020-5998 were classified as moderate intensity, and values ≥ 5999 were classified as vigorous intensity. Data were then classified as being either BPA or SPA of different intensities, as explained in the following paragraph and as illustrated in Figure 3.1.

![Figure 3.1 Classification of physical activity data from 95 minutes of accelerometer data obtained on a 24-year-old man.]

Initially, bouted MVPA was defined in the dataset as periods of at least 10 consecutive minutes where the accelerometer counts exceeded the moderate threshold, with an allowance of 20% of the counts (e.g. 2 minutes for a 10 minute bout) being below the moderate threshold. Once more than 20% of the minutes were below the moderate threshold, the bout was stopped (i.e. no more time was added to the bout length) and the subsequent accelerometer data were searched to locate the next bout. The time spent in bouted MVPA was summed and a daily average was created. Bouted MVPA was then removed from the dataset. Next, light intensity BPA was defined in the remaining dataset as periods of at least 10 consecutive minutes where the accelerometer counts exceeded the light intensity threshold,
with an allowance of 20% of the counts being below the threshold. As with bouted MVPA, once the 20% threshold was surpassed, the bout was stopped and the subsequent accelerometry data was searched to locate the next bout. Note that light intensity BPA included MVPA, if the amount of MVPA did not satisfy the criteria for bouted MVPA. After light intensity BPA was counted it was removed from the dataset. The remaining dataset was therefore limited to SPA and sedentary behaviour. Within that dataset the daily averages for light intensity SPA, moderate intensity SPA, and vigorous intensity SPA were calculated.

**Statistical Analysis**

Analyses were conducted using SAS v9.3 (SAS Institute Inc., Cary, NC) and SPSS v22 (IBM Corporation, Armonk, NY) and accounted for the clustered nature of NHANES and the adjusted sample weights that we created. Since the physical activity data were not normally distributed, we reported medians and interquartile ranges. Differences in median values across age, sex, ethnicity, and BMI groups were determined using Kruskal-Wallis omnibus and pairwise comparison tests. A p-value of < 0.05 was used to denote statistical significance. Adjusted p-values were used when there were multiple pairwise comparisons. Since almost all group comparisons were statistically significant, the statistical significance of these differences is not highlighted in the Results.

**3.4 Results**

A description of the sample is presented in Table 3.1. The majority of participants were between the ages of 20-30 and 40-59 years and of non-Hispanic white ethnicity. Approximately 32% were obese.
Median daily minutes of SPA in the total sample is shown in Table 3.2. American adults spent 103 minutes/day engaging in SPA, which represented 27% of their total (SPA + BPA) physical activity. The vast majority of SPA was of a light intensity (i.e. 100 of 103 minutes) and 91% of participants accumulated no vigorous intensity SPA.

### Table 3.1 Characteristics of the study sample

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<thead>
<tr>
<th>Variable</th>
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<td>Crude N</td>
<td>Weighted % (SE)</td>
<td>Crude N</td>
<td>Weighted % (SE)</td>
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<td>Weighted % (SE)</td>
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<td>976</td>
<td>39.4 (1.3)</td>
<td>992</td>
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<td>23.3 (1.0)</td>
<td>1209</td>
<td>20.9 (1.1)</td>
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<td></td>
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<td>Weighted % (SE)</td>
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<tr>
<td>Non-Hispanic white</td>
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<td>1666</td>
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<td>Non-Hispanic black</td>
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<td>Mexican American</td>
<td>1226</td>
<td>7.7 (1.1)</td>
<td>650</td>
<td>8.6 (1.2)</td>
<td>576</td>
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<tr>
<td>Other</td>
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<td>8.8 (0.8)</td>
<td>192</td>
<td>8.6 (0.9)</td>
<td>212</td>
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<tr>
<td>Body Mass Index</td>
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<td>Weighted % (SE)</td>
<td>Crude N</td>
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<td>18.5-24.9 kg/m²</td>
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<td>826</td>
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<td>917</td>
<td>30.9 (1.5)</td>
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</table>

Women accumulated slightly more SPA than men, both in minutes per day (105 vs. 101 minutes/day) and when expressed as a fraction of total physical activity (28 vs. 26%). The median minute per day SPA values were 3 to 4 minutes lower in 20-39 year olds than in the older two age groups. However in 60+ year olds, SPA as a fraction of total physical activity was 7 to 8 percentage points higher than in the two younger age groups. Mexican Americans spent 9 to 11 minutes/day less in SPA than non-Hispanic blacks and non-Hispanic whites. SPA did not differ in a meaningful way across normal weight, overweight, and obese groups; however, the underweight group accumulated 7 to 8 minutes/day more SPA than the other BMI groups. The
age, race/ethnicity, and BMI patterns noted above were almost entirely attributable to
differences in light intensity SPA. These patterns were also consistent when the sample was
divided into men (Table 3.3) and women (Table 3.4).
Table 3.2 Median (interquartile range) daily time spent in sporadic physical activity of different intensities, in minutes per day and as a fraction of total of sporadic physical activity, within the total sample and according to sex, age, race/ethnicity, and body mass index.

<table>
<thead>
<tr>
<th></th>
<th>Minutes Per Day</th>
<th>Fraction of Total Physical Activity</th>
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</thead>
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<tr>
<td></td>
<td>Light Intensity</td>
<td>Moderate Intensity</td>
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<tr>
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<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>97.6 (79.8-114.5)</td>
<td>2.6 (1.4-4.5)</td>
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<tr>
<td>Women</td>
<td>102.9 (86.0-121.0)</td>
<td>1.6 (0.9-2.8)</td>
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<tr>
<td>Age</td>
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<td></td>
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<td>20-39 years</td>
<td>97.6 (78.3-114.8)</td>
<td>2.8 (1.7-4.6)</td>
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<tr>
<td>40-59 years</td>
<td>101.4 (84.5-119.8)</td>
<td>2.3 (1.3-3.6)</td>
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<td>2.0 (1.0-3.7)</td>
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<td>102.8 (84.8-120.1)</td>
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</tr>
<tr>
<td>Mexican American</td>
<td>92.0 (69.1-111.9)</td>
<td>2.2 (1.3-3.6)</td>
</tr>
<tr>
<td>Other</td>
<td>101.4 (80.8-122.9)</td>
<td>2.2 (1.3-3.5)</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;18.5 kg/m²</td>
<td>107.8 (84.6-121.7)</td>
<td>2.2 (1.2-4.4)</td>
</tr>
<tr>
<td>18.5-24.9 kg/m²</td>
<td>100.7 (82.6-119.0)</td>
<td>2.3 (1.2-3.9)</td>
</tr>
<tr>
<td>25-29.9 kg/m²</td>
<td>100.0 (83.3-117.2)</td>
<td>2.1 (1.0-3.7)</td>
</tr>
<tr>
<td>≥30 kg/m²</td>
<td>99.5 (82.3-116.8)</td>
<td>1.9 (1.1-3.2)</td>
</tr>
</tbody>
</table>

Note: All group comparisons were statistically significant
Table 3.3 Median (interquartile range) daily time spent in sporadic physical activity of different intensities, in minutes per day and as a fraction of total of sporadic physical activity, within men and according to sex, age, race/ethnicity, and body mass index.

<table>
<thead>
<tr>
<th>Minutes Per Day</th>
<th>Fraction of Total Physical Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Intensity</td>
<td>Moderate Intensity</td>
</tr>
<tr>
<td>All Men</td>
<td>97.6 (79.8-114.5)</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>20-39 years</td>
<td>93.4 (72.6-110.7)</td>
</tr>
<tr>
<td>40-59 years</td>
<td>99.5 (80.8-116.6)</td>
</tr>
<tr>
<td>≥60 years</td>
<td>101.3 (86.1-117.1)</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>98.4 (81.6-114.7)</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>100.8 (83.8-118.7)</td>
</tr>
<tr>
<td>Mexican American</td>
<td>82.0 (61.2-105.2)</td>
</tr>
<tr>
<td>Other</td>
<td>97.5 (76.5-115.9)</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td></td>
</tr>
<tr>
<td>&lt;18.5 kg/m²</td>
<td>109.8 (81.4-122.7)</td>
</tr>
<tr>
<td>18.5-24.9 kg/m²</td>
<td>98.2 (78.8-114.6)</td>
</tr>
<tr>
<td>25-29.9 kg/m²</td>
<td>97.5 (80.8-114.5)</td>
</tr>
<tr>
<td>≥30 kg/m²</td>
<td>97.2 (79.1-113.8)</td>
</tr>
</tbody>
</table>

Note: All group comparisons were statistically significant.
Table 3.4  Median (interquartile range) daily time spent in sporadic physical activity of different intensities, in minutes per day and as a fraction of total of sporadic physical activity, within women and according to sex, age, race/ethnicity, and body mass index.

<table>
<thead>
<tr>
<th>Age</th>
<th>Light Intensity</th>
<th>Moderate Intensity</th>
<th>Vigorous Intensity</th>
<th>All Intensities</th>
<th>Light Intensity</th>
<th>Moderate Intensity</th>
<th>Vigorous Intensity</th>
<th>All Intensities</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Women</td>
<td>102.9 (86.0-121.0)</td>
<td>1.6 (0.9-2.8)</td>
<td>0 (0-0)</td>
<td>105.2 (88.6-124.1)</td>
<td>27.3 (19.6-35.5)</td>
<td>0.4 (0.2-0.7)</td>
<td>0 (0-0)</td>
<td>27.7 (20.0-36.2)</td>
</tr>
<tr>
<td>20-39 years</td>
<td>102.0 (83.8-119.2)</td>
<td>2.4 (1.4-3.9)</td>
<td>0 (0-0)</td>
<td>104.6 (86.2-122.7)</td>
<td>25.7 (17.7-33.0)</td>
<td>0.6 (0.3-1.0)</td>
<td>0 (0-0)</td>
<td>26.6 (18.4-33.8)</td>
</tr>
<tr>
<td>40-59 years</td>
<td>103.4 (87.0-123.1)</td>
<td>1.8 (1.1-2.8)</td>
<td>0 (0-0)</td>
<td>105.6 (89.4-126.3)</td>
<td>25.7 (19.0-33.4)</td>
<td>0.4 (0.3-0.7)</td>
<td>0 (0-0)</td>
<td>26.5 (19.4-34.2)</td>
</tr>
<tr>
<td>≥60 years</td>
<td>103.6 (88.1-120.2)</td>
<td>0.8 (0.4-1.3)</td>
<td>0 (0-0)</td>
<td>104.7 (89.1-121.4)</td>
<td>32.4 (23.5-44.3)</td>
<td>0.2 (0.1-0.5)</td>
<td>0 (0-0)</td>
<td>32.7 (23.7-44.6)</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>102.8 (86.4-120.6)</td>
<td>1.6 (0.8-2.9)</td>
<td>0 (0-0)</td>
<td>105.0 (89.3-123.1)</td>
<td>27.5 (20.1-35.6)</td>
<td>0.4 (0.2-0.7)</td>
<td>0 (0-0)</td>
<td>28.2 (20.6-36.2)</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>104.1 (86.0-121.0)</td>
<td>1.6 (0.9-2.6)</td>
<td>0 (0-0)</td>
<td>106.7 (88.2-124.7)</td>
<td>27.0 (19.8-35.9)</td>
<td>0.4 (0.2-0.7)</td>
<td>0 (0-0)</td>
<td>27.6 (20.1-36.7)</td>
</tr>
<tr>
<td>Mexican American</td>
<td>98.1 (79.8-118.5)</td>
<td>1.7 (1.0-2.7)</td>
<td>0 (0-0)</td>
<td>100.1 (82.0-120.9)</td>
<td>24.5 (16.2-32.5)</td>
<td>0.4 (0.2-0.7)</td>
<td>0 (0-0)</td>
<td>25.0 (16.6-33.7)</td>
</tr>
<tr>
<td>Other</td>
<td>104.6 (85.6-126.8)</td>
<td>1.7 (1.0-2.6)</td>
<td>0 (0-0)</td>
<td>105.9 (87.3-129.6)</td>
<td>26.7 (17.1-34.5)</td>
<td>0.4 (0.3-0.6)</td>
<td>0 (0-0)</td>
<td>27.1 (17.3-35.5)</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;18.5 kg/m²</td>
<td>106.1 (85.5-121.1)</td>
<td>2.0 (1.0-3.6)</td>
<td>0 (0-0)</td>
<td>108.3 (90.9-125.6)</td>
<td>29.8 (22.8-42.3)</td>
<td>0.6 (0.3-1.0)</td>
<td>0 (0-0)</td>
<td>31.1 (23.0-43.0)</td>
</tr>
<tr>
<td>18.5-24.9 kg/m²</td>
<td>102.1 (85.2-121.6)</td>
<td>1.8 (0.9-3.0)</td>
<td>0 (0-0)</td>
<td>104.7 (87.6-125.3)</td>
<td>26.7 (19.1-33.7)</td>
<td>0.4 (0.2-0.8)</td>
<td>0 (0-0)</td>
<td>27.3 (19.5-34.5)</td>
</tr>
<tr>
<td>25-29.9 kg/m²</td>
<td>103.6 (88.7-122.2)</td>
<td>1.4 (0.8-2.6)</td>
<td>0 (0-0)</td>
<td>106.0 (90.2-124.1)</td>
<td>27.1 (19.4-35.9)</td>
<td>0.4 (0.2-0.7)</td>
<td>0 (0-0)</td>
<td>27.7 (19.9-36.7)</td>
</tr>
<tr>
<td>≥30 kg/m²</td>
<td>102.9 (85.8-119.2)</td>
<td>1.6 (0.9-2.6)</td>
<td>0 (0-0)</td>
<td>104.6 (87.5-121.2)</td>
<td>27.9 (19.9-36.8)</td>
<td>0.4 (0.3-0.7)</td>
<td>0 (0-0)</td>
<td>28.6 (20.3-37.4)</td>
</tr>
</tbody>
</table>

Note: All group comparisons were statistically significant with the exception of vigorous intensity minutes in the Non-Hispanic black and Mexican American groups and light intensity minutes in the <18.5 kg/m² and ≥30 kg/m² groups.
Given the lack of moderate and vigorous intensity SPA, we decided *a posteriori* to investigate moderate and vigorous intensity activity embedded within light intensity BPA. This is hereafter referred to as embedded MVPA. Visual inspection of the accelerometer data revealed that many of the light intensity bouts contained some embedded MVPA (see Figure 3.1 for example). As shown in Table 3.5, the median value for embedded MVPA within the total sample was 16 minutes/day. Men accumulated twice as much embedded MVPA as women (20 vs. 10 minutes/day) and 20-39 year olds accumulated more embedded MVPA than 40-59 year olds and 60+ year olds. Non-Hispanic blacks accumulated the least amount of embedded MVPA. Median embedded MVPA values were 5 to 8 minutes/day higher in the normal weight and overweight groups than in the underweight and obese groups.

| Table 3.5 Median (interquartile range) minutes per day spent in moderate-to-vigorous intensity physical activity embedded within bouts of light intensity physical activity within the total sample and according to sex, age, race/ethnicity, and body mass index |
|---------------------------------------------|-----------------|-----------------|-----------------|
|                                             | Moderate Intensity | Vigorous Intensity | Moderate-to-Vigorous Intensity |
| Total Sample                                | 14.4 (5.2-28.5)  | 0.0 (0.0-0.2)   | 15.5 (5.7-29.7)  |
| Sex                                         |                  |                 |                 |
| Men                                         | 19.8 (8.3-36.2)  | 0.0 (0.0-0.4)   | 20.3 (8.5-38.2)  |
| Women                                       | 9.7 (3.3-20.8)   | 0.0 (0.0-0.0)   | 9.8 (3.4-22.0)   |
| Age                                         |                  |                 |                 |
| 20-39 years                                 | 20.5 (10.3-34.5) | 0.0 (0.0-0.7)   | 21.2 (10.8-37.0) |
| 40-59 years                                 | 15.4 (6.5-28.8)  | 0.0 (0.0-0.2)   | 15.9 (6.7-29.7)  |
| ≥60 years                                   | 3.3 (0.7-11.4)   | 0.0 (0.0-0.0)   | 3.3 (0.7-11.4)   |
| Race/Ethnicity                              |                  |                 |                 |
| Non-Hispanic white                         | 14.0 (4.7-28.0)<sup>a</sup> | 0.0 (0.0-0.2)<sup>a</sup> | 14.6 (4.8-29.4)<sup>a</sup> |
| Non-Hispanic black                         | 12.6 (4.8-26.2)<sup>a</sup> | 0.0 (0.0-0.2)<sup>a</sup> | 12.7 (4.9-27.6)<sup>a</sup> |
| Mexican American                           | 18.8 (8.4-37.0)<sup>b</sup> | 0.0 (0.0-0.3)<sup>a</sup> | 19.2 (8.5-38.0)<sup>b</sup> |
| Other                                       | 15.1 (6.6-29.0)<sup>b</sup> | 0.0 (0.0-0.2)<sup>a</sup> | 15.3 (6.7-30.7)<sup>b</sup> |
### Table 1: Body Mass Index

<table>
<thead>
<tr>
<th>Group</th>
<th>Median (IQR)</th>
<th>Mean (IQR)</th>
<th>Mean (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;18.5 kg/m²</td>
<td>12.0 (4.8-23.5)</td>
<td>0.0 (0.0-0.2)</td>
<td>12.2 (4.8-24.0)</td>
</tr>
<tr>
<td>18.5-24.9 kg/m²</td>
<td>17.1 (6.6-33.2)</td>
<td>0.0 (0.0-0.6)</td>
<td>18.3 (6.8-35.3)</td>
</tr>
<tr>
<td>25-29.9 kg/m²</td>
<td>16.0 (5.8-29.7)</td>
<td>0.0 (0.0-0.2)</td>
<td>16.7 (5.9-30.9)</td>
</tr>
<tr>
<td>≥30 kg/m²</td>
<td>10.2 (3.5-21.7)</td>
<td>0.0 (0.0-0.0)</td>
<td>10.3 (3.5-22)</td>
</tr>
</tbody>
</table>

*Note: All group comparisons were statistically significant unless the median (interquartile range) is followed by an † or ‡ symbol. Groups with the same letter symbols were not statistically different from each other.*

#### 3.5 Discussion

This representative sample of American adults spent 103 minutes/day engaging in SPA of any intensity, which represented 27% of their total physical activity. Only 3 minutes/day of the SPA was of a moderate-to-vigorous intensity; however, the sample accumulated another 16 minutes/day of MVPA embedded within bouts of primarily light intensity activity. Although there were statistically significant differences in SPA across age, sex, ethnicity and BMI groups, these differences were small and primarily due to light intensity SPA.

Our finding that moderate-to-vigorous SPA represents 13% of total MVPA in American adults is lower than what has been reported previously. Within the Third Generation Cohort of the Framingham Heart Study, mean sporadic MVPA was 19 minutes/day, which represented 68% of total MVPA time.\(^9\) Within a representative sample of Canadian adults, sporadic MVPA accounted for 53% of total MVPA energy expenditure.\(^10\) In a representative sample of youth\(^14\) and a small convenience sample of older adults,\(^15\) sporadic MVPA accounted for 66% of total MVPA time. The difference between our findings and previous findings is likely explained in large measure by differences in how SPA was classified. Specifically, in previous studies all MVPA occurring outside of bouted MVPA was considered sporadic. Conversely, in our study we
calculated two forms of non-bouted physical MVPA; MVPA that was truly sporadic and MVPA that was embedded within bouts of primarily light intensity activity. While the truly sporadic MVPA only accounted for 2 minutes/day or 13% of total MVPA, the truly sporadic and embedded MVPA combined accounted for 17 minutes/day or 98% of total MVPA in the typical participant.

We feel that it is important to differentiate between MVPA that is truly sporadic and MVPA that is embedded within bouts of primarily light intensity activity as they may influence health differently and act through different biological mechanisms. True SPA may play a role in breaking up extended sedentary periods. Recent studies have shown that the frequency of breaks in sedentary periods is associated with cardiometabolic risk factors.\textsuperscript{23-25} Conversely, MVPA embedded within light intensity bouts may impact health primarily by increasing energy expenditure. As the majority of American adults do not engage in sports\textsuperscript{26,27} that are known to contain a mixture of different movement intensities,\textsuperscript{28} it is likely that a major source of embedded MVPA in adults is through occupational activity. For example, a farmer may spend a large amount of time in light intensity activity walking around the farm then perform short bursts of higher intensity activity in the form of animal tending or hay baling.

It is encouraging that the typical American adult accumulates 18 minutes/day of non-bouted MVPA, particularly given that they spend an average of <10 minutes/day in bouted MVPA,\textsuperscript{18} a volume of MVPA that falls well below that recommended for good health.\textsuperscript{3-5} Non-bouted or SPA may also represent another intervention opportunity. In fact, SPA may be easier to intervene upon in populations without the free time or self-efficacy to participate in
extended BPA. SPA based interventions also may have potential for greater maintenance of physical activity behavior post intervention, which can be a problem for BPA interventions. Key limitations of this study warrant recognition. The physical activity patterns observed in this sample from 2003-2006 may not represent current behavior. While accelerometers provide an objective measure of physical activity, they are not without fault. They do not accurately capture activities that are not step-based (i.e. cycling, swimming), and the accelerometers used in NHANES were uniaxial and primarily captured horizontal movement at the hip. Nonetheless, we feel that a vast majority of physical activity was captured since walking is the most common form of leisure-time physical activity and is heavily involved in occupational and transportation activities. Conversely, less than 2% of Americans engage in strength training and cycling.

In summary, SPA of any intensity accounted for 27% of total daily physical activity in Americans adults. Sporadic MVPA and MVPA embedded within light intensity bouts accounted for 98% of total MVPA. Future research is needed to better understand the types of activity that represent embedded MVPA patterns, and to investigate if sporadic MVPA and embedded MVPA have a different impact on health outcomes.
3.6 References


Chapter 4

Intensity of Sporadic and Bouted Physical Activity and the Metabolic Syndrome in Adults
4.1 Abstract

**Background:** Our objective was to examine the health benefits of physical activity that does not meet the bouted moderate-to-vigorous intensity physical activity (MVPA) criteria. Specifically, we examined the association between bouted and sporadic physical activity of light and moderate-to-vigorous intensities with the metabolic syndrome (MetS).

**Methods:** The study sample consisted of 1,974 adults (≥20 years old) from the 2003-2006 U.S. National Health and Examination Nutrition Survey, a representative cross-sectional study. Physical activity was measured over 7 days using Actigraph uniaxial accelerometers. Using a cut-point of 10 minutes to differentiate between bouted and sporadic activity, we determined average daily time spent in bouts of light intensity physical activity (LIPA) and MVPA, sporadic LIPA and MVPA, and embedded MVPA. Embedded MVPA refers to MVPA that occurs within bouts of primarily LIPA. MetS status was classified based on the Joint Interim Societies definition. Associations were examined using logistic regression controlling for relevant covariates.

**Results:** The relative odds (95% confidence interval) of the MetS for every 30 minutes/day of physical activity were 0.96 (0.93-0.99) for bouted LIPA, 0.43 (0.33-0.55) for embedded MVPA, and 0.36 (0.26-0.49) for bouted MVPA. Sporadic LIPA was not associated with the MetS and the sample accumulated a negligible volume of sporadic MVPA (median of 1 minute/day).

**Conclusions:** Embedded MVPA had a stronger association with the MetS than sporadic LIPA and a comparable association to bouted MVPA.

**Key Words:** motor activity; risk factors; adult; metabolic syndrome X
4.2 Introduction

Physical activity guidelines for adults only recognize the health benefits of bouted physical activity, or physical activity that occurs in a period of at least 10 consecutive minutes. The exclusion of sporadic physical activity (i.e. physical activity occurring in periods of <10 minutes) from the guidelines implies that there is a lack of evidence supporting the health benefits of this pattern of physical activity. However, recent findings indicate that sporadic moderate-to-vigorous intensity physical activity (MVPA) is associated with cardiometabolic risk factors.\textsuperscript{1-3} There is conflicting evidence as to whether sporadic light intensity physical activity (LIPA) has health benefits. Two small experimental studies reported that breaking up prolonged periods of sedentary behaviour with sporadic LIPA improved acute postprandial glucose response.\textsuperscript{4,5} Conversely, two observational studies of abdominally obese adults who did not accumulate bouted MVPA reported that sporadic LIPA, as assessed by accelerometry over 7 days, was not associated with cardiorespiratory fitness or abdominal obesity.\textsuperscript{6,7}

Non-bouted MVPA can occur in a truly sporadic manner (e.g. a 3 minute brisk walk preceded and followed by sedentary time) and also within bouts that are primarily comprised of LIPA (e.g. a 3 minute brisk walk preceded and followed by slow walking).\textsuperscript{8} We refer to these two forms of non-bouted MVPA as sporadic MVPA and embedded MVPA, respectively. A typical adult accumulates only 2 minutes/day of sporadic MVPA, but 16 minutes/day of embedded MVPA, the latter of which accounts for 85% of total daily MVPA.\textsuperscript{8} Previous studies examining the health benefits of sporadic MVPA have not differentiated between these two forms of non-bouted MVPA.\textsuperscript{1-3} This is important because sporadic MVPA and embedded MVPA may reflect distinct behaviours that could impact cardiometabolic health through different
physiological pathways. Sporadic MVPA may affect cardiometabolic health through interruptions in prolonged periods of sedentary time, while embedded MVPA may operate through increased energy expenditure in a manner more similar to bouted MVPA.

The purpose of this study was to examine the health benefits associated with physical activity that does not meet the bouted MVPA criteria. Specifically, we examined the association between bouted and sporadic physical activity of different intensities with the metabolic syndrome (MetS) in adults. The MetS was used as the health outcome of interest because it represents a common clustering of cardiometabolic risk factors that is linked to an increased risk of type 2 diabetes, cardiovascular disease, some cancers, and all-cause mortality.9-11

4.3 Methods

Study Design and Participants

Participants were from the 2003-2004 and 2005-2006 cycles of the U.S. National Health and Nutrition Examination Survey (NHANES), a nationally representative cross-sectional survey.12 NHANES collects data through home interviews and physical examinations in mobile exam centres. All participants gave informed consent and the NHANES was approved by the National Center for Health Statistics.

The current study was limited to NHANES participants aged 20 years of age and older, non-pregnant women, and those who completed the home interview, mobile exam centre visit, and had fasted for at least 8 hours prior to blood draw. This left an eligible sample of 4903. We excluded 1579 participants with missing or invalid physical activity accelerometer data, 885 with missing metabolic syndrome (MetS) data, and 465 with missing covariate data. This left a
final sample of 1974. Adjusted sample weights were created from the weighting variable provided in the NHANES dataset to account for differences in age, sex, and ethnicity between the eligible sample and the final sample.

**Physical Activity**

Physical activity was assessed using Actigraph AM-7164 uniaxial accelerometers (Actigraph, Ft. Pensacola, FL). These accelerometers recorded average movement intensity, measured by counts in 1 minute intervals or epochs. Participants were given accelerometers at their mobile examination centre visit and asked to wear them on an elasticized belt on their right hip for the 7 days after the visit. Participants were instructed to only remove the accelerometer when sleeping or when the accelerometer would get wet (e.g. bathing or swimming). After the 7 day measurement period was completed, participants mailed the accelerometers back to the NHANES researchers. The accelerometers were then tested to ensure calibration, the data were downloaded, and implausible count values were removed.

Further data reduction was carried out by the authors based on existing protocols. Initially, we removed non-wear periods and calculated the wear time for each day. Non-wear periods were defined as periods with ≥90 minutes of zero counts, with an allowance for 2 minutes of counts between 0 and 100. Next, each day was coded as valid or invalid, and invalid days were removed from the dataset. Days were considered valid if the participant had ≥10 hours of wear time. We then removed participants with 3 or fewer valid days.

After removing invalid days and participants with an insufficient number of valid days, each minute of physical activity data was categorized into one of four intensities based on established count per minute cut-points for the Actigraph AM-7164 accelerometer.
Specifically, values between 0-99 were classified as sedentary, values between 100-2019 were classified as light intensity, values between 2020-5998 were classified as moderate intensity, and values ≥5999 were classified as vigorous intensity. Data were then classified as being either bouted or sporadic of different intensities.

Initially, bouted MVPA was defined in the dataset as periods of at least 10 consecutive minutes where the accelerometer counts exceeded the moderate intensity threshold, with an allowance of 20% of the counts (e.g. 2 minutes for a 10 minute bout) being below the moderate threshold. Once more than 20% of the minutes were below the moderate threshold, the bout was stopped (i.e. no more time was added to the bout length) and the subsequent accelerometry data were searched to locate the next bout. The time spent in bouted MVPA was summed and a daily average was created. Bouted MVPA was then removed from the dataset. Next, bouted light intensity physical activity (LIPA) was defined in the remaining dataset as periods of at least 10 consecutive minutes where the accelerometer counts exceeded the light intensity threshold, with an allowance of 20% of the counts being below the threshold. As with bouted MVPA, once the 20% threshold was surpassed, the bout was stopped and the subsequent accelerometry data were searched to locate the next bout. In some cases, bouted LIPA included MVPA if the amount of MVPA did not satisfy the bouted MVPA criteria. We then calculated the minutes of embedded MVPA (i.e. MVPA embedded within bouts comprised primarily of LIPA) and removed it from the dataset prior to calculating the minutes of bouted LIPA. After embedded MVPA and bouted LIPA were counted and removed from the dataset, the remaining dataset was limited to sporadic physical activity and
sedentary behaviour. Within that dataset the daily averages for sporadic LIPA and sporadic MVPA were calculated.

**Metabolic Syndrome**

The main outcome of interest was the MetS; a clustering of cardiometabolic risk factors that is associated with an increased risk of type 2 diabetes, cardiovascular disease, certain cancers, and all-cause mortality.\(^9\)\(^-\)\(^11\) Presence of the MetS was based on the 2009 Joint Interim Societies definition\(^20\) of having at least three of the following five criteria: high waist circumference (men \(\geq 102\) cm, women \(\geq 88\) cm), high triglycerides (\(\geq 150\) mg/dL), low HDL-cholesterol (men \(< 40\) mg/dL, women \(< 50\) mg/dL), high blood pressure (systolic \(\geq 130\) mmHg or diastolic \(\geq 85\) mmHg or hypertension medication use) and high fasting glucose (\(\geq 100\) mg/dL or diagnosed diabetes or insulin use or glucose medication use). Note that the Joint Interim Societies definition of the MetS also proposed lower waist circumference cut-points (men \(\geq 94\) cm, women \(\geq 80\) cm).\(^{21}\) We re-ran all of the analyses in the paper using these lower waist circumference cut-points, and outside of a greater prevalence of the MetS, the findings were almost identical to those presented in the Results section (data not shown).

Waist circumferences were measured to the nearest 0.1 cm at the level of the iliac crest using a flexible measuring tape. Blood pressure measures were taken four times in a seated position using a manual sphygmomanometer. The average of all four measurements was used. Blood samples were obtained after a minimum 8-hour fast and were analyzed for triglycerides, HDL-cholesterol and fasting glucose. Triglyceride levels were measured enzymatically using a series of coupled reactions.\(^{22}\) HDL-cholesterol was assessed using the direct HDL assay method.\(^{23}\) Fasting plasma glucose was assessed using a hexokinase enzymatic method.\(^{24}\) Lastly,
information on medication use for hypertension or diabetes and physician diagnosed diabetes (outside of gestational diabetes) were collected via self-report during the home interview.

**Covariates**

Covariates included sex, age (20-39 years old, 40-59 years old, 60+ years old), ethnicity (non-Hispanic White, non-Hispanic Black, Mexican American, other), smoking (non-smoker, former smoker, current smoker), alcohol consumption (non-drinker, light to moderate drinkers defined as 1-15 drinks/week for men and 1-8 drinks/week for women, heavy drinkers defined as ≥15 drinks/week for men and ≥8 drinks/week for women)\(^\text{25}\), and tertiles of the poverty-to-income ratio. The poverty-to-income ratio measures a family’s income in relation to the poverty threshold for their family size and composition.\(^\text{26}\)

**Statistical Analysis**

Analyses were conducted using SAS v9.3 (SAS Institute Inc., Cary, NC) and accounted for the clustered nature of NHANES and the adjusted sample weights. Since several of the physical activity and MetS component variables were not normally distributed, medians and interquartile ranges were reported in the descriptive tables. Spearman correlations were used to assess associations between the physical activity variables. Associations between physical activity and the MetS were assessed via logistic regression. Separate bivariate logistic regression models were run for each physical activity variable. This was followed by multivariable models. Multivariable model 1 controlled for the covariates while multivariable model 2 controlled for the covariates and the other physical activity variables. There was evidence of collinearity for the embedded MVPA and bouted MVPA variables and therefore we did not include them in the same multivariable model. Logistic regression findings are
presented as odds ratios (OR) and their associated 95% confidence intervals (CIs) per each additional 30 minutes/day in physical activity.

4.4 Results

Descriptive characteristics of the sample are in Table 4.1. The majority were between the ages of 20-39 and 40-59 years and of non-Hispanic white ethnicity, while 43% had the MetS. The median bouted LIPA, sporadic LIPA, embedded MVPA and bouted MVPA values were 266.9, 16.2, and 1.4 minutes/day, respectively. Because 95% of the sample accumulated less than 5 minutes/day of bouted or sporadic vigorous intensity physical activity, we combined moderate and vigorous intensity activity together for all analyses. Furthermore, because only 11% of the sample accumulated ≥5 minutes/day of sporadic MVPA and only 1% accumulated ≥10 minutes/day, we did not explore this form of physical activity in the regression analyses.

All of the physical activity variables were significantly correlated with each other (p < 0.0001). Sporadic LIPA was negatively correlated with embedded MVPA (r = -0.32), bouted LIPA (r = -0.44), and bouted MVPA (r = -0.19). Embedded MVPA was positively correlated with bouted LIPA (r = 0.53) and bouted MVPA (r = 0.76). Finally, bouted LIPA was positively correlated with bouted MVPA (r = 0.21).

The odds ratio for the MetS per 30 minutes/day of each of the physical activity variables are presented in Table 4.2. After adjusting for the covariates and the other physical activity variables (Multivariable Model 2), sporadic LIPA was not significantly associated with the MetS (p = 0.15). However, bouted LIPA (p < 0.01), embedded MVPA (p < 0.001), and bouted MVPA (p < 0.001) were all associated with the MetS. These associations are further illustrated in Figure 4.1. The final multivariable model suggested that for every 30 minutes/day of physical activity,
there is a corresponding 4%, 57%, and 64% reduction in the relative odds of the MetS for
bouted LIPA, embedded MVPA, and bouted MVPA, respectively. The associations for embedded
and bouted MVPA, while not statistically different from each other, were considerably stronger
than they were for bouted LIPA.
Table 4.1 Descriptive characteristics of the study sample

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n=1974)</th>
<th>Men (n=1120)</th>
<th>Women (n=854)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-39 years</td>
<td>38.0 (1.5)</td>
<td>39.6 (2.0)</td>
<td>36.4 (1.9)</td>
</tr>
<tr>
<td>40-59 years</td>
<td>39.8 (1.3)</td>
<td>40.0 (2.0)</td>
<td>39.6 (1.6)</td>
</tr>
<tr>
<td>60+ years</td>
<td>22.2 (1.3)</td>
<td>20.3 (1.5)</td>
<td>24.0 (1.7)</td>
</tr>
<tr>
<td>Race/ethnicity (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>71.9 (2.3)</td>
<td>72.5 (2.6)</td>
<td>71.3 (2.4)</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>11.6 (1.4)</td>
<td>10.5 (1.4)</td>
<td>12.7 (1.6)</td>
</tr>
<tr>
<td>Mexican American</td>
<td>7.6 (1.1)</td>
<td>8.4 (1.3)</td>
<td>6.9 (1.1)</td>
</tr>
<tr>
<td>Other</td>
<td>8.9 (1.1)</td>
<td>8.6 (1.4)</td>
<td>9.1 (1.4)</td>
</tr>
<tr>
<td>Smoking Status (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-smoker</td>
<td>47.5 (1.3)</td>
<td>39.7 (1.8)</td>
<td>55.1 (1.7)</td>
</tr>
<tr>
<td>Former smoker</td>
<td>28.5 (1.2)</td>
<td>32.5 (1.7)</td>
<td>24.6 (1.4)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>24.0 (1.4)</td>
<td>27.9 (1.5)</td>
<td>20.3 (1.8)</td>
</tr>
<tr>
<td>Alcohol consumption (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-drinker</td>
<td>21.5 (1.5)</td>
<td>19.2 (1.5)</td>
<td>23.7 (2.1)</td>
</tr>
<tr>
<td>Light to moderate drinker</td>
<td>57.5 (1.7)</td>
<td>56.9 (1.7)</td>
<td>58.2 (2.2)</td>
</tr>
<tr>
<td>Heavy drinker</td>
<td>21.0 (1.6)</td>
<td>23.9 (1.6)</td>
<td>18.2 (1.9)</td>
</tr>
<tr>
<td>Physical activity (median, min/day)</td>
<td>16.2 (5.6-31.9)</td>
<td>21.0 (8.7-37.5)</td>
<td>10.5 (3.5-25.4)</td>
</tr>
<tr>
<td>Sporadic LIPA</td>
<td>99.8 (81.9-116.7)</td>
<td>94.5 (77.6-113.4)</td>
<td>104.2 (87.4-119.7)</td>
</tr>
<tr>
<td>Sporadic MVPA</td>
<td>2.2 (1.2-3.8)</td>
<td>2.6 (1.5-4.6)</td>
<td>1.8 (0.9-2.9)</td>
</tr>
<tr>
<td>Embedded MVPA</td>
<td>16.2 (5.6-31.9)</td>
<td>21.0 (8.7-37.5)</td>
<td>10.5 (3.5-25.4)</td>
</tr>
<tr>
<td>Bouted LIPA</td>
<td>266.9 (186.5-365.2)</td>
<td>281.7 (185.5-378.2)</td>
<td>256.4 (187.8-349.0)</td>
</tr>
<tr>
<td>Bouted MVPA</td>
<td>1.4 (0.0-8.6)</td>
<td>2.2 (0-8.9)</td>
<td>0.0 (0.0-8.1)</td>
</tr>
<tr>
<td>Metabolic syndrome components</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolic syndrome (%)</td>
<td>41.9 (1.7)</td>
<td>42.9 (2.1)</td>
<td>40.9 (2.0)</td>
</tr>
<tr>
<td>Waist circumference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median, cm</td>
<td>95.9 (86.3-107.7)</td>
<td>99.8 (91.0-110.1)</td>
<td>92.1 (82.1-103.5)</td>
</tr>
<tr>
<td>High waist circumference (%)</td>
<td>53.1 (1.6)</td>
<td>45.6 (2.1)</td>
<td>60.5 (1.9)</td>
</tr>
<tr>
<td>Triglycerides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median, mg/dL</td>
<td>112.6 (77.8-167.2)</td>
<td>124.1 (84.2-189.6)</td>
<td>104.6 (72.2-151.2)</td>
</tr>
<tr>
<td>High triglycerides (%)</td>
<td>31.2 (1.6)</td>
<td>37.0 (2.1)</td>
<td>25.5 (1.6)</td>
</tr>
<tr>
<td>HDL-cholesterol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median, mg/dL</td>
<td>52.1 (43.1-63.7)</td>
<td>46.8 (39.9-56.6)</td>
<td>58.3 (48.8-69.6)</td>
</tr>
<tr>
<td>Low HDL-cholesterol (%)</td>
<td>62.2 (2.2)</td>
<td>58.9 (2.8)</td>
<td>65.4 (2.4)</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median systolic, mmHg</td>
<td>119 (109-131)</td>
<td>121 (113-132)</td>
<td>115 (107-129)</td>
</tr>
<tr>
<td>Median diastolic, mmHg</td>
<td>70 (63-77)</td>
<td>72 (64-79)</td>
<td>69 (62-76)</td>
</tr>
<tr>
<td>High blood pressure (%)</td>
<td>35.3 (1.3)</td>
<td>39.3 (1.8)</td>
<td>31.4 (1.9)</td>
</tr>
<tr>
<td>Fasting Glucose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median, mg/dL</td>
<td>96.7 (90.2-104.0)</td>
<td>98.9 (92.6-106.3)</td>
<td>94.1 (88.0-101.9)</td>
</tr>
<tr>
<td>High fasting glucose (%)</td>
<td>38.6 (2.1)</td>
<td>45.9 (2.2)</td>
<td>31.5 (2.3)</td>
</tr>
</tbody>
</table>

Data presented as prevalence (95% confidence interval) for categorical data and median (interquartile range) for categorical variables.

Note: LIPA, light intensity physical activity; MVPA, moderate-to-vigorous intensity physical activity.
Table 4.2 Associations between physical activity variables and the metabolic syndrome

<table>
<thead>
<tr>
<th>Physical Activity Type</th>
<th>Bivariate Model</th>
<th>Multivariable Model 1</th>
<th>Multivariable Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sporadic LIPA</td>
<td>1.15 (1.04-1.27)</td>
<td>1.11 (1.00-1.24) (^a)</td>
<td>0.91 (0.81-1.03) (^b)</td>
</tr>
<tr>
<td>Bouted LIPA</td>
<td>0.93 (0.91-0.96)</td>
<td>0.96 (0.93-0.99) (^a)</td>
<td>0.96 (0.93-0.99) (^c)</td>
</tr>
<tr>
<td>Embedded MVPA</td>
<td>0.38 (0.30-0.47)</td>
<td>0.44 (0.35-0.54) (^a)</td>
<td>0.43 (0.33-0.55) (^b)</td>
</tr>
<tr>
<td>Bouted MVPA</td>
<td>0.29 (0.21-0.41)</td>
<td>0.36 (0.26-0.48) (^a)</td>
<td>0.36 (0.26-0.49) (^c)</td>
</tr>
</tbody>
</table>

Data presented as odds ratios (95% confidence interval) per 30 minute/day difference in physical activity relative to 0 minutes

\(^a\) Adjusted for age, sex, ethnicity, poverty-income ratio, alcohol, and smoking

\(^b\) Adjusted for age, sex, ethnicity, poverty-income ratio, alcohol, smoking, and the other physical activity variables with the exception of bouted MVPA

\(^c\) Adjusted for age, sex, ethnicity, poverty-income ratio, alcohol, smoking, and the other physical activity variables with the exception of embedded MVPA

Note: LIPA, light intensity physical activity; MVPA, moderate-to-vigorous intensity physical activity

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Figure 4.1 Odds ratios for the metabolic syndrome per daily minute of physical activity. Values are plotted from 0 minutes/day to the value that corresponds to the 98th percentile of the physical activity variable within the study sample. MVPA, moderate-to-vigorous physical activity; LIPA, light intensity physical activity.
The associations between the different types of physical activity and the components of
the MetS are shown in Table 4.3. The statistical significance and directionality of these
associations were similar to those for the MetS as a whole (exceptions: bouted LIPA was not
significantly associated with low HDL-cholesterol, high blood pressure, or high glucose).
Table 4.3 Associations between physical activity variables and the metabolic syndrome components

<table>
<thead>
<tr>
<th>Physical activity type</th>
<th>High waist circumference</th>
<th>High triglycerides</th>
<th>Low HDL cholesterol</th>
<th>High blood pressure</th>
<th>High glucose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sporadic LIPA</td>
<td>0.88 (0.77-1.00)</td>
<td>0.94 (0.83-1.06)</td>
<td>0.99 (0.88-1.11)</td>
<td>0.96 (0.80-1.12)</td>
<td>0.99 (0.86-1.14)</td>
</tr>
<tr>
<td>Bouted LIPA</td>
<td>0.96 (0.93-0.98)</td>
<td>0.93 (0.90-0.96)</td>
<td>0.98 (0.94-1.01)</td>
<td>0.98 (0.94-1.02)</td>
<td>0.97 (0.94-1.01)</td>
</tr>
<tr>
<td>Embedded MVPA</td>
<td>0.48 (0.37-0.63)</td>
<td>0.71 (0.54-0.94)</td>
<td>0.79 (0.66-0.95)</td>
<td>0.61 (0.46-0.81)</td>
<td>0.64 (0.51-0.80)</td>
</tr>
<tr>
<td>Bouted MVPA</td>
<td>0.41 (0.27-0.61)</td>
<td>0.66 (0.45-0.96)</td>
<td>0.73 (0.55-0.96)</td>
<td>0.51 (0.35-0.74)</td>
<td>0.64 (0.48-0.84)</td>
</tr>
</tbody>
</table>

Data presented as odds ratios (95% confidence interval) per 30 minute/day difference in physical activity relative to 0 minutes.

°Adjusted for age, sex, ethnicity, poverty-income ratio, alcohol, smoking, and the other physical activity variables with the exception of bouted MVPA.

°Adjusted for age, sex, ethnicity, poverty-income ratio, alcohol, smoking, and the other physical activity variables with the exception of embedded MVPA.

Note: LIPA, light intensity physical activity; MVPA, moderate-to-vigorous intensity physical activity.
4.5 Discussion

This study determined the extent to which physical activity not meeting the bouted MVPA criteria is associated with the MetS. There were two major findings. First, the intensity of this activity was important; specifically, while the amount of MVPA embedded within bouts of primarily LIPA was strongly associated with the MetS, bouted LIPA and sporadic LIPA were weak or insignificant correlates of the MetS. The second major finding was that the participants accumulated an insufficient amount of truly sporadic MVPA to influence their health. The median sporadic MVPA was 1 minute/day and only 11% of participants accumulated at least 5 minutes/day of sporadic MVPA.

As indicated in the Introduction, there are discrepant findings on the health effects of sporadic LIPA. Observational studies, including the present study and a prior study of abdominally obese adults that assessed free-living physical activity over 7 days using accelerometers, have found that sporadic LIPA was not independently associated with cardiometabolic risk factors. Conversely, two experimental studies observed reductions in acute postprandial glucose response when sporadic LIPA was used to interrupt prolonged sedentary periods. The discrepancy between the observational and experimental studies may reflect that the benefits of sporadic LIPA observed in the experimental studies may have been limited to an acute glucose response. These experimental studies did not find comparable changes in other cardiometabolic risk factors and did not demonstrate whether the acute changes in glucose had chronic benefits. The discrepancy between the observational and experimental studies may also reflect that the experimental studies used sporadic LIPA to break
up prolonged sedentary time (e.g. 5 hours) whereas the observational studies captured all sporadic LIPA irrespective of the length of the sedentary period was that it interrupted.

Although previous studies have assessed the health benefits of non-bouted MVPA,\textsuperscript{1-3} to our knowledge this is the first study to differentiate between sporadic MVPA and MVPA embedded within bouts of primarily LIPA. It is worth noting that the study sample accumulated only 1 minute of sporadic MVPA for every 8 minutes of embedded MVPA. Thus, the association between non-bouted MVPA and cardiometabolic health observed in previous studies is likely a reflection of embedded MVPA.\textsuperscript{1-3} We feel that this is important to distinguish between sporadic and embedded MVPA because these likely represent two distinct types of activity that are performed for different reasons and which may elicit different physiological responses. An example of sporadic MVPA is a two minute trip to the washroom that is preceded and followed by sitting at a desk. An example of embedded MVPA is walking to take the garbage out in between light household chores. Sporadic MVPA may influence cardiometabolic risk factors through the changes in lipoprotein lipase (LPL) activity associated with interrupting prolonged sedentary periods.\textsuperscript{27} Conversely, embedded MVPA may influence cardiometabolic risk factors through increases in catecholamine concentration and LPL activity associated with increased intensity activity during non-sedentary periods.\textsuperscript{27-29}

The findings of our study suggest that MVPA does not need to occur in 10 minute bouts, as proposed in current public health guidelines for physical activity,\textsuperscript{30-32} but rather that MVPA can be accumulated during bouts of non-sedentary time, which can include bouts of primarily LIPA. Encouraging MVPA, even if just for a few minutes at a time, during bouts of LIPA may be especially relevant for individuals whose occupation involves performing a lot of light intensity
tasks, such as nursing or farming, as there may be greater underlying potential for improvement.

The present study is not without limitations. While accelerometers represent an objective measure of physical activity, they do not capture all types of activity. Specifically, the accelerometers used in the NHANES were uniaxial in nature and primarily captured horizontal movement at the hip. This limits their ability to accurately capture physical activity that is not step based (e.g. cycling, swimming, strength training). However, we feel that this type of activity represents the minority of leisure-time physical activity, as less than 2% of Americans engage in strength training and cycling. The study is also limited by its cross-sectional design, precluding conclusions about the temporality of the observed associations. However, given evidence from randomized control trials and prospective cohorts that MVPA has a positive influence on cardiometabolic risk factors and the MetS, it is likely that low MVPA was present before the MetS.

In conclusion, embedded MVPA was more strongly associated with the MetS than sporadic LIPA and as strongly associated with the MetS as bouted MVPA. Future research is need to provide more information as to the types of activity that represent embedded MVPA and to confirm whether the cross-sectional findings observed in this study hold true in other study designs.
4.6 References


26. Institute for Research on Poverty. What are poverty thresholds and poverty guidelines?


Chapter 5

General Discussion

5.1 Summary of key findings

This thesis described the volume and intensity of sporadic physical activity (SPA) in adults and also investigated the relationship between SPA intensity and the metabolic syndrome (MetS) in adults. This research addresses important gaps surrounding the lack of descriptive information about SPA in adults and the role intensity plays in the relationship between SPA and cardiometabolic health.

The first manuscript described the amount of daily SPA that adults accumulate, the intensity at which it is accumulated, the contribution of SPA to total daily physical activity, and whether these characteristics vary by sociodemographic factors. The primary finding was that American adults accumulated 103 minutes/day of SPA of any intensity, which represented 27% of their total daily physical activity. There were subtle differences within sociodemographic groups, as women accumulated 4 minutes/day of SPA more than men, 20-39 year olds accumulated 3 to 4 minutes/day less than 40-59 year olds and 60+ year olds, and Mexican Americans accumulated 9 to 11 minutes/day less than non-Hispanic blacks and non-Hispanic whites. Additionally, adults classified by body mass index (BMI) as underweight accumulated 7 to 8 minutes/day more SPA than adults classified as normal weight, overweight or obese. The observed differences within socioeconomic and BMI groups were primarily driven by light intensity SPA.
In terms of the contribution of SPA to total daily moderate-to-vigorous physical activity (MVPA), sporadic MVPA only accounted for 2 minutes/day or 13% of total MVPA. This represents a lower total than had been previously reported for adults,\textsuperscript{1,2} children,\textsuperscript{3} and older adults.\textsuperscript{4} However, this finding is likely explained by differences in how SPA was classified. Past studies considered all MVPA occurring outside of bouted MVPA as sporadic, whereas we calculated two forms of non-bout MVPA. These two forms consisted of truly sporadic MVPA that happened between sedentary periods and MVPA that was embedded within bouts of primarily light intensity physical activity (LIPA). When also considering embedded MVPA, which accounted for 16 minutes/day, non-bouted MVPA accounted for 98% of total MVPA in the typical participant. Overall, the finding that the typical American adult accumulates 17 minutes/day of non-bouted MVPA is encouraging given that most adults accumulate 10 minutes/day or less of bouted MVPA.\textsuperscript{5} Non-bouted MVPA may represent an opportunity for future interventions aimed at increasing MVPA in populations without the free time or self-efficacy to participate in extended BPA.

The second manuscript investigated the relationship between sporadic LIPA, sporadic MVPA, and embedded MVPA with the MetS in adults. There were two main findings. First, participants did not accumulate enough truly sporadic MVPA to have any bearing on health. Second, accumulating 30 minutes/day of embedded MVPA reduced the odds of having the MetS by 57%, while accumulating 30 minutes/day of sporadic LIPA did not reduce the odds of having the MetS. This finding demonstrates an intensity-dependent relationship between non-bouted physical activity and the MetS. To my knowledge this is the first study to examine the specific relationship between embedded MVPA and health. The odds reduction associated with
embedded MVPA was similar to that of bouted MVPA and consistent with past studies comparing non-bouted and bouted MVPA. These findings suggest that the recommended 150 minute weekly dose of bouted MVPA can be accumulated in a non-bouted manner without compromising the associated cardiometabolic health benefits. Increasing the amount of daily embedded MVPA may be particularly relevant for those in occupations that involve a lot of walking or standing, such as nursing or farming. Given that less than 15% of North Americans meet the current guidelines, often due to a reported lack of time, accumulating embedded MVPA represents a viable option for increasing overall MVPA given that it involves simply increasing the intensity for a few minutes during already occurring bouted LIPA.

The omission of non-bouted physical activity in the current public health recommendations is largely the result of a previous lack of evidence likely attributable to the limitations of measuring this type of activity before the advent of accelerometers. This thesis adds to the growing evidence base surrounding the health benefits of non-bouted MVPA, by demonstrating that 30 minutes/day of non-bouted physical activity of at least moderate intensity embedded within bouts of primarily light intensity activity is just as protective against the MetS as 30 minutes/day of bouted MVPA. Additionally, this thesis describes how common non-bouted physical activity is within adults and identifies populations where this type of activity is lacking. However, it is important to note that the MetS is not a fully encompassing marker of health. Although components of the MetS represent several risk factors associated with increased risk of type 2 diabetes, cardiovascular disease, some cancers and all-cause mortality, the individual associations with these risk factors were not as strong or consistent as they were for the MetS overall. Therefore, it is necessary to conduct further research in
order to better understand the specific relationships between non-bouted MVPA accumulation and other chronic conditions and outcomes.

5.2 Strengths of this thesis

The use of the National Health and Nutrition Examination Survey (NHANES) conveyed several strengths to the thesis. First, the NHANES is a large nationally-representative cross-sectional survey with a high response rate (>75%). This allows generalizability of the results to the American adult population and potentially to the Canadian adult population, which is similar. The NHANES is also the first North American survey to use accelerometer-derived data to estimate physical activity levels compared to self-report data. Accelerometers have several advantages over self-report data, most importantly the objective minute-by-minute recording of physical activity. This is important because self-reported data have been previously shown to be unable to effectively capture short and incidental bouts of physical activity. Furthermore, self-reported data are based on participants’ perceptions of intensity, which can be problematic. Given the focus on these two aspects of physical activity and the associated potential for recall and social desirability bias when they are measured by self-report, it is likely that this thesis would not have been feasible without the use of accelerometer data.

This thesis also provides two novel analyses. To my knowledge, this is the first time that non-bouted physical activity has been described in adults and the first time that the distinction has been made between embedded MVPA and sporadic MVPA. The description of non-bouted physical activity in adults is important, as this type of activity was found to represent 98% of total daily MVPA time in American adults. It is also important to differentiate between embedded MVPA and sporadic MVPA when talking about non-bouted physical activity, as these
two types of activity are likely performed for different reasons and may have different physiological effects.

5.3 Limitations of this thesis

While the use of NHANES data has major strengths, it is also subject to some weaknesses. Since the NHANES is a cross-sectional survey, it precludes conclusions on the temporality of the relationship for manuscript two. Therefore, it is not fully known whether the physical activity patterns came before the MetS or as a result of the MetS. However, given consistent evidence from randomized control trials and prospective cohorts demonstrating that accumulating MVPA has a positive influence on cardiometabolic risk factors and the MetS,\textsuperscript{20,21} it is likely that low MVPA was present before the MetS. While the data in manuscript two cannot establish temporality, it can comment on other aspects of causality.\textsuperscript{22} Mainly, it presents consistent findings with the past literature on non-bouted physical activity and health\textsuperscript{1,2,6} and suggests that a strong dose-response relationship exists. Additionally, the observed associations are biologically plausible provided the research consistently demonstrating a positive influence of bouted physical activity for all the individual components of the MetS\textsuperscript{23} is at all transferable to non-bouted activity.

Some non-response and selection bias may also be present. While the response rate in the NHANES itself is high,\textsuperscript{16} valid accelerometer data as defined in this thesis was unavailable for 36% of the eligible sample for manuscript one and 32% of the eligible sample for manuscript two. While this is not a major limitation for manuscript two, since a biological relationship was investigated, the missing data in manuscript one may affect the generalizability of the results.
The eligible sample with valid accelerometer data in manuscript one was more likely to be female, younger and non-Hispanic white than the eligible sample without valid accelerometer data. A reweighting procedure based on age, sex and ethnicity was therefore was performed to minimize the effect of potential selection bias (Appendix D).

While accelerometer use for measuring physical activity offers advantages over self-report, it is also not without limitations. The accelerometers used in the NHANES were uniaxial in nature and primarily captured horizontal movement at the hip. Therefore, these monitors do not accurately capture activities that are not step-based (e.g. cycling, swimming),\textsuperscript{24,25} and do assess the added energy expenditure associated with load-bearing activities.\textsuperscript{26} As a result, accelerometers normally underestimate total physical activity.\textsuperscript{27} However, it is believed that the majority of physical activity in the adult population was captured, as walking is the most common form of leisure-time physical activity\textsuperscript{28} and is also heavily involved in occupational and transportation activities. Furthermore, less than 2% of Americans participate in strength training and cycling.\textsuperscript{29}

With the 7 day accelerometer protocol used in NHANES, there is an underlying assumption that the accelerometer data captured over a 1 week period is representative of habitual physical activity. Participants may alter their typical physical activity levels in response to being measured; which is referred to as reactivity bias. This bias is unlikely to play a role, as the accelerometer itself is a black box that provides no feedback for the participant to act on. Additionally, the intraclass correlation (ICC) between repeated 7 day accelerometer physical
activity measures has previously been measured at 0.90, suggesting participants do not exhibit a period of adjustment to wearing an accelerometer.

Finally, as it pertains to manuscript one specifically, the observed physical activity patterns were from the years 2003-2006 and may not necessarily represent current behaviour. However, recent self-report data collected in the United States based Behavioral Risk Factor Surveillance System shows no increase in the number of participants with any physical activity between 2001 and 2011, and a small increase in the number of participants meeting the 150 weekly minutes of MVPA target between 2001 and 2009. These findings suggest that the physical activity levels in American adults are relatively stable and the patterns reported in manuscript one are likely only a slight underestimation of current behaviour at worst.

5.4 Public health implications

The findings reported in both manuscripts in this thesis have important public health implications, specifically with respect to the prevalence of non-bouted physical activity and the feasibility of this type of activity as an interventional opportunity. While non-bouted physical activity is not addressed in the current physical activity guidelines, manuscript one illustrates a high prevalence of this type of activity in American adults and manuscript two supports the current literature suggesting that MVPA embedded within LIPA has comparable health benefits to bouted MVPA.

The relatively high volume of non-bouted physical activity, in that it represents 98% of total daily MVPA in American adults, suggests that accumulating minutes of MVPA in this manner is already common. The majority of non-bouted MVPA was in the form of MVPA
embedded within prolonged periods of primarily LIPA. An important source of this type of activity is likely through occupational activity. For example, a nurse may spend a large amount of time in LIPA tending to patients and then perform short bursts of moderate intensity activity walking throughout the hospital. The findings of manuscript two suggest that this embedded MVPA is as strongly associated with the MetS as bouted MVPA and that sporadic LIPA is not associated with the MetS. Therefore, minutes of MVPA may not need to be accumulated in 10 minute bouts specifically, but rather during 10 minutes or more of non-sedentary time which can include bouts of primarily LIPA. The fact that minutes of MVPA can be accumulated in this way may be important for public health messaging aimed at increasing physical activity levels, especially for those in an occupation or setting that already involves a lot of light intensity walking or standing. Furthermore, the finding that intensity of non-bouted physical activity is important may be useful for future interventions. Increased energy expenditure through at least moderate intensity activity appears critical to reap the health benefits of non-bouted activity, not necessarily the specific interruption of sedentary periods as had been previously suggested.  

Non-bouted physical activity interventions may represent a greater avenue for increasing habitual physical activity levels, as interventions using BPA have seen less than ideal post-intervention maintenance.  

5.5 Future research directions

Manuscript one is the first study to describe daily SPA levels of light, moderate and vigorous intensity in American adults. It is also the first study to identify non-bouted MVPA embedded within bouts of primarily LIPA. This embedded MVPA was found to account for a major proportion of daily MVPA in adults; however, additional research is needed to better
understand the major sources of embedded MVPA in adults. Of specific interest is the role occupational activity plays as a source of this type of activity.

Manuscript two is the first study to evaluate the role of intensity of non-bouted activity in a large sample of adults. Additional research is needed to further investigate the role of sporadic LIPA specifically as a means of breaking up sedentary periods. While past studies demonstrate acute reductions in postprandial glucose using sporadic LIPA sedentary interruptions, whether these reductions are meaningful outside of a controlled environment and over a longer timeframe is unknown. Also, further research is needed to determine whether distinct biological mechanisms exist for embedded MVPA versus sporadic MVPA, and if multiple shorter (1-2 minutes) periods of embedded MVPA are equivalent to one longer period (4-6 minutes). It will also be of interest to investigate whether equivalent minutes/day of embedded MVPA and sporadic MVPA have comparable cardiometabolic health effects; however, given the rarity of sporadic MVPA found in this thesis, this may be difficult to evaluate. Finally, experimental studies are needed to confirm the causality of the relationship between embedded MVPA and the MetS.

5.6 Summary of MSc research experiences

Over the course of completing the requirements for the MSc degree, including coursework, the independent study and the thesis, I have acquired the background and key skills necessary to design and conduct a research project using large epidemiological datasets. Throughout this process, I was required to critically review scientific literature to identify important research gaps in order to develop novel research questions for the basis of this thesis research and for developing the analytical strategy to evaluate these research questions. As a
major component of the thesis research, I was required to develop a SAS program to categorize and quantify the main physical activity exposure variables from the raw accelerometer data collected in the NHANES (described in greater detail in Appendix C). Additionally, I managed the NHANES databases and performed all statistical analyses for each manuscript, which took into account the complex survey design of the NHANES and involved modifying sample weights (outlined in Appendix D). I was also responsible for interpreting the results of the statistical analyses, placing them into the context of the current literature and suggesting future research directions. Throughout the process of writing the thesis, I have critically evaluated my own work, while also understanding and incorporating important epidemiological concepts to assess the strengths and weaknesses of the thesis research. Lastly, I was able to gain experience preparing the findings of manuscript one and two for peer-reviewed publication, as well as for presentation at a scientific conference (Canadian Society for Epidemiology and Biostatistics Student Conference, spring 2014).

5.7 Conclusions

In conclusion, the research in this thesis provides descriptive information about SPA in American adults suggesting that nearly all MVPA is accumulated outside of the current bout length recommendations, and that minutes of MVPA accumulated embedded within bouts of primarily LIPA result in a comparable reduction in the likelihood of having the MetS as bouted MVPA. The results of this thesis provide evidence of the importance of non-bouted physical activity, which will inform future revisions of public health recommendations for physical activity and future interventions centered on non-bouted physical activity.
5.8 References


Appendix A

Ethics Approval
QUEEN’S UNIVERSITY HEALTH SCIENCES AND AFFILIATED TEACHING HOSPITALS
RESEARCH ETHICS BOARD ANNUAL RENEWAL

Queen’s University, in accordance with the "Tri-Council Policy Statement 2, 2010" prepared by the Interagency Advisory Panel on Research Ethics for the Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada and Social Sciences and Humanities Research Council of Canada requires that research projects involving human participants be reviewed annually to determine their acceptability on ethical grounds.

A Research Ethics Board composed of:

**Dr. A.F. Clark**, Emeritus Professor, Department of Biomedical and Molecular Sciences, Queen's University (Chair)
**Dr. H. Abdollah**, Professor, Department of Medicine, Queen's University
**Dr. C. Cline**, Assistant Professor, Department of Medicine, Director, Office of Bioethics, Queen's University, Clinical Ethicist, Kingston General Hospital
**Dr. R. Brison**, Professor, Department of Emergency Medicine, Queen's University
**Dr. M. Evans**, Community Member
**Ms. J. Hudacin**, Community Member
**Dr. B. Kisilevsky**, Professor, School of Nursing, Departments of Psychology and Obstetrics and Gynaecology, Queen's University
**Dr. J. MacKenzie**, Pediatric Geneticist, Department of Pediatrics, Queen's University
**Mr. D. McNaughton**, Community Member
**Ms. P. Newman**, Pharmacist, Clinical Care Specialist and Clinical Lead, Quality and Safety, Pharmacy Services, Kingston General Hospital
**Ms. S. Ruhlman**, Privacy Officer, ICES-Queen’s Health Services Research Facility, Research Associate, Division of Cancer Care and Epidemiology, Queen’s Cancer Research Institute
**Dr. A. Singh**, Professor, Department of Psychiatry, Queen’s University
**Ms. K. Weisbaum**, LL.B. and Adjunct Instructor, Department of Family Medicine (Bioethics)

has reviewed the request for renewal of Research Ethics Board approval for the project **Generating Evidence to Inform Physical Activity Guidelines** as proposed by **Dr. Ian Michael Janssen** of the School of Kinesiology & Health Studies, at Queen’s University. The approval is renewed for one year, effective **June 15, 2013**. If there are any further amendments or changes to the protocol affecting the participants in this study, it is the responsibility of the principal investigator to notify the Research Ethics Board. Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other adverse events must be reported within 15 days after becoming aware of the information.

**Albert J. Clarke**

Date: October 16, 2013

Chair, Health Sciences Research Ethics Board
Renewal 1[ ] Renewal 2 [X ] Extension [ ] Code# PHE-113-11 Romeo file# 6006002
Appendix B

NHANES Study Design

Background

The National Health and Nutrition Examination Survey (NHANES) is a representative cross-sectional survey administered in the United States. The NHANES program first began in the early 1960s, involving a series of surveys to address different population groups and health topics over the years. In 1999 the survey shifted to become a continuous program in order to better amend its focus to meet emerging health issues. The NHANES is a major program under the control of the National Center for Health Statistics and the Centers for Disease Control and Prevention. Data collected from the NHANES has several major functions, including generating prevalence estimates for major diseases and risk factors for diseases, providing a basis for national standards, and providing data for researchers to help develop health programs and policies. Both manuscripts within this thesis were based on data from the 2003/04 and 2005/06 cycles of the NHANES.

Sampling strategy

The NHANES collects data for approximately 5000 individuals each year, resulting in a sample size of nearly 20,000 for the combined 2003/04 and 2003/05 cycles used in this thesis. While data is collected annually, it is released two years at a time to increase the reliability of its estimates and to alleviate privacy concerns surrounding rare events. The NHANES sampling procedure involves 4 stages and draws from the total noninstitutionalized civilian population residing in the 50 states and the District of Columbia. First, primary sampling units are selected that generally consist of single counties with the probability proportional to a measure of size.
(PPS). Next, the primary sampling units are divided into segments, roughly equivalent to city blocks, also with PPS. Third, households within each segment are randomly selected. Lastly, individuals are randomly chosen with designed age, sex and Hispanic origin sub-domains from a list of all persons residing in each selected household. On average, 1.6 persons are selected per household. Select subgroups are oversampled, including African Americans, Mexican Americans, low income white Americans, adolescents aged 12-19 years old and older adults aged 60 years of age and up. This is done in order to increase the reliability and precision of the health status indicators for these subgroups. Additionally, to produce unbiased national estimates, sampling weights are assigned to each participant to allow analysts to produce statistical estimates as if the population had been surveyed. Special sampling weights were calculated for the combination of the 2003/04 and 2003/05 NHANES cycles.

Data Collection

In order to collect information across a wide variation of health status indicators, data collection for the NHANES involves 3 levels: a household screener, interview and physical examination. The household screener is used to determine whether selected household members are eligible for interview and examination. The interview portion collects individual-level demographic, health and nutritional data, in addition to data about the household. All interviews are done at the participant’s home utilizing computer-assisted personal interviewing. The physical examination portion happens in specialized mobile examination centres and includes physical measures, tests such as auditory and dental examinations, and the collection of blood and urine samples for laboratory testing. It is also at this point that accelerometers and instructions on their use are provided to the participants for physical
activity monitoring during the 7 days following their mobile exam centre visit.\textsuperscript{4} After the 7 days of monitoring, participants are asked to return the accelerometers by mail in a postage-paid padded envelope.\textsuperscript{4}

In order to facilitate and encourage participation, the NHANES provides transportation to participants if needed.\textsuperscript{2} Participants also received compensation and the results of their medical findings.\textsuperscript{2} Participants are required to sign informed consent forms for the household interview, examination, allergy testing and storage of their provided blood and urine samples. If a participant is under the age of 18, then parental consent was required.
References


Appendix C

Accelerometer Protocol

As mentioned in Appendix B, all participants were asked to wear an accelerometer for 7 days excepting those under the age of 6 years old, those with abdominal girth too large to accommodate the accelerometer belt, those who had undergone recent abdominal surgery and those who were wheelchair bound.¹ After the 7 days were complete, the accelerometers were mailed in prepaid envelopes back to the NHANES contractor where the data was downloaded and processed. The following sections explain the accelerometer data, data processing completed by the NHANES contractor and the additional data processing completed by the thesis candidate.

National Health and Nutrition Examination Survey Accelerometer Data Processing

The Actigraph 7164-AM accelerometers used in the NHANES were uniaxial and recorded vertical accelerations to provide an indication of movement intensity. The base unit of measurement recorded by the accelerometer is a counts per minute (CPM) value, based on the number of vertical accelerations over a 1 minute period.² A CPM value is recorded for every minute of each day, resulting in 10,080 data points per participant (7 days x 1440 minutes = 10,080). Once the NHANES contractor received the accelerometer, it was checked to ensure that the device was properly calibrated.¹ The accelerometer data was then downloaded and checked for outliers and unreasonable values.¹ After this processing, the data was released as a “SAS Xport Transport File” downloadable from the NHANES website.

Data Processing by Thesis Candidate
Once the accelerometer data files were downloaded, there were several additional stages of data processing and reduction completed using a specially designed macro or program in SAS statistical software version 9.3 (SAS Institute Inc., Cary, NC).

First, non-wear time was calculated and removed from the dataset. Non-wear time was defined as 90 or more consecutive minutes of a 0 CPM value, with an allowance for 2 minutes of counts between 0 and 100. The wear time for each day was then determined, and any day without at least 600 minutes of wear time was considered invalid. The participants with 3 or less valid days were removed from the sample. Once these participants were removed, the remaining minutes of activity were assigned an intensity category based on existing cut points (sedentary between 0-99 CPM, light between 100-2019, moderate between 2020-5998, vigorous ≥5999), as well as a bout type (sporadic, embedded, bouted).

To calculate the number of minutes/day for each intensity, the SAS macro assigned a flag to each minute based on the intensity category it was assigned to. The macro then identified whether any given minute was adjacent to a minute of similar intensity, higher intensity or lower intensity, to identify the bout type. If 10 minutes or more of the same intensity category were together, with an allowance of 20% of the counts below the referent threshold, those minutes of activity were considered bouted (e.g. 8 minutes of moderate intensity activity with 2 minutes of light intensity activity). If a bout contained a mix of two intensity types and the higher intensity type made up less than 80% of the minutes, the bout was classified as the lower intensity type (e.g. 7 minutes of moderate intensity and 3 minutes of vigorous intensity would count as a moderate intensity bout). If less than 10 minutes of the same intensity category occurred together, with minutes of sedentary intensity on both sides,
the activity was considered sporadic (e.g. 15 consecutive minutes of sedentary intensity, 3 minutes of moderate intensity, then 10 minutes of sedentary intensity). The macro was designed to count minutes of bouted activity and then remove them, starting with vigorous intensity bouts followed by those of moderate intensity and finally those of light intensity. The remaining minutes represented sporadic and sedentary activity.

Daily minutes of light, moderate and vigorous intensity were summed for both the bouted and sporadic bout types. A daily average of time spent in these activities was created for each valid participant using all available valid days. At this point, the minutes/day values for sporadic light, moderate and vigorous intensity activity were complete, as well as bouted MVPA. Embedded MVPA was calculated separately by subtracting the minutes/day of sporadic MVPA from the total minutes/day of non-bouted MVPA for each participant. Lastly, due to the design of the macro, the minutes/day of embedded MVPA were included within the bouted light intensity activity type. Therefore, the final minutes/day of bouted light intensity activity was calculated by subtracting the minutes/day of embedded MVPA from the algorithm-measured minutes/day of bouted light intensity activity.
References


Appendix D

Sample Reweighting

Comparison between the sample without valid accelerometer data and those with 4 days or more of valid accelerometer data revealed differences in age, ethnicity, and sex. Participants without valid accelerometer data were more likely to be male and of non-Hispanic black ethnicity and were 5.7 years younger. Since manuscript one involved a descriptive analysis, it was important that these differences be addressed in order to minimize potential bias and maintain sample generalizability. To correct for this, new sample weights were created as explained below.

Following a similar methodology as Troaino et al., the sample was reweighted on three main variables: age group, sex and ethnicity. The relative proportions of the sample for all 24 possible combinations (e.g. 20-39 year old male of non-Hispanic white ethnicity as one possible combination) were calculated in the total sample and the sample with valid accelerometer data. Twenty four ratios were then calculated by dividing the proportion of each combination in the total sample by the proportion in the valid accelerometer sample. The ratios were then multiplied by the existing weighting score provided by NHANES for every participant of each possible combination of age group, sex and ethnicity. The result was the new reweighting variable value. Comparisons between the reweighted sample with valid accelerometer data and the sample without valid accelerometer data showed no differences in age group, sex and ethnicity.
References