THE RELATIONSHIP BETWEEN DIFFERENT PATTERNS OF WEEKLY PHYSICAL ACTIVITY ACCUMULATION AND THE METABOLIC SYNDROME IN CANADIAN ADULTS

by

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Abstract

Total weekly moderate-to-vigorous (MVPA) accumulated in different patterns has not been well studied: it is not yet known whether sporadic MVPA (periods of <10 consecutive minutes) or whether the weekly frequency of MVPA is associated with health benefits in adults. For this reason, the physical activity guidelines recommend that adults aged 18 to 64 years accumulate at least 150 minutes of MVPA per week in bouts of at least 10 minutes. The overall objective of this thesis was therefore to study the relationships between different patterns of MVPA and the metabolic syndrome (MetS) – a clustering of risk factors that increases the risk of developing cardiovascular disease and type 2 diabetes in adults.

Both manuscripts in this thesis used data from the Canadian Health Measures Survey (CHMS), a nationally-representative sample of Canadians. The MetS was determined from direct physical measurements and blood samples, while physical activity levels were assessed by accelerometers (also known as activity monitors). Complex statistical models were used to determine the relationship between patterns of MVPA and the MetS.

The first study assessed whether bouted MVPA was associated with lower odds for MetS than an equal volume of sporadic MVPA. Results showed that both bouted and sporadic MVPA were equally related to the MetS; even small bursts of sporadic MVPA <3 minutes in length were meaningful when predicting the MetS. The second study evaluated whether more frequent weekly MVPA was associated with lower odds for the MetS in physically active adults. Among those who were considered physically active, there was no difference in the odds of the MetS between those who were infrequently or frequently active. Together, the results of this thesis suggest that the pattern in which weekly MVPA is accumulated is unimportant, provided that sufficient energy is expended.
Co-Authorship

This thesis presents the work of Janine Clarke in collaboration with her supervisor, Dr. Ian Janssen.

**Manuscript 1:** “Sporadic and bouted physical activity and the metabolic syndrome in adults” has been accepted for publication in *Medicine and Science in Sports and Exercise* and is presented according to the journal guidelines. Janine Clarke was responsible for reviewing relevant literature to identify research needs related to sporadic and bouted moderate-to-vigorous physical activity, identifying relevant data from the Canadian Health Measures Survey (CHMS), developing the data reduction procedures of the minute-by-minute accelerometer data, conducting all of the statistical analyses, writing the first draft of the manuscript, and revising the manuscript based on feedback received from Dr. Janssen. Dr. Janssen also provided guidance and feedback on how to analyze the data, how to conduct and interpret the statistical analysis, and provided editorial feedback on the written work prepared by Janine.

**Manuscript 2:** “Is the frequency of weekly moderate-to-vigorous physical activity associated with the metabolic syndrome in Canadian adults?” has been published online ahead of print in *Applied Physiology, Nutrition and Metabolism* and is again presented according to the journal guidelines. The contributions of the two authors (Janine Clarke and Ian Janssen) are comparable to what was explained above for manuscript 1.

The remaining chapters of the thesis (i.e. Introduction, Literature Review, General Discussion, and Appendices) were the work of Janine Clarke, with input and feedback from Dr. Janssen.
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First and foremost, I would like to thank my supervisor Dr. Ian Janssen, for his continued support, patience, understanding, and guidance. He was incredibly accommodating for the work I did with him, knowing that I was also working full-time in Ottawa. I am incredibly grateful for the opportunity and the knowledge that he has given me.

I would also like to acknowledge Shirley Bryan, my manager at the Canadian Health Measures Survey. Shirley inspired me to pursue a Master’s, and is the one that suggested I speak with Dr. Janssen at Queen’s University. Shirley is a role model and mentor for both my career and my Master’s, and I truly appreciate all of the support she has given me over the last few years. I could not ask for a better manager.

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<table>
<thead>
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<th>Abbreviation</th>
<th>Full Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHMS</td>
<td>Canadian Health Measures Survey</td>
</tr>
<tr>
<td>CI</td>
<td>confidence interval</td>
</tr>
<tr>
<td>HDL</td>
<td>high density lipoprotein</td>
</tr>
<tr>
<td>MET</td>
<td>metabolic equivalent of task</td>
</tr>
<tr>
<td>MetS</td>
<td>metabolic syndrome</td>
</tr>
<tr>
<td>MVPA</td>
<td>moderate-to-vigorous physical activity</td>
</tr>
<tr>
<td>OR</td>
<td>odds ratio</td>
</tr>
</tbody>
</table>
Chapter 1

General introduction

1.1 Overview

It is well accepted that moderate-to-vigorous physical activity (MVPA) plays an important role in the prevention and treatment of several chronic diseases within adults.1-3 A recent systematic review concluded that there is strong evidence that regular physical activity is important in the primary prevention of coronary artery disease, stroke, hypertension, colon cancer, breast cancer, type 2 diabetes, and osteoporosis.2 Physical activity is also important in the prevention and treatment of the metabolic syndrome – a clustering of cardiometabolic risk factors that increases the risk for cardiovascular disease and type 2 diabetes – a condition prevalent in nearly 1 in 5 Canadian adults.4,5

Current physical activity guidelines of the World Health Organization and several countries recommend that adults accumulate at least 150 minutes of MVPA per week in bouts of at least 10 minutes.6-9 The abundance of research on the relationship between physical activity and several health outcomes contributed significantly to the development of the current recommendations, although several research gaps remain.2,6 In particular, there is limited evidence relating to the effect that different patterns of physical activity (i.e. different combinations of frequency, intensity, and duration of activity throughout the week) have on various health outcomes, and as such the optimal dose of physical activity remains unclear.

There is strong evidence that regular MVPA accumulated in short 10 minute bouts is as effective as a single, continuous bout at improving health and fitness in adults.1,10-13 Conversely, there is very limited evidence as to whether MVPA accumulated sporadically (in less than 10 consecutive minutes) contributes to health or fitness.13 These incidental movements and non-
exercise activities (e.g. fidgeting, incidental activities of daily living, chores, etc.) contribute more to total daily energy expenditure than purposeful exercise\textsuperscript{14,15} and as such, it has been acknowledged that sporadic activity has the potential to play an important role in health.\textsuperscript{6,14,15} Recent studies have found that sporadic MVPA is independently associated with several cardiovascular risk factors,\textsuperscript{16-19} and cardiorespiratory fitness\textsuperscript{20} in adults. These studies provide some evidence that sporadic MVPA influences health, however, it is unclear whether equivalent volumes of sporadic and bouted MVPA influence health to a similar degree.

Similarly, there is limited research on the frequency of MVPA throughout the week and health in adults. One study compared the effect of being regularly active (≥1,000 kcal of MVPA on ≥3 days/week) compared to being irregularly active (≥1,000 kcal of MVPA on 1 to 2 days/week) on mortality in a cohort of adult men. Compared to inactive men, the relative risk of mortality was decreased by 15% in irregularly active men and by 36% in regularly active men,\textsuperscript{21} although the results were not significantly different from one another. It is therefore unclear whether more frequent MVPA elicits a greater health benefit than an equivalent amount of less frequent MVPA.\textsuperscript{2,6} For example, relating to the current physical activity guidelines, it is unknown whether 30 minutes of MVPA on five days of the week has a greater influence on health than 50 minutes of MVPA on three days of the week.

\textbf{1.2 Scientific and public health significance}

Physical inactivity has been determined to contribute to more than 3 million deaths worldwide,\textsuperscript{3,22} and is an important risk factor for several chronic conditions.\textsuperscript{3} As such, public health guidelines for physical activity have been developed and disseminated in several industrialized nations such as Canada and the United States since the 1990’s. Most recently, physical activity guidelines were revised following in-depth reviews of the existing literature on the relationship between physical activity and health; the guidelines have been aligned across
nations and internationally and ultimately convey the same message regarding the amount of physical activity that adults should engage in, in order to reduce the risk of chronic conditions. Through the revision process important research gaps were identified relating to patterns of physical activity. For example, does the frequency of physical activity throughout the week matter? Or does the accumulation of sporadic or bouts of physical activity less than 10 minutes influence health? These are important questions to answer from both a scientific and a public health perspective. As mentioned, from a scientific perspective, this will help to fill important research gaps in the understanding of the relationship between physical activity and health. From a public health perspective, this information can help to address some of the commonly identified barriers to participation in physical activity, such as a lack of time, and hopefully decrease levels of physical inactivity worldwide.

1.3 Thesis objectives and hypotheses

The purpose of this thesis was to examine the relationship between different patterns of weekly physical activity accumulation and the MetS in Canadian adults. Manuscript 1: The objective of the first study was to examine the relationship between MVPA accumulated sporadically versus bouts of at least 10 minutes and MetS. It was hypothesized that there would be no difference in the association between sporadic or bouted MVPA and the MetS. Manuscript 2: The second study had two objectives: a) to examine the relationship of the metabolic syndrome and regularly active versus irregularly active adults; and b) to examine whether meeting the current physical activity guidelines is associated with the MetS in adults. It was hypothesized that a) that there would be no difference in the association between regular and irregular physical activity and the MetS in active adults; and b) that meeting the current physical activity guidelines would significantly decrease the relative odds for the MetS. These relationships were explored using data from the Canadian Health Measures Survey, a large nationally-representative sample
of Canadians.\textsuperscript{24,25} Data on each of the components of the metabolic syndrome were obtained through direct physical measurements and through the collection of blood samples from survey participants. Physical activity data was measured directly through the use of accelerometers.

1.4 Thesis organization

This thesis conforms to the regulations outlined in the Queen’s School of Graduate Studies and Research “General forms of theses”. Chapter 2 presents an overview of the literature related to the relationship between physical activity dose and various health outcomes in adults. Individual elements of physical activity dose are explored in more detail, particularly as they relate to the association between different patterns of weekly physical activity and health in adults. Chapter 3 presents the first manuscript entitled “Physical activity accrued in bouts does not influence the metabolic syndrome to a greater extent than an equivalent volume of sporadic physical activity”. This manuscript has been submitted to \textit{Medicine \\& Science in Sports \\& Exercise} and is formatted according to the requirements of the journal. The second manuscript entitled “Is the frequency of weekly moderate-to-vigorous physical activity associated with the metabolic syndrome in Canadian adults?” is presented in Chapter 4. This manuscript has been submitted to \textit{Applied Physiology, Nutrition, and Metabolism} and is formatted according to the specific requirements of the journal. Finally, Chapter 5 includes a general discussion on the key findings, the strengths and limitations, public health and policy implications, future directions, and overall conclusions of the thesis.
1.5 References


Chapter 2

Literature review

2.1 Overview and outline

Physical inactivity is a known risk factor for several chronic conditions in adults such as cardiovascular disease, stroke, hypertension, certain types of cancer, type 2 diabetes, and osteoporosis,\(^1\)\(^-\)^\(^4\) among others. Additionally, physical inactivity is thought to contribute to more than 3 million deaths worldwide annually.\(^5\) The following literature review begins by summarizing the current and historical physical inactivity levels of Canadian adults. A brief overview of the literature that provides evidence of the association between physical activity and health in adults is then presented, followed by a critical review of the available literature on the dose of physical activity required for health benefits. Specifically, the frequency, intensity, duration and type of physical activity required for good health are reviewed and summarized.

2.2 Definitions of key terms and concepts

2.2.1 Physical activity and physical inactivity

Physical activity is defined as any bodily movement produced by skeletal muscle that results in energy expenditure above that at rest.\(^6\) Physical activity can be characterized by the frequency, intensity, time (or duration) and type (or mode) of activity, commonly referred to as the FITT formula.\(^6\) The frequency refers to the number of sessions of physical activity within a given time period, e.g. per day or per week. The intensity is the measured or estimated effort or energy cost associated with the activity. A common unit of measurement for the intensity of physical activity is a metabolic equivalent (MET), which is the ratio of the metabolic rate of a given activity to a standard resting metabolic rate of 1.0 kcal/kg/h or 3.5 mL O\(_2\)/kg/min.\(^7\) Intensity can
then be grouped into categories that correspond to a range of MET values: sedentary (1-1.5 METs), light (1.6-2.9 METs), moderate (3-5.9 METs), or vigorous (≥6 METs). Note that the MET values represent the absolute intensity of the activity, and not the relative intensity, which will be discussed later in this chapter. The time or duration refers to the number of minutes of physical activity performed in a given session or over a specific period of time such as a day or week. Finally the type or mode refers to the nature of the activity, which can in fact refer to several things. In terms of physiological response and energy demand, “type” can refer to aerobic activities (activities that use large muscle groups and are repetitive in nature, such as walking, running, etc.), resistance training activities (i.e. weight lifting), or flexibility activities (i.e. stretching). Alternatively, in the context of many surveillance questionnaires, “type” usually refers to the domain in which the activity takes place (i.e. leisure-time, occupational, domestic, or transportation).

The level of physical activity of an individual is typically assessed through some combination of information on the FITT criteria described above. In the context of epidemiological research, an individual is commonly considered to be “active” or “inactive” based on their daily or weekly level of physical activity. “Active” individuals are those who attain a minimum amount of physical activity daily or weekly, and “inactive” individuals are those who do not. The cut-point that differentiates “active” from “inactive” can differ markedly between surveys, often depending on the nature of the information collected (this is described in more detail below). Since the existence of official public health guidelines for physical activity, “active” commonly refers to individuals to meet the recommended guidelines, while “inactive” refers to individuals who do not meet the recommended guidelines. Otherwise, the cut-point between physical activity and physical inactivity might refer to a minimum level as assessed by any one or more of the FITT components.
2.2.2 Physical activity guidelines

As reviewed in subsequent sections, there is overwhelming evidence that physical activity is important in the prevention and treatment of many chronic conditions. However, the increasing levels of physical inactivity and the consequent public health burden prompted the development of public health guidelines on the amount and type of physical activity needed for health benefit. The first public health recommendations for physical activity for health benefits were released in 1995 by the American College of Sports Medicine jointly with the Centers for Disease Control and Prevention, which was closely followed by the 1996 Report of the US Surgeon General.3,8 The recommendations in both of these guidelines were for adults to accumulate at least 30 minutes of moderate-to-vigorous intensity physical activity on most, preferably all days of the week, in bouts of at least 10 minutes.

Similar recommendations were released shortly thereafter in Canada: the first physical activity guide for adults was developed by the Canadian Society for Exercise Physiology, with the support and approval of Health Canada and the Canadian Federal-Provincial-Territorial Ministers responsible for sport, physical activity and recreation. Canada’s physical activity guide to healthy active living for adults aged 18 to 55 years was launched in 1998.9 The recommendations targeted inactive individuals as it was then understood that the greatest improvements in health status were seen when inactive individuals became active.10 The guidelines were developed based on the scientific evidence available at the time; however, it was acknowledged that the recommendations were not subjected to a rigorous review process, and as a result, no supporting scientific documents were made available.10,11

In response to these limitations, the Physical Activity Measurement and Guidelines project was undertaken in 2006 by the Canadian Society for Exercise Physiology with support of the Public Health Agency of Canada with the purpose of establishing a formal process for
reviewing and updating the Canadian guidelines. A major goal of this project was to develop a set of revised guidelines using a comprehensive and transparent process. This was accomplished by conducting several systematic reviews, by involving several physical activity content experts and guidelines development experts from Canada and across the world, and eliciting feedback from thousands of relevant stakeholders. More than 20 background papers, systematic reviews, process descriptions, and other papers relevant to the dissemination and effectiveness of the physical activity guidelines have been published in a 2007 supplement of *Applied Physiology, Nutrition & Metabolism*, in a 2010 issue of the *International Journal of Behavioral Nutrition and Physical Activity*, and a 2011 issue of *Applied Physiology, Nutrition & Metabolism*. The resultant and most current Canadian guidelines for adults, which were released in 2010, recommend that adults should accumulate at least 150 minutes of moderate-to-vigorous physical activity in 10-minute bouts throughout the week. These are consistent with guidelines of other countries and with those of the World Health Organization. As will be discussed throughout this chapter, the guidelines are based on evidence for a dose-response relationship between physical activity and health, as well as the evidence for the accumulation of physical activity throughout the day in 10-minute bouts. Although a lot of research has been devoted to studying the potential health benefits associated with the different frequencies, intensities, durations and types of physical activity, an optimal dose of weekly physical activity has not yet been identified, nor have the effects of different patterns of physical activity been sufficiently studied.

### 2.2.3 Measuring physical activity levels

Information on physical activity levels has historically been collected through the self-reporting of physical activity through questionnaires. The test-retest reliability of many physical activity questionnaires has been shown to be high but is generally best in assessing higher-intensity activities. Questionnaires have also been validated against more direct measures of
physical activity such as heart rate monitoring or techniques for measuring energy expenditure, such as calorimetry. Questionnaires are used because they are practical and cost-effective, but they can vary significantly according to several factors such as the respondent recall period (e.g. physical activity participation in the past week, past month, past year), the dimensions of physical activity dose (e.g. frequency, intensity, duration, type), the domains of physical activity (e.g. leisure-time, occupational, domestic, transportation), the mode of administration (e.g. self-administered, telephone, in-person), and the outcome measure (e.g. time, energy expenditure). These differences can lead to important biases in the results, affect the comparability of results across studies, and/or limit the understanding of the relationship between physical activity and health outcomes.

Self-report questionnaires are subject to several biases which can influence the interpretability of the results. For example, participants might be more likely to over-report levels of physical activity because it is seen as a “socially desirable” behavior (social desirability bias), or participants might have difficulty remembering all of the activities they did, particularly over a longer recall period (recall bias). Additionally, the mode of self-reported data collection also has an influence on the accuracy of reporting. For instance, analysis of body mass index data from the Canadian Community Health Survey indicates that participants under-report their weight and body mass index to a greater extent when interviewed by telephone than when interviewed in person. Furthermore, specific details within a questionnaire may not be appropriate across an entire population: participation in different activities might vary by culture, by region, by climate, by season, by age, etc. This might also limit the generalizability of findings from the questionnaire.

Accelerometers have been introduced to several national surveillance programs, in Canada and elsewhere, in order to address some of the limitations of physical activity data collected by questionnaire. Accelerometers are small devices commonly worn on a belt around
the waist that record the acceleration of movement over a user-specified time interval (commonly one minute), which is captured as an activity count. The device can be worn continuously for an extended period and the minute-by-minute data can be downloaded onto a computer for analysis and interpretation (more details provided in Appendix C). Accelerometer data allows for an objective and more complete profile of daily or weekly physical activity: pre-determined cut-points can be applied to each activity count to determine the intensity of activity on a minute-to-minute basis. Accordingly, accelerometer data also allows for the assessment of different patterns of physical activity that cannot be captured by questionnaire. For example, the minute-by-minute profiling of physical activity from accelerometers (Figure 2.1) allows researchers to determine and differentiate between physical activity accumulated in bouts (e.g., > 10 consecutive minutes) versus sporadically (e.g., a few minutes here and there done intermittently).

![Figure 2.1 Example of the minute-by-minute data collected by an accelerometer over a 7-day (10,080 minute) period](image)

**Figure 2.1** Example of the minute-by-minute data collected by an accelerometer over a 7-day (10,080 minute) period
2.2.4 Metabolic syndrome

The metabolic syndrome (MetS) is a term that is used to define the clustering of cardiometabolic risk factors that increase the relative risk of developing cardiovascular disease and type 2 diabetes by approximately 50%.26,27 Under the current consensus definition, MetS is present if at least three of the following criteria are met: abdominal obesity (waist circumference $\geq 102$ for men and $\geq 88$ cm for women), elevated plasma triglycerides ($\geq 1.7$ mmol/L) or related drug therapy, decreased high-density lipoprotein (HDL) cholesterol ($<1.03$ mmol/L for men and $<1.30$ mmol/L for women) or related drug therapy, elevated blood pressure ($\geq 130/85$ mmHg) or related drug therapy, or elevated fasted glucose ($\geq 5.6$ mmol/L) or related drug therapy.26,28

Recent estimates from the Canadian Health Measures Survey indicate that MetS is prevalent in approximately 19% of the Canadian population aged 18 to 79 using the current definition;29 the prevalence of each of the component risk factors ranges from 16.2% for elevated fasting glucose levels to 35% for abdominal obesity.29 Since the presence of MetS increases cardiovascular and diabetes risk by $\sim 50\%$,27 the high prevalence of MetS in the Canadian population is a significant public health concern.29 As such, the MetS is the main outcome of interest in this thesis.

2.3 Public health burden of physical inactivity in adults

Physical inactivity is the fourth leading cause of death, causing more than 3 million deaths world-wide.5 The level of self-reported physical inactivity in adults worldwide has nearly doubled within the last decade: in 2008, the World Health Organization estimated that 31% of adults aged 15 years and older were insufficiently active5,30 compared to 17% in 2002.4 According to the World Health Organization, physical inactivity levels are generally higher in females
compared to males, in older age groups compared to younger age groups, and in high-income countries compared to low-income countries.\textsuperscript{4,30}

In Canada, self-reported data from the National Population Health Surveys and the Canadian Community Health Survey has suggested that physical inactivity in adults has decreased significantly over the last few decades. Cameron et al. found that physical inactivity levels (defined as less than 30 minutes of moderate physical activity daily) decreased from 62\% in 1994/95 to 51\% in 2005 in adults aged 20 years and older.\textsuperscript{31} Similarly, Bryan et al. found that physical inactivity (defined as not meeting the physical activity guidelines of at least 30 minutes of moderate-intensity physical activity 5 times per week, or 20 minutes of vigorous intensity physical activity at least 4 times per week) decreased from 46\% in 1994/95 to 35\% in 2007 in adults aged 18 to 55 years.\textsuperscript{32} Both studies show a similar trend for a decrease in physical inactivity from 1994/95 to 2005. The differences in estimates across time could reflect true temporal changes in physical activity, the different definitions of physical inactivity across survey years, and/or variations in the questionnaire items used to assess physical activity.

The trend of self-reported physical inactivity levels decreasing in Canada in recent years is in stark contrast to the increasing levels of physical inactivity reported by the World Health Organization: as mentioned, physical inactivity levels world-wide have nearly doubled in the last decade.\textsuperscript{30} An important difference between the assessment of physical inactivity at the global level was the inclusion of surveys that assessed physical activity in all domains (leisure-time, occupational, transportation, and domestic), whereas results discussed from Canadian studies reported only on leisure-time physical activity.

Meanwhile, recent assessment of physical activity through objective measurements suggests that physical inactivity levels are extremely high in Canadian adults. Specifically, accelerometer data was collected from nationally representative samples of Canadians as part of the Canadian Health Measures Survey from 2007 to 2009. According to the accelerometer data,
approximately 85% of adults aged 20 to 79 were considered to be inactive (i.e. not meeting Canada’s current physical activity guideline of 150 minutes per week of moderate-to-vigorous physical activity in bouts of at least 10 minutes). Colley et al. also assessed adherence to the previous version of the guidelines (i.e. 30 minutes of moderate-to-vigorous physical activity in 10 minute bouts at least 5 days out of 7). When these old guidelines were considered, nearly 95% of adults aged 20 to 79 did not meet the guidelines.

Surveillance of physical inactivity levels in populations is paramount as it has a direct and indirect impact on health: physical inactivity is associated with several diseases such as coronary heart disease, hypertension, type 2 diabetes, as well as all-cause mortality, among others. The population attributable fraction is a statistic that provides an indication of the proportion of new cases of disease that would not occur in the absence of the risk factor, in this case physical inactivity. Globally, population attributable fraction estimates range from 5-10% for diseases such as coronary heart disease, type 2 diabetes, certain cancers, as well as all-cause mortality. In Canada population attributable fractions have been estimated to range from 14% for hypertension to more than 20% for stroke and type 2 diabetes based on self-reported physical activity data, and from 23% for hypertension to nearly 40% for type 2 diabetes for directly-measured physical activity data. Differences in the global and Canadian can likely be attributed to the significant differences in the definition of physical inactivity and the different methods of data collection from the different sources.

Physical inactivity also results in significant direct (e.g. hospital care, drug, and physician expenditures) and indirect (the economic output lost because of illness, injury-related work disability, and premature death) costs to the healthcare system. In Canada, the most recent assessment of the economic burden of physical inactivity is estimated at $2.4 billion, $4.3 billion, and $6.8 billion in direct, indirect, and total health care costs, respectively; these values represented almost 4% of the overall healthcare costs in Canada.
2.4 Influence of physical activity on health in adults

The relationship between the volume of physical activity and chronic conditions has been well studied. Epidemiological studies have consistently shown that the volume physical activity reduces the risk for many chronic conditions in a dose-response manner. A recent review of the literature concerning physical activity and health in adults by concluded that regular physical activity is effective in the primary prevention of all-cause mortality and seven chronic conditions (cardiovascular disease, stroke, hypertension, colon cancer, breast cancer, type 2 diabetes, and osteoporosis) (Table 2.1).²

Table 2.1 Summary of the evidence of the relationship between physical activity and all-cause mortality and chronic diseases in adults²

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Evidence of a dose-response</th>
<th>Mean Risk Reduction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause mortality</td>
<td>Yes</td>
<td>31%</td>
</tr>
<tr>
<td>Cardiovascular disease</td>
<td>Yes</td>
<td>33%</td>
</tr>
<tr>
<td>Stroke</td>
<td>Yes</td>
<td>31%</td>
</tr>
<tr>
<td>Hypertension</td>
<td>Yes</td>
<td>32%</td>
</tr>
<tr>
<td>Breast cancer</td>
<td>Yes</td>
<td>20%</td>
</tr>
<tr>
<td>Colon cancer</td>
<td>Yes</td>
<td>30%</td>
</tr>
<tr>
<td>Type 2 diabetes</td>
<td>Yes</td>
<td>44%</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>Yes</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*Most active compared to least active group

Several of the aforementioned chronic diseases such as cardiovascular disease, hypertension, and diabetes are among the leading causes of death world-wide. In Canada, cardiovascular disease and diabetes were both among the top ten causes of death in 2009, causing nearly 30% of deaths collectively.³⁶ Since physical activity plays such an important role in the prevention of these diseases, it is imperative that we better understand the relationship between the dose (frequency, intensity, time and type) of physical activity and health conditions. The following sections critically review the available literature on the total volume of physical activity as well as the individual components of a physical activity dose.
2.4.1 Volume of physical activity and health

The total volume or dose of physical activity is a function of the frequency x intensity x duration of physical activity being performed. There is substantial evidence of a dose-response relationship between physical activity, general health\textsuperscript{37} and several chronic conditions such as cardiovascular disease, stroke, hypertension, colon cancer, breast cancer, type 2 diabetes, and osteoporosis.\textsuperscript{2} In general, evidence from prospective cohort studies suggests that the nature of the dose-response curve is curvilinear such that health benefit increases with increasing physical activity volume, but that greater improvements to health are seen with lower levels of physical activity, as illustrated in Figure 2.2. The current physical activity guidelines reflect the current understanding of the dose-response relationship. The recommendation for weekly physical activity is such that the greatest benefit is likely to result for individuals who are currently inactive (section “A” of the graph in Figure 2.2). It is also recommended that “more is better” which reflects the fact that additional health benefit occurs with more physical activity (sections “B” and “C” of the graph).
Unfortunately, in many of the studies on dose-response, the individual components of the physical activity dose (frequency, intensity, or duration) cannot be assessed individually, and therefore it is not entirely clear whether an optimal dose of physical activity exists for a given health outcome. The current guidelines do imply that a “minimum” amount of physical activity is required based on the evidence that the volume of physical activity is associated with an approximate 30% lower risk for all-cause mortality in adults. Health benefit has been observed at lower volumes of physical activity but there is insufficient evidence to determine whether a minimum dose actually exists.38 Similarly, although it is confirmed that greater health benefit can be gained from higher amounts of physical activity, there is insufficient data available that provides any indication of a maximum physical activity dose, beyond which no additional health benefit occurs.38 The literature on the type, intensity, and frequency (weekly patterns) of physical activity and their relationship to health are discussed in more detail below.
2.4.1 Type of physical activity and health

Some of the first evidence of the relationship between physical activity and health comes from early modern epidemiological studies of physical activity in various occupations. For example, the London Bus Study, a prospective cohort study of more than 30,000 employees of the London transit system, determined that the more active bus conductors had approximately 50% lower incidence rates of coronary heart disease than the less active bus drivers.\(^{39}\) Similarly, Paffenbarger et al. studied a cohort of American longshoremen and found approximately 20% lower rates of coronary heart disease in those who were more physically active in their day-to-day work than those who less active in their work.\(^ {40}\) A limitation of these original studies is that occupational physical activity level was assumed based on job title and was not quantitatively measured. In more recent population-based cohort studies of occupational physical activity assessed by questionnaire, the highest levels of occupational physical activity lowered the risk for all-cause mortality (31% lower), cardiovascular disease (46% lower) and type 2 diabetes (26% lower) compared to the lowest levels of occupational physical activity.\(^ {41},^{42}\)

Large prospective cohort studies have shown that physical activity from other domains contributes significantly to total daily physical activity and is associated with health. Recent cohort studies have also found positive associations between transportation, domestic, and leisure-time physical activity, as assessed by questionnaire, and health outcomes. Both leisure-time and transportation physical activity have been shown to lower the risk for type 2 diabetes by approximately 40% and 30%, respectively.\(^ {41}\) Similarly, the risk for all-cause mortality and cardiovascular disease were lowered by up to 50% for leisure-time, transportation or domestic physical activity.\(^ {42}\) An important strength of these studies was the adjustment for relevant confounders (age, sex, body mass index, etc.), in addition to the adjustment for physical activity accrued through the other domains. Depending on the individual, physical activity accrued
through a given domain might only contribute minimally to total daily energy expenditure, which could lead to false conclusions because of the physical activity accrued in the other domains. By adjusting for physical activity accrued through the other domains, the independent effect of a given domain can truly be assessed.

An important consideration when assessing physical activity domains, involves understanding that participants might under- or over-report activity in a given domain depending on their interpretation of the nature of certain activities. For example, certain domestic activities like gardening or other chores are actually promoted as exercise and included in the collection of information on leisure-time activities. Similarly, walking could easily be reported as a transportation activity, or as a leisure-time activity. These limitations are important when considering the magnitude of risk reductions, especially when comparing results across studies; as suggested, activities might be over- or underreported in a given domain which might over- or underestimate the magnitude of association.

In Canada, the surveillance of physical activity has focused primarily on leisure-time physical activity. The questionnaires have collected limited information on the activities or the energy expended through other domains. Although some research has suggested that leisure-time physical activity has increased in Canada, it has also been acknowledged that adults have only 3 or 4 hours of available leisure-time per day, with the remaining waking hours devoted to non-leisure-time activities within the domains of occupational, domestic and transportation. As such, leisure-time physical activity accounts for only a small portion of the daily physical activity energy expenditure: the consideration of physical activity in other domains is therefore important in understanding the relationship between total physical activity (or total energy expenditure) and health outcomes.

Another interpretation of the “type” of physical activity is the physiological nature of the activity i.e. aerobic, resistance training, and flexibility. The guidelines for moderate-to-vigorous
physical activity and the relationships between physical activity or inactivity and health discussed throughout this chapter so far relate primarily to aerobic physical activity, which is physical activity that is repetitive in nature and involves large muscle groups (e.g. walking, running, swimming, etc.). However, musculoskeletal fitness (strength and flexibility) has been shown to be positively associated with health. As such, the physical activity guidelines recommend that adults participate in muscle and bone strengthening activities at least 2 days per week. Several longitudinal studies have shown that higher measured muscular strength reduces the risk for all-cause mortality, cancer, and functional limitations, independent of cardiorespiratory fitness levels. Results appear to be consistent across studies for men, but not women.

2.4.2 Intensity of physical activity and health

All physical activity guidelines recommend participation in physical activity of at least moderate intensity for health benefit. Moderate-intensity physical activity is sufficiently strenuous to elicit a physiological response and improve aspects of physical fitness, although not so strenuous that it limits a person from talking during a workout, and therefore appropriate for the general public. It has been suggested that physical activity at higher intensities can be offset by shorter duration. In fact, some guidelines recommend that adults should accumulate 150 minutes of moderate-intensity physical activity, but that comparable benefits can be achieved through 75 minutes of vigorous-intensity physical activity or through some combination of moderate and vigorous physical activity. This suggests that the duration and intensity of physical activity are directly inversely related in the determination of the total volume of physical activity (i.e. that 1 minute of vigorous-intensity activity is equivalent to 2 minutes of moderate-intensity activity).

There is evidence from both observational and experimental studies that vigorous physical activity intensity has an independent effect on health and various risk factors for
In a recent cross-sectional study, Janssen and Ross used data from the 2003 to 2006 U.S. National Health and Nutrition Examination Survey to determine whether the intensity of physical activity influenced the MetS independent of physical activity dose (total volume of MVPA).\textsuperscript{51} After adjusting for total MVPA, the authors found that the odds ratio for MetS was nearly 2 times lower for vigorous-intensity physical activity compared to moderate-intensity physical activity.\textsuperscript{51} Similarly, results from a large cohort study showed that the relative risk for an equivalent volume of vigorous physical activity was nearly 20\% lower compared to moderate physical activity.\textsuperscript{52} Finally, in a 24-week intervention trial, equivalent volumes of vigorous physical activity resulted in greater improvements in cardiorespiratory fitness and percent body fat compared to moderate-intensity physical activity;\textsuperscript{53} additionally, only the vigorous intensity exercise group saw significant improvements in total cholesterol and low density lipoprotein (LDL) cholesterol.\textsuperscript{53}

Some research has shown that some individuals benefit from light intensity physical activity. This was evidenced most recently through the study of non-exercise activity thermogenesis (NEAT), which is the daily energy expenditure from activities that are not for the purpose of improving fitness (i.e. light intensity, non-exercise activities).\textsuperscript{54} It has been shown that variations in NEAT, particularly the differences between NEAT levels in obese compared to non-obese individuals, contribute significantly to the energy imbalance that leads to weight gain and obesity levels.\textsuperscript{54} Results from questionnaire-based cohort studies are inconsistent, with some showing a positive association between light physical activity and lower risks for cardiovascular disease or premature mortality,\textsuperscript{42} while others have found no such association.\textsuperscript{52}

An important limitation that is common in the study of physical activity intensity and its relationship to health is that many studies have not controlled for the total volume of physical activity when assessing the independent effects of physical activity intensity; therefore, it remains unclear from such studies whether the effect of physical activity is related to intensity or to total
energy expenditure.\textsuperscript{38,44} Research from prospective cohort studies indicate that it is in fact the total energy expenditure, and not physical activity intensity, that is important in reducing the risk for mortality in both men and women.\textsuperscript{52}

Another issue that often confounds the understanding of the relationship between physical activity intensity and health benefit is the consideration of the absolute versus the relative intensity. The relative intensity of a given activity differs between individuals due to differences in cardiorespiratory fitness levels. For example, a brisk walk is considered a moderate-intensity activity in absolute terms. In relative terms, a brisk walk might be a light-intensity activity for a younger, fitter individual or a vigorous-intensity activity for an older, less fit individual. This is especially important in the context of self-reported physical activity data as individual perspectives of physical activity intensity might result in the over- or under-reporting of activity at a given absolute intensity.

Time spent sedentary is also increasingly being acknowledged as an independent risk factor for many chronic conditions. A recent review by Tremblay et al. explains that there is evidence to show that even short periods of sedentary behaviour (as little as five days in some cases) result in significant increases in metabolic risk (as characterized by increases in total cholesterol, triglyceride, glucose and insulin resistance, and decreases in high density lipoprotein - cholesterol).\textsuperscript{55} Several studies have suggested that the relationship between sedentary behaviour and health is independent of physical activity level and that such high levels of sedentary activity for extended durations are associated with negative health outcomes such as obesity and cardiovascular disease even when recommended levels of physical activity are achieved.\textsuperscript{55}

2.4.3 Frequency (patterns) of physical activity and health

While it is well accepted that physical activity is important in the prevention and treatment of chronic disease, there remain several research gaps relating to physical activity and
health. The development of the physical activity guidelines was based on strong evidence of a
dose-response relationship between MVPA and health, which includes strong evidence that
MVPA can be accumulated in 10-minute bouts.\textsuperscript{2,13} What remains unclear is whether there exists
an optimal pattern of physical activity, i.e. whether the accumulation of physical activity in
different patterns results in a difference in health benefit. The following sections discuss the
existing literature of two specific patterns of physical activity which form the basis for this thesis.

\textbf{2.4.3.1 Sporadic physical activity versus bouted physical activity}

Support for participation in MVPA in short bouts of a minimum 10 minutes in duration
emerged in earlier iterations of public health physical activity guidelines following evidence that
several 10-minute bouts of MVPA were as effective as an equivalent continuous session of
MVPA at improving cardiorespiratory fitness and several cardiometabolic risk factors.\textsuperscript{3,56,57} As
such, public health messages began advocating the idea of accumulating physical activity in
shorter bouts throughout the day under the premise that shorter bouts of physical activity could fit
better into busy schedules, as compared to one continuous session.\textsuperscript{3}

Randomized-controlled trials have consistently shown that moderate-intensity aerobic
exercise resulted in increases in cardiorespiratory fitness when exercise was completed in one
continuous 30-minute session or in accumulated shorter sessions (e.g. three short 10-minute
sessions).\textsuperscript{58,59} One of the first studies to compare short versus continuous sessions of MVPA was
conducted by DeBusk et al. (1990) in a sample of inactive but otherwise healthy middle-aged
men. The men were randomly assigned to complete an 8-week aerobic training program where
moderate-intensity exercise was completed either in one continuous 30-minute session (long-bout
group) or in three short 10-minute sessions (short-bout group) each day. Significant increases in
cardiorespiratory fitness were seen in both groups following the 8-week training program,
although the relative increase from baseline was significantly higher in the long-bout group (14\%)
compared to the short-bout group (8%). Osei-Tutu et al. (2004) followed a similar study protocol in a sample of inactive, healthy men and women. The authors found that cardiorespiratory fitness increased by approximately 7% from baseline in both the long-bout and the short-bout groups following the 8-week training intervention.

Research on the relationship between shorter bouts or sporadic (<10 minutes) MVPA and cardiorespiratory fitness or cardiometabolic risk factors has been limited. This is largely due to the limitations inherent in the measurement of physical activity as sporadic physical activity is not easily or accurately captured through questionnaire. However, the potential role of sporadic MVPA in influencing health has been recently acknowledged given the known contribution of sporadic activity to total daily energy expenditure.

Recently, studies have used accelerometers to measure sporadic MVPA and have suggested that it is positively associated with cardiorespiratory fitness and cardiometabolic risk factors such as visceral adipose tissue, triglycerides, and total cholesterol. For example, Ross and McGuire (2011) used accelerometers to study the associations between sporadic MVPA, cardiorespiratory fitness, and abdominal fat in a small sample of inactive, obese adults. The average minutes of sporadic MVPA per day was calculated from all minutes of MVPA accumulated in less than 10 consecutive minutes. The authors found that sporadic MVPA was positively associated with cardiorespiratory fitness levels (measured as peak oxygen consumption during a maximal treadmill test); these results provide evidence to suggest that physical activity may not need to be accumulated in bouts of at least 10 minutes for improvements in cardiorespiratory fitness. In the same sample the authors also found that sporadic MVPA was negatively associated with visceral adipose tissue (as measured by magnetic resonance imaging), suggesting that the accumulation of sporadic MVPA in obese adults might be beneficial in attenuating the accumulation of abdominal fat.
Only two studies have compared the strength of the association between bouted (≥10 minutes) and sporadic (<10 consecutive minutes) and cardiometabolic risk factors, with inconsistent results. Strath et al. (2008) used accelerometer data from the 2003-2004 National Health and Nutrition Examination Survey in the United States to study the effects of MVPA accumulated sporadically and in bouts of at least 10 minutes on the body mass index and waist circumference of adults 18 years of age and older. The authors did this by determining the daily average of minutes of sporadic MVPA (accumulated in less than 10 consecutive minutes) and the daily average of minutes of MVPA accumulated in bouts of at least 10 consecutive minutes. The authors found that MVPA accumulated sporadically was significantly and independently associated with a lower BMI and waist circumference after controlling for various confounders and minutes of MVPA bouts; however, the association between average daily minutes of MVPA accumulated in bouts was three and four times greater for waist circumference and BMI, respectively, suggesting that MVPA accumulated in bouts is more beneficial than MVPA accumulated sporadically.63

Meanwhile, Glazer et al. collected accelerometer data from a sample of the 3rd Generation cohort of the Framingham Heart Study to study the effects of MVPA accumulated sporadically and in bouts of at least 10 minutes on cardiovascular risk factors in adults.64 The authors used comparable methods as Strath et al. to determine bouted (≥10 consecutive minutes) and sporadic (<10 consecutive minutes) MVPA. They found that there was no difference in the strength of associations with cardiovascular risk factors when comparing MVPA accumulated in bouts or sporadically.64

While important, the above studies are not without limitations. The work by Ross and McGuire (2011) was completed on a sample of abdominally obese, inactive individuals, and is therefore not generalizable to a broader population. Additionally, none of the participants accumulated MVPA in bouts of at least 10 minutes; therefore the relative effect of sporadic
MVPA versus bouts of MVPA could not be compared. Strath et al. (2008) studied a larger, more heterogeneous sample of American adults; however, the authors focused only on obesity measures. Furthermore, these studies are all cross-sectional in nature. No cohort studies, and very few randomized, controlled trials have been completed evaluating sporadic or shorter bouts of MVPA (<10 minutes). However, at least two such studies have shown that MVPA accumulated in shorter bouts (10 x 3 minutes) was as effective as a continuous session (30 minutes) in reducing post-prandial triglyceride levels as well as resting systolic blood pressure in healthy young men.65,66

2.4.3.2 Weekly patterns of physical activity

Previous versions of physical activity guidelines for adults have advocated daily MVPA or MVPA on most days of the week as being necessary to improve and maintain health.3 The current guidelines differ from this in that there is no longer a specific recommendation provided regarding the frequency of MVPA throughout the week as it was determined that there is currently insufficient evidence to suggest that more frequent physical activity offers greater health benefit than an equivalent volume of less frequent MVPA.13-16,50

There is currently very limited research on the frequency of physical activity throughout the week and its relationship with health. One large cohort-based study in males determined weekly moderate-to-vigorous physical activity energy expenditure at baseline and compared mortality over a 9-year follow-up period for those who were inactive (<500 kcal per week), insufficiently active (500-999 kcal per week), “weekend warriors” (1000 kcal or more over 1 or 2 days per week) and regularly active (1000 kcal or more on 3 or more days per week). Results showed that although the relative risk of premature mortality was nearly two times greater for regularly active men compared to weekend warriors, the difference was not significant.67 However, in men with at least 1 major cardiovascular risk factor at baseline (e.g., smoker,
overweight, hypertension, or high cholesterol) a significantly lower relative risk of premature mortality was seen in regularly active men, but not in weekend warriors.67. No evidence from experimental studies of physical activity frequency currently exists.

Although studies of the frequency of weekly physical activity is limited, the suggestion that more frequent physical activity might be more beneficial to health than equivalent amounts of irregular activity also originates from research on the acute effects of exercise in adults. This includes the known physiological and metabolic changes that occur during exercise and which persist for up to several hours or days following a single exercise session. A review of the evidence by Kesaniemi et al. and Thompson et al. concluded that there is strong evidence from randomized, controlled trials that a single exercise session has a positive effect on blood lipids, blood pressure, and insulin sensitivity.57,68 Specifically, improvements in high density lipoprotein-cholesterol and triglycerides occur 24 hours post-exercise, and persist for up to 72 hours.68 Meanwhile, improvements in insulin sensitivity occur immediately following an exercise session and may persist for several days.68 Finally, improvements blood pressure also occur immediately following exercise but only persist for up to 16 hours post-exercise.68 Given that high density lipoprotein-cholesterol, blood glucose levels, and blood pressure are important component risk factors of the MetS, cardiovascular disease and type 2 diabetes in adults, it can be postulated that more regular physical activity might offer a reduction in such risk factors, and consequently a reduction in risk for disease.

2.5 Summary and conclusions

This literature review presents some of the research that illustrates and confirms that physical activity is negatively associated with disease. Many population-based cross-sectional and cohort studies have demonstrated that the total volume of physical activity recommended in the past and present physical health guidelines significantly decreases the likelihood for diseases such
as cardiovascular disease, type 2 diabetes, obesity, hypertension, and MetS. Many of these same studies have been able to identify and confirm a dose-response relationship between physical activity and health, such that occurrences of disease decrease with increasing volumes of physical activity. Unfortunately, to date, physical activity has typically been evaluated by self-report, which has not allowed for conclusions to be drawn regarding an optimal dose of physical activity required for health mainly because of difficulties in comparing results due to differing survey methodologies and the inability to evaluate different patterns of MVPA through questionnaire data. While randomized, controlled trials would be ideal for comparing the efficacy of different doses, the length of intervention and number of participants required to study such effects is unrealistic because the incubation period between the exposure (physical inactivity) and the outcome (chronic disease of interest) could be years. Several longitudinal cohort studies have evaluated the relationship between physical activity and disease; however, the measurement of physical activity at baseline is not necessarily representative of regular physical activity patterns, nor is the pattern of physical activity easily determined.

Recently, accelerometers have been introduced to many population-based and intervention surveys and allow for more complete physical activity profiles to be evaluated. Accelerometer data has the potential to contribute to the dearth of research that exists on the possible effect that different patterns of physical activity might have on health. In particular, accelerometer data allows researchers to evaluate whether physical activity accumulated sporadically or in short bouts is as effective as longer bouts or continuous physical activity in influencing health or fitness. It also allows researchers to look at the frequency of physical activity throughout the week. Information on physical activity patterns such as these can contribute to the existing evidence that forms the basis for the physical activity guidelines so as to determine whether there is an optimal dose (frequency, intensity, time or type) of physical activity that most benefits health.
References


19. Valanou EM, Bamia C, Trichopoulou A. Methodology of physical activity and energy-


Chapter 3

Sporadic and bouted physical activity and the metabolic syndrome in Canadian adults
3.1 Abstract

**Purpose:** Physical activity guidelines recommend that adults accumulate at least 150 minutes of moderate-to-vigorous physical activity (MVPA) per week in bouts of at least 10 minutes. However, sporadic MVPA contributes significantly to total physical activity and may also impact health. The study objective was to determine, within adults aged 18 to 64, whether MVPA accumulated in bouts is more strongly associated with metabolic syndrome (MetS) than an equivalent volume of MVPA accumulated sporadically.

**Methods:** The study sample included 1,119 adults aged 18 to 64 from the 2007-2009 Canadian Health Measures Survey, a nationally-representative cross-sectional study. The energy expenditure from bouted (at least 10 consecutive minutes) and sporadic (<10 consecutive minutes) MVPA was measured over 7 days using Actical accelerometers. The presence of MetS was determined using established criteria. Associations were examined using logistic regression and controlled for covariates (age, sex, education, diet, and smoking).

**Results:** After adjusting for the covariates and each other, bouted and sporadic MVPA were independently associated with the MetS. For each additional MET hour/week of bouted MVPA, the relative odds of the MetS decreased by 9% (95% CI: 3-14%). For each additional MET hour/week of sporadic MVPA the relative odds of the MetS decreased by 11% (5-16%). Overlapping CIs indicate no difference in the effect estimates for bouted and sporadic MVPA. Secondary analyses revealed that small bursts of sporadic MVPA (1-3 minutes) were meaningful when predicting the MetS.

**Conclusion:** Within this representative sample of Canadian adults, sporadic MVPA was associated with the MetS to a similar order of magnitude as an equivalent volume of bouted MVPA.

**Key Words:** cardiometabolic risk factors; accelerometer; exercise; guidelines;
3.2 Introduction

The role that regular moderate-to-vigorous physical activity (MVPA) has in the prevention of several chronic diseases is well accepted. A recent systematic review concluded that there is strong evidence that regular physical activity is important in the primary prevention of coronary artery disease, stroke, hypertension, colon cancer, breast cancer, type 2 diabetes, and osteoporosis.1

The current physical activity guidelines of the World Health Organization2 and several countries3-5 recommend that adults accumulate at least 150 minutes of MVPA per week in bouts of at least 10 minutes.2-5 The notion that MVPA can be accumulated in brief, 10 minute bouts is based on evidence that a few short bouts of MVPA have comparable effects on fitness and health as a single longer bout.6-10 While short and long bouts of MVPA are known to have important health benefits, there is currently limited evidence as to whether MVPA accumulated sporadically (in less than 10 consecutive minutes) has health benefits. The study of sporadic MVPA is important as it contributes significantly to total daily energy expenditure, and therefore may play an important role in health.3,11,12 A recent study found that sporadic MVPA was associated with several cardiovascular risk factors and that, from a statistical standpoint, the associations for sporadic MVPA were similar to those for bouted MVPA.13 While this and other6,8,14-16 evidence provides support for the notion that sporadic MVPA benefits health, what remains uncertain is whether comparable volumes of sporadic MVPA and bouted MVPA influence health outcomes to a similar order of magnitude.

The purpose of this study was to determine whether bouted MVPA is more strongly associated with cardiometabolic risk factors, specifically with the metabolic syndrome (MetS), than an equivalent volume of sporadic MVPA. Secondary analyses assessed the duration of sporadic MVPA needed to influence the MetS. MetS is a highly prevalent 17 clustering of cardiometabolic risk factors that increase the relative risk of the developing cardiovascular disease
and type 2 diabetes by ~50\%.\textsuperscript{18,19} We have the opportunity to assess these associations within a large and representative sample of Canadian adults.

### 3.3 Methods

#### Data source

The study is based on cycle 1 of the Canadian Health Measures Survey (CHMS). The CHMS covers the Canadian population aged 6 to 79 living in private dwellings. The present study is limited to adults aged 18-64 years. Residents of Indian Reserves or Crown lands, institutions, certain remote regions, and full-time members of the Canadian Forces were excluded. Approximately 96\% of the Canadian population is represented.\textsuperscript{20,21} Data were collected from March 2007 to February 2009. The survey consisted of two parts: 1) an in-home interview that collected information on socio-demographic characteristics and health behaviours; and 2) a subsequent visit to a mobile clinic for a series of physical measurements, including anthropometric and fitness tests, and the collection of blood samples. Of the households selected for the survey, 69.6\% provided the sex and date of birth of all household members. Within each responding household one or two members were then selected to participate. Of those selected, 88.3\% completed the household questionnaire, and 84.9\% of those participated in the visit to the mobile clinic. The final response rate after adjusting for the sampling strategy was 51.7\%.\textsuperscript{20} The sample for this article is based on 1,119 respondents aged 18-64 years with valid physical activity and MetS data. Ethics approval for the CHMS was obtained from Health Canada’s Research Ethics Board.\textsuperscript{20,22} Informed written consent was obtained (see Appendix B).

#### Physical activity

At the mobile clinic, an Actical accelerometer was provided to ambulatory participants to wear on an elasticized belt over the right hip during all waking hours for one week.\textsuperscript{20}
Accelerometers were initialized to begin collection at midnight following the clinic visit and were mailed back to Statistics Canada after the 7-day collection period.\textsuperscript{20} The Actical accelerometer measures the acceleration of movement in all directions (omnidirectional); movement is captured and recorded as a digitized value that is summed over one minute intervals (epoch), resulting in 10,080 activity count per minute (cpm) values. Accelerometer data reduction followed published guidelines to identify and remove invalid data.\textsuperscript{23-25} Total daily accelerometer wear time was determined by identifying non-wear time and subtracting it from 24 hours. Non-wear time was defined as periods of at least 60 consecutive minutes of zero counts, with an allowance for up to two minutes of counts between 0 and 100.\textsuperscript{23-25} A non-wear period of 90 minutes was also explored following results of a recent validation study suggesting that a 90-minute window is more appropriate in accurately identifying non-wear time.\textsuperscript{26} A non-wear time period of 90 minutes had no effect on the current findings; therefore a 60 minute period was chosen to align with previously published accelerometer research from the CHMS and the National Health and Nutrition Examination Survey (NHANES) in the United States.\textsuperscript{24,25} A valid day was defined as having at least 10 hours of wear-time; a valid person was defined as having at least 4 valid days of data.\textsuperscript{23-25} Only participants with at least 4 valid days of data were included in this paper.

A cut-point of \(\geq 1,535\text{cpm}\) was used to denote epoch values of at least a moderate intensity.\textsuperscript{27} For each epoch above this value, the regression equation developed by Heil\textsuperscript{28} was used to estimate energy expenditure (kcal/kg/min) as follows: activity energy expenditure (kcal/kg/min) = 0.02663 + (0.00001107*cpm). The resulting value was converted to metabolic equivalents (METs) by multiplying by 60 and then adding 1 MET to account for resting energy expenditure, as the Heil equation predicts energy expenditure above rest. We chose to express MVPA in METs because this allowed us to merge the moderate and vigorous activity minutes, and when doing so, to account for the fact that more energy is expended for each minute of
vigorous activity than for each minute of moderate activity. For each individual in the study the total weekly MET hours was determined by summing the MET hour values for all bouted MVPA (i.e., MVPA accumulated in at least 10-minute bouts) and sporadic MVPA (i.e., MVPA accumulated in period of 9 minutes or less) epochs. A bout of MVPA was defined as a period of at least 10 consecutive minutes above the moderate-intensity cut-point; a bout continued until 80% (i.e. 8 out of 10 minutes) was no longer above the cut-point. Since not all participants had seven valid days of data, each total was divided by the number of valid days to obtain a daily average, and then multiplied by 7 to obtain a weekly total. Thus, the final derived physical activity variables for each participant consisted of MET hours/week of bouted MVPA and MET hours/week of sporadic MVPA. As this was an observational study, all participants had a bouted MVPA and a sporadic MVPA value, and these were not mutually exclusive groups.

Because of the error involved in converting accelerometer counts to energy expenditure, we also considered MVPA in minutes/week in addition to MET hours/week. For the calculations, we assumed that the energy expended for each minute of vigorous activity would be twice that expended during moderate activity. Thus, total weekly minutes of MVPA was obtained by multiplying the vigorous intensity minutes by two and adding them to moderate intensity minutes. As the results for the analyses based on MVPA in minutes/week were comparable to those for MVPA in MET hours/week, we have only presented the findings based on the latter MVPA variable throughout the paper.

**Metabolic syndrome**

MetS was defined based on the 2009 Joint Interim Statement and was present if three or more of the following conditions were met: high blood pressure (≥130/85 mmHg) or drug treatment; high triglycerides (≥1.7 mmol/L for men and women) or drug treatment; low high-density lipoprotein (HDL) cholesterol (<1.0 mmol/L for men, <1.3 mmol/L for women) or drug treatment; high fasting blood glucose (≥5.6 mmol/L) or drug treatment; and high waist
circumference (≥102 cm for men, ≥88 cm for women). Lower waist circumference cut-offs have been proposed in the definition of MetS; however, there is limited evidence supporting either cut-off. The cut-offs used in the present analysis were chosen as they are those currently recommended by Health Canada.

Measurement procedures for the MetS components are described briefly here. Greater detail is provided elsewhere. Waist circumference was measured to the nearest 0.1 cm at the mid-point between the last floating rib and the top of the iliac crest, at the end of a normal expiration, using a Gulick tape measure. Resting BP was measured electronically using a BPTru™ BP-300 device (BpTRU Medical Devices Ltd., Coquitlam, British Columbia). After resting quietly for 5 minutes, a minimum of 6 measurements were then taken automatically, one minute apart, and the average systolic and diastolic blood pressure was determined using the last 5 of the 6 measurements. Venous blood samples were collected following a 10-hour fasting period: glucose levels were measured in plasma, while triglycerides and HDL-cholesterol were measured in serum. Blood samples were analyzed at the Health Canada Laboratory (Bureau of Nutritional Sciences, Nutrition Research Division). Glucose, HDL-cholesterol and triglycerides were all measured on the Vitros 5,1FS (Ortho Clinical Diagnostics). Results below the limit of detection were included in analysis by imputing a value of the limit of detection divided by two. For medication use, respondents provided all prescription and over-the-counter products taken in the past month. Drug identification numbers were coded using the Anatomical Therapeutic Chemical classification system.

Covariates

Covariates include age, sex, education (post-secondary graduate, yes/no), smoking status (current smoker or non-smoker), diet, Health Utilities Index (HUI), and total accelerometer wear time. Dietary information was obtained through a food frequency questionnaire. Principal component analysis was used to create a single diet quality index variable based on the yearly
frequency of consumption of the following food items: brown bread, fruit, lettuce, spinach, salt-water and fresh-water fish, shellfish, and nuts. These food items were identified as being part of a healthy diet, and are known to have a positive association with the MetS risk factors.\textsuperscript{33,34} Therefore, the diet index was included in the regression models as a means of adjusting for a good diet, and higher scores indicated a more healthy diet. The HUI is a summary score of an individual’s overall functional health based on vision, hearing, speech, mobility, dexterity, cognition, emotion, and pain and discomfort, which are attributes that are associated with PA and the MetS. The index ranges in value from -0.360 (a state considered worse than death) to 1 (perfect health). More information on the index has been published elsewhere.\textsuperscript{35} Finally, total accelerometer wear time was included as a covariate to account for differences in wear time. Time spent in light physical activity and time spent sedentary were also considered as possible confounders; however, preliminary analysis indicated that neither variable was related to the MetS and they were therefore not included as covariates.

**Statistical analysis**

Conventional descriptive statistics were used to describe the sample. Partial correlations (adjusted for age and sex) were used to examine relations between the MVPA variables. Relations between the MVPA and MetS variables were determined using logistic regression. An initial model (Model 1) that included all covariates was run separately for the sporadic and bouted MVPA variable. A second model (Model 2) that included both the sporadic and bouted MVPA variables and the covariates was run so that the independent effects of sporadic and bouted MVPA could be examined. The MVPA variables were included in the logistic regression models as continuous variables; thus the odds ratios (OR) and associated 95% confidence intervals (95% CI) are expressed per each 1 MET hour/week difference in MVPA. The variance inflation factors were calculated for each of the covariates in model 2 to determine if multicollinearity was an issue.\textsuperscript{36}
In a second set of analyses, participants were divided into three groups for both sporadic and bouted MVPA using cut-points that are equivalent to the physical activity guidelines: inactive (0-249 MET-minutes); somewhat active (250-499 MET-minutes or meeting 50% of the guideline); and active (≥500 MET-minutes or meeting 100% of the guideline). The grouped variable was included in the logistic regression models, and ORs and associated 95% CI are expressed using the inactive group as the referent. Finally, the c-statistic was determined for each logistic regression model to assess the overall fit of the model. The c-statistic is identical to the area under the receiver operating characteristic (ROC) curve, with values ranging from 0.5 (no better discrimination than chance alone) to 1.0 (perfect discrimination).

In secondary analyses, different lengths of sporadic MVPA were assessed to determine the minimum duration of sporadic MVPA needed to influence the MetS. Sporadic MVPA in lengths of 7-9 minutes, 4-9 minutes, and 1-9 minutes was determined. In a series of logistic regression models, we considered whether adding shorter sessions of sporadic MVPA to the sporadic MVPA variable resulted in a model that was better able to predict the MetS (e.g., did the volume of sporadic MVPA accumulated in 1-9 minutes predict MetS better than sporadic MVPA accumulated in 4-9 minutes). The Akaike information criterion (AIC) was calculated to compare the goodness-of-fit between the regression models. A difference in AIC values of between 2 to 7 indicates a moderate difference in fit of the models, while a difference of 7 or more indicates a large difference in model fit. The Akaike weight was calculated to indicate the probability that each regression model was the best choice amongst the set of candidate models based on model fit.

All analyses were completed using SAS v9.2 and SUDAAN v10. All results were weighted using the activity monitor sub-sample weights. Standard errors, coefficients of variation and 95% CI were calculated using the bootstrap technique. The CHMS study design
requires that 11 degrees of freedom be specified in the software,²⁰ and this limits the number of variables that can be included in the regression models to 10.

### 3.4 Results

Descriptive characteristics of the 1,119 participants are presented in Table 3.1. The mean age of the sample was 41.1 years and 49.1% were male. Approximately 12.7% had high fasting glucose, 18.9% had high blood pressure, 22.9% had high triglycerides, 29.5% had a high waist circumference, 31.2% had low HDL-cholesterol, and 15.2% had MetS.

#### Table 3.1 Participant characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n=1,119)</th>
<th>Males (n=532)</th>
<th>Females (n=587)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>41.1 ± 0.4</td>
<td>40.6 ± 0.7</td>
<td>41.6 ± 0.7</td>
</tr>
<tr>
<td>Sex (%)</td>
<td>49.1</td>
<td>50.9</td>
<td></td>
</tr>
<tr>
<td>Race (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>81.7</td>
<td>80.6</td>
<td>82.8</td>
</tr>
<tr>
<td>Other</td>
<td>18.3 E</td>
<td>19.4 E</td>
<td>17.2 E</td>
</tr>
<tr>
<td>Current daily smoker (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>18.1</td>
<td>20.1</td>
<td>16.2</td>
</tr>
<tr>
<td>No</td>
<td>81.9</td>
<td>79.9</td>
<td>83.8</td>
</tr>
<tr>
<td>Post-secondary graduation (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>65.0</td>
<td>64.6</td>
<td>65.3</td>
</tr>
<tr>
<td>No</td>
<td>35.0</td>
<td>35.4</td>
<td>34.7</td>
</tr>
<tr>
<td>Income quartile (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower income quartile</td>
<td>18.7</td>
<td>16.0</td>
<td>21.3</td>
</tr>
<tr>
<td>Lower-middle income quartile</td>
<td>22.3</td>
<td>21.9</td>
<td>22.6</td>
</tr>
<tr>
<td>Upper-middle income quartile</td>
<td>25.5</td>
<td>24.7</td>
<td>26.3</td>
</tr>
<tr>
<td>Upper income quartile</td>
<td>28.9</td>
<td>34.5</td>
<td>23.4</td>
</tr>
<tr>
<td>No income reported</td>
<td>4.7</td>
<td>2.9 E</td>
<td>6.5 E†</td>
</tr>
<tr>
<td>Physical activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total MVPA (total MET hours/week)</td>
<td>13.5 ± 0.9</td>
<td>14.8 ± 1.0</td>
<td>12.3 ± 1.0 †</td>
</tr>
<tr>
<td>Bouts MVPA (total MET hours/week)</td>
<td>6.4 ± 0.6</td>
<td>6.5 ± 0.7</td>
<td>6.4 ± 0.7</td>
</tr>
<tr>
<td>Sporadic MVPA (total MET hours/week)</td>
<td>7.2 ± 0.4</td>
<td>8.6 ± 0.4</td>
<td>6.1 ± 0.5 †</td>
</tr>
<tr>
<td>Cardiometabolic risk factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waist circumference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>Total (n=1,119)</td>
<td>Males (n=532)</td>
<td>Females (n=587)</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------</td>
<td>--------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Mean (cm)</td>
<td>89.1 ± 0.8</td>
<td>93.4 ± 0.9</td>
<td>84.9 ± 1.3†</td>
</tr>
<tr>
<td>High waist circumference (%)</td>
<td>29.5</td>
<td>23.9</td>
<td>35.0</td>
</tr>
<tr>
<td>Blood pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean systolic (mmHg)</td>
<td>109 ± 1</td>
<td>112 ± 1</td>
<td>106 ± 1 †</td>
</tr>
<tr>
<td>Mean diastolic (mmHg)</td>
<td>71 ± 1</td>
<td>73 ± 1</td>
<td>68 ± 1 †</td>
</tr>
<tr>
<td>High blood pressure (%)</td>
<td>18.9</td>
<td>20.0</td>
<td>17.8</td>
</tr>
<tr>
<td>HDL-cholesterol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mmol/L)</td>
<td>1.3 ± 0.0</td>
<td>1.2 ± 0.0</td>
<td>1.5 ± 0.0 †</td>
</tr>
<tr>
<td>Low HDL-cholesterol (%)</td>
<td>31.2</td>
<td>25.4</td>
<td>36.8 †</td>
</tr>
<tr>
<td>Triglycerides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mmol/L)</td>
<td>1.28 ± 0.04</td>
<td>1.39 ± 0.05</td>
<td>1.18 ± 0.05 †</td>
</tr>
<tr>
<td>High triglycerides (%)</td>
<td>22.9</td>
<td>27.1</td>
<td>18.9 †</td>
</tr>
<tr>
<td>Fasting glucose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mmol/L)</td>
<td>5.01 ± 0.03</td>
<td>5.16 ± 0.04</td>
<td>4.86 ± 0.03 †</td>
</tr>
<tr>
<td>High fasting glucose (%)</td>
<td>12.7</td>
<td>16.6</td>
<td>9.0 †</td>
</tr>
<tr>
<td>Metabolic syndrome (%)</td>
<td>15.2</td>
<td>13.1 E</td>
<td>17.3</td>
</tr>
</tbody>
</table>

Data presented as mean ± SE for continuous variables or prevalence (%) for categorical variables. E Interpret with caution (coefficient of variation between 16.6 and 33.3%) † Significantly different from estimate for males (p<0.05)

The average total, bouted, and sporadic MVPA energy expenditure values were 13.5, 6.4, and 7.2 MET hours/week, respectively (Table 3.1). Partial correlation analysis showed that total MVPA was highly correlated with bouted MVPA (r = 0.91, p < 0.0001), but less so with sporadic MVPA (r = 0.63, p < 0.0001). Bouted MVPA was modestly correlated with sporadic MVPA (r = 0.25, p < 0.0001).

The OR (95% CI) for MetS and its component risk factors per each 1 MET hour/week difference in total, bouted, and sporadic MVPA are presented in Table 3.2. After adjusting for the covariates (Model 1), total, bouted, and sporadic MVPA were all related to the MetS. A comparison of the c-statistic values for Model 1 indicates that the bouted and sporadic MVPA measures had a similar ability to distinguish between participants with and without MetS. The findings for Model 2 indicate that bouted and sporadic MVPA were also related to MetS after
adjusting for each other. The OR of 0.91 (0.86-0.97) for bouted MVPA indicates that for each additional MET hour/week of bouted MVPA the relative odds of the MetS decreased by 9%. The OR of 0.89 (0.84-0.95) for sporadic MVPA indicates that for each additional MET hour/week of sporadic MVPA the relative odds of the MetS decreased by 11%. The 95% CI for the effect estimates for the bouted and sporadic MVPA variables overlapped, indicating that these estimates were not statistically different from each other. The variance inflation factors for sporadic (1.23) and bouted (1.11) were both <5, implying that multicollinearity was not an issue for the primary exposure variables. The relationship between sporadic and bouted MVPA with the MetS, based on Model 2 in Table 3.2, are further illustrated in Figure 3.1 with MVPA expressed in MET hours per week.
Table 3.2 Odds ratio (95% confidence interval) for the metabolic syndrome and its component risk factors according to total, bouted, and sporadic moderate-to-vigorous physical activity (MET hours per week)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Physical activity (MET hours per week)</th>
<th>Model 1&lt;sup&gt;a&lt;/sup&gt; OR* (95% CI)</th>
<th>c-statistic</th>
<th>Model 2&lt;sup&gt;b&lt;/sup&gt; OR* (95% CI)</th>
<th>c-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic syndrome</td>
<td>Total (sporadic + bouted)</td>
<td>0.90 (0.86 - 0.94)</td>
<td>0.79</td>
<td>0.90 (0.86 - 0.94)</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Bouted</td>
<td>0.89 (0.84 - 0.95)</td>
<td>0.77</td>
<td>0.91 (0.86 - 0.97)</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Sporadic</td>
<td>0.86 (0.81 - 0.92)</td>
<td>0.78</td>
<td>0.89 (0.84 - 0.95)</td>
<td>0.79</td>
</tr>
<tr>
<td>High BP</td>
<td>Total (sporadic + bouted)</td>
<td>1.00 (0.96 - 1.03)</td>
<td>0.80</td>
<td>1.00 (0.95 - 1.05)</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>Bouted</td>
<td>1.00 (0.95 - 1.04)</td>
<td>0.80</td>
<td>1.00 (0.95 - 1.05)</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>Sporadic</td>
<td>0.99 (0.91 - 1.07)</td>
<td>0.80</td>
<td>0.99 (0.91 - 1.08)</td>
<td>0.80</td>
</tr>
<tr>
<td>High WC</td>
<td>Total (sporadic + bouted)</td>
<td>0.96 (0.94 - 0.98)</td>
<td>0.73</td>
<td>0.96 (0.94 - 0.98)</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>Bouted</td>
<td>0.95 (0.93 - 0.98)</td>
<td>0.72</td>
<td>0.96 (0.94 - 0.98)</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>Sporadic</td>
<td>0.95 (0.90 - 1.00)</td>
<td>0.71</td>
<td>0.96 (0.91 - 1.02)</td>
<td>0.73</td>
</tr>
<tr>
<td>High glucose</td>
<td>Total (sporadic + bouted)</td>
<td>0.97 (0.96 - 0.99)</td>
<td>0.77</td>
<td>0.96 (0.93 - 1.00)</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>Bouted</td>
<td>0.96 (0.93 - 0.99)</td>
<td>0.77</td>
<td>0.96 (0.93 - 1.00)</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>Sporadic</td>
<td>0.98 (0.94 - 1.02)</td>
<td>0.76</td>
<td>1.07 (1.04 - 1.11)</td>
<td>0.77</td>
</tr>
<tr>
<td>High triglycerides</td>
<td>Total (sporadic + bouted)</td>
<td>0.97 (0.94 - 1.01)</td>
<td>0.69</td>
<td>0.97 (0.94 - 1.01)</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>Bouted</td>
<td>0.97 (0.92 - 1.03)</td>
<td>0.68</td>
<td>0.98 (0.92 - 1.04)</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>Sporadic</td>
<td>0.96 (0.91 - 1.01)</td>
<td>0.69</td>
<td>0.97 (0.91 - 1.02)</td>
<td>0.69</td>
</tr>
<tr>
<td>Low HDL</td>
<td>Total (sporadic + bouted)</td>
<td>0.98 (0.96 - 1.00)</td>
<td>0.61</td>
<td>0.98 (0.96 - 1.00)</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>Bouted</td>
<td>0.98 (0.95 - 1.00)</td>
<td>0.60</td>
<td>0.98 (0.96 - 1.00)</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>Sporadic</td>
<td>0.97 (0.93 - 1.01)</td>
<td>0.61</td>
<td>0.97 (0.94 - 1.01)</td>
<td>0.61</td>
</tr>
</tbody>
</table>

<sup>a</sup> Model 1: adjusted for age, sex, education, diet, smoking status, total accelerometer wear time, and Health Utilities Index; <sup>b</sup> Model 2: adjusted for age, sex, education, diet, smoking status, total accelerometer wear time, Health Utilities Index, and the other physical activity variable (bouts or sporadic MVPA); * OR (odds ratio) presented per 1 unit change in MET hours per week of physical activity
Figure 3.1 Association between sporadic and bouted moderate-to-vigorous physical activity and the metabolic syndrome. Odds ratios are plotted from 0 (referent) to values that correspond to the 99th percentile of the sample for moderate-to-vigorous physical activity (MET hours per week). Odds ratios were adjusted for age, sex, education, diet, smoking, and the other physical activity variable (sporadic or bouted).

The associations between total, bouted, and sporadic MVPA with the individual components of the MetS were not as strong or consistent as they were for the MetS per se (Table 3.2). Irrespective of the MetS component, the c-statistic values for the models that included bouted or sporadic MVPA were comparable to each other. Furthermore, the 95% CI for the effect estimates for the bouted and sporadic MVPA variables overlapped.

The OR (95% CI) for MetS according to three different levels of sporadic and bouted MVPA are shown in Table 3.3. After adjusting for confounders and bouted MVPA, participants who were active (e.g., ≥500 MET min/week) based on their sporadic MVPA were only 0.36
(0.15-0.86) times as likely to have the MetS by comparison to participants who were inactive (e.g., <250 MET min/week) based on their sporadic MVPA. Similarly, after adjusting for confounders and sporadic MVPA, participants who were active based on their bouted MVPA were only 0.32 (0.13-0.80) times as likely to have the MetS by comparison to participants who were inactive based on their bouted MVPA. A comparison of the c-statistic values for Model 2 indicates that the bouted and sporadic MVPA measures had a similar ability to distinguish between participants with and without MetS.

**Table 3.3** Odds ratio (95% confidence interval) for the metabolic syndrome according to bouted and sporadic moderate-to-vigorous physical activity levels

<table>
<thead>
<tr>
<th>Condition</th>
<th>Model 1&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Model 2&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>c-statistic</td>
</tr>
<tr>
<td><strong>Sporadic MVPA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inactive (referent)</td>
<td>1.00</td>
<td>0.77</td>
</tr>
<tr>
<td>Somewhat active</td>
<td>0.73 (0.35 - 1.52)</td>
<td>0.85 (0.44 - 1.64)</td>
</tr>
<tr>
<td>Active</td>
<td>0.27 (0.11 - 0.65)&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>0.36 (0.15 - 0.86)&lt;sup&gt;c,d&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Bouted MVPA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inactive (referent)</td>
<td>1.00</td>
<td>0.77</td>
</tr>
<tr>
<td>Somewhat active</td>
<td>0.32 (0.12 - 0.86)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.39 (0.15 - 1.02)</td>
</tr>
<tr>
<td>Active</td>
<td>0.25 (0.11 - 0.58)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.32 (0.13 - 0.80)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Estimates adjusted for age, sex, education, diet, smoking status, total accelerometer wear time, and Health Utilities Index
<sup>b</sup> Estimates adjusted for age, sex, education, diet, smoking status, total accelerometer wear time, Health Utilities Index, and the other physical activity variable (bouts or sporadic)
<sup>c</sup> Significantly different from referent (p<0.05)
<sup>d</sup> Significantly different from 'Somewhat active' group (p<0.05)

The OR (95% CI) for MetS according to bouted MVPA and different durations of sporadic MVPA are presented in **Table 3.4**. As shown in Models 2 to 4, sporadic MVPA accumulated in 7-9 minutes, 4-9 minutes, and 1-9 minutes predicted the MetS independent of bouted MVPA and the covariates. The AIC-related values comparing the goodness-of-fit between regression models are also included in **Table 3.4**. Sporadic MVPA of 1 to 9 minutes (model 4)
had the lowest AIC value and there was a 95.9% probability that this model provided the best fit among all the models. Thus, even the shorter bursts of sporadic MVPA (e.g., 1-3 minutes) were relevant in the prediction of the MetS.

**Table 3.4** Odds ratio (95% confidence interval) for the metabolic syndrome according to bouted moderate-to-vigorous physical activity and different lengths of sporadic moderate-to-vigorous physical activity

<table>
<thead>
<tr>
<th>Model*</th>
<th>Physical activity (MET hours per week)</th>
<th>OR** (95% CI)</th>
<th>ΔAIC***</th>
<th>relative AIC</th>
<th>Akaike weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bouts (≥10 minutes)</td>
<td>0.89 (0.84 - 0.95)</td>
<td>18.61</td>
<td>0.0001</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Bouts (≥10 minutes)</td>
<td>0.90 (0.84 - 0.95)</td>
<td>20.49</td>
<td>0.0000</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Sporadic (7-9 minutes)</td>
<td>0.95 (0.70 - 1.29)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bouts (≥10 minutes)</td>
<td>0.93 (0.89 - 0.98)</td>
<td>6.29</td>
<td>0.0431</td>
<td>4.13</td>
</tr>
<tr>
<td></td>
<td>Sporadic (4-9 minutes)</td>
<td>0.82 (0.72 - 0.94)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bouts (≥10 minutes)</td>
<td>0.91 (0.86 - 0.97)</td>
<td>0.00</td>
<td>1.0000</td>
<td>95.86</td>
</tr>
<tr>
<td></td>
<td>Sporadic (1-9 minutes)</td>
<td>0.89 (0.84 - 0.95)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.0432</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AIC = Akaike information criterion

*All models adjusted for age, sex, education, diet, smoking status, total accelerometer wear time, and Health Utilities Index

** OR (odds ratio) presented per 1 unit change in MET hours per week of physical activity

*** difference in AIC vs. the optimal model (model 4)

### 3.5 Discussion

The purpose of this study was to determine whether equivalent amounts of bouted and sporadic MVPA are associated with the MetS to a similar order of magnitude. The key finding was that for every additional weekly MET-hour of MVPA, which is equivalent to approximately 20 minutes of moderate or 10 minutes of vigorous activity, the odds of MetS were approximately 10% lower, regardless of whether the MVPA was accumulated in bouts or sporadically (**Table 3.2**). This finding suggests that the total amount of MVPA accumulated throughout the week is important, but that the nature in which that MVPA is accumulated (e.g., sporadically or in bouts)
is not. Secondary analyses confirmed that even small bursts of sporadic MVPA (1-3 minutes) were meaningful when predicting the MetS (Table 3.4).

Recent work has suggested that sporadic physical activity contributes significantly to total daily energy expenditure, and therefore has the potential to play an important role in health.\textsuperscript{3,11,12} The advent of accelerometers in physical activity assessment allows for sporadic physical activity levels to be measured accurately in natural settings, and permits the independent effects of sporadic and bouted MVPA on health to be assessed. Previous studies have found associations between bouted\textsuperscript{16} and sporadic\textsuperscript{13-16} MVPA, as measured by accelerometry, and various cardiometabolic risk factors. Strath et al. used accelerometer data from the 2003-04 U.S. National Health and Nutrition Examination Survey to compare the relationships between bouted and sporadic MVPA and markers of obesity in adults.\textsuperscript{16} The volumes of both bouted and sporadic MVPA were negatively associated with WC, but the association was significantly stronger for bouted MVPA. However, consistent with the present study there was no difference in the association with WC between bouted and sporadic MVPA, after the authors controlled for physical activity intensity. McGuire and Ross collected accelerometer data from a sample of 126 obese middle-aged adults who did not engage in bouted MVPA. They found that sporadic MVPA was negatively associated with visceral adipose tissue\textsuperscript{14} but not cardiometabolic risk factors such as glucose and insulin resistance.\textsuperscript{38} Also consistent with the present study are recent findings by Glazer et al. who collected accelerometer data from a sample of the 3rd Generation cohort of the Framingham Heart Study.\textsuperscript{13} They found that there was no difference in the strength of associations with cardiovascular risk factors when comparing MVPA accumulated in shorter (<10 minutes) versus longer (≥10 minutes) bouts.

The results of this study and other studies\textsuperscript{13-16} provide important findings on the role that sporadic MVPA plays in health and have important implications for public health guidelines and the way the MVPA is prescribed and promoted. Current physical activity guidelines of the World
Health Organization\textsuperscript{2} and several countries (e.g., Australia, Canada, US)\textsuperscript{3-5} recommend that the weekly dose of 150 minutes of MVPA be accumulated in bouts of at least 10 minutes.\textsuperscript{2-5} However, an important finding of the present study is that sporadic MVPA is important in the prediction of MetS. These and other findings\textsuperscript{13-16} suggest that the weekly dose of MVPA can be accumulated sporadically in periods of 9 minutes or less. Given that only 15\% of Canadian adults\textsuperscript{24} and <10\% of American adults\textsuperscript{25} meet the current guidelines, and that a lack of time is the most-often cited reason for physical inactivity,\textsuperscript{39} the current study supports promoting sporadic MVPA as another way for individuals to accumulate a sufficient weekly dose MVPA. Sporadic MVPA could be accumulated through life-style embedded activities such as stair climbing and household chores.\textsuperscript{40}

The biological mechanisms that explain how sporadic MVPA influences health have not been well studied and are poorly understood.\textsuperscript{41} There is some evidence that 30 minutes of MVPA accumulated in 3-minute bouts is as effective as a continuous 30-minute session of MVPA in reducing post-prandial triglyceride levels as well as resting systolic BP.\textsuperscript{42,43} This lends support to the notion that the duration of activity is unimportant provided sufficient energy is expended.

Strengths of this study include the use of a large, nationally-representative sample of Canadian adults and the use of accelerometers, which provide an objective and unbiased measure of physical activity.\textsuperscript{28,40} As with any study, this study is not void of limitations. The cross-sectional nature does not allow for assumptions to be made regarding causality. However, it is likely that low MVPA preceded the MetS based on previous randomized-controlled trials and prospective cohort studies have found that MVPA has a positive influence on cardiometabolic risk factors and is effective in the prevention of MetS.\textsuperscript{1,44} Several limitations also exist in the use of accelerometers. Accelerometers are unable to accurately capture non-step-based activities (e.g. swimming, cycling, and weightlifting).\textsuperscript{40,45} Accelerometers are also unable to account for the added energy expenditure associated with load-bearing activities or added incline.\textsuperscript{28,40} Further it
must be assumed that the accelerometer data collected over the 4 to 7 day measurement period are representative of an individual’s normal physical activity behavior. Finally, the survey design requires that 11 degrees of freedom be specified in the statistical software,\textsuperscript{20} which also limited the number of covariates that were included in the regression models.

In conclusion, this study found comparable associations between equivalent doses of sporadic and bouted MVPA and the relative odds of MetS. This study adds to the dearth of information that currently exists on the relationship between sporadic MVPA and MetS. Additional studies based on randomized controlled trials are needed to confirm the cross-sectional associations found in the present study.
3.6 References


35. Furlong W, Feeny D, Torrance G. Health Utilities Index (HUI): Algorithm for determining HUI mark 2 (HUI2)/HUI mark 3 (HUI3) health status classification levels, health states, health-
related quality of life utility scores and single-attribute utility score from 40-item interviewer administered health status questionnaires. 1999.


Chapter 4

Is the frequency of weekly moderate-to-vigorous physical activity associated with the metabolic syndrome in Canadian adults?
4.1 Abstract

**Background:** Previous physical activity guidelines recommended that adults be active on most or all days of the week. Current guidelines recommend accumulating $\geq 150$ minutes/week of moderate-to-vigorous physical activity (MVPA), with no recommendation for frequency. This study examined the association between the frequency of physical activity throughout the week and the metabolic syndrome (MetS) in physically active adults.

**Methods:** This cross-sectional study included 2,324 adults aged 18-64 from the 2007-2011 cycles of the nationally representative Canadian Health Measures Survey. MVPA was measured over 7 days using Actical accelerometers. Physically active participants ($\geq 150$ minutes/week of MVPA) were assigned to frequently active ($\geq 5$ days/week with $\geq 30$ minutes of MVPA) and infrequently active (1-4 days/week with $\geq 30$ minutes of MVPA) groups. Associations were examined using logistic regression controlling for age, sex, and education.

**Results:** The relative odds of the MetS was 4.43 (95% confidence interval: 2.26-8.69) times higher in physically inactive participants than physically active participants. Within physically active participants, the relative odds of the MetS was 1.73 (0.87-3.41) times higher in the infrequently active group than the frequently active group. However, this was not a significant difference ($p=0.11$), and after adjustment for total weekly MVPA, the relative odds of the MetS in the infrequently active group was reduced to 0.85 (0.42-1.72).

**Conclusions:** The frequency of physical activity throughout the week was not independently associated with the MetS among active adults. Conversely, the weekly volume of MVPA was strongly associated with the MetS.

**Key Words:** cardiometabolic risk factors; accelerometer; exercise; guidelines;
4.2 Introduction

Current physical activity guidelines of the World Health Organization\textsuperscript{1} and several countries\textsuperscript{2-4} are that adults accumulate at least 150 minutes of moderate-to-vigorous physical activity (MVPA) throughout the week in bouts of at least 10 minutes. There is no stipulation on how many days of the week a person needs to be active. Conversely, previous guidelines recommended the same weekly volume of MVPA, but stipulated that the 150 min/week of MVPA be accumulated by participating in at least 30 minutes of MVPA on most or all days of the week.\textsuperscript{5,6} The decision to remove the stipulation around the frequency of participation for the current guidelines was based on systematic reviews that found insufficient evidence to conclude that more frequent MVPA elicits a greater health benefit than an equivalent amount of MVPA performed less frequently.\textsuperscript{2,3,7} For example, it is unknown whether accumulating 150 minutes of MVPA over five days of the week (i.e., 30 minutes X 5 days) is better for one’s health than accumulating 150 minutes of MVPA over two days of the week (i.e., 75 minutes X 2 days).

Few studies have evaluated the daily frequency of MVPA participation throughout the week and its relationship with health. Lee et al. (2004) studied the effect of being a weekend warrior (≥1,000 kcal of MVPA on 1 to 2 days/week) compared to being regularly active (≥1,000 kcal of MVPA on ≥3 days/week) on the risk of mortality in a cohort of men. Compared to inactive men, the relative risk of mortality was decreased by 15% in weekend warriors and by 36% in regularly active men.\textsuperscript{8} Although this might suggest that more frequent physical activity may elicit additional health benefits, mortality risk was only statistically different between sedentary men and weekend warriors in a sub-analysis of participants without at least one cardiometabolic risk factor. Additionally, this study was limited to middle-aged men, assessed physical activity by self-report, and did not consider potential differences in the total amount of MVPA in the weekend warriors and regularly active men.
The primary objective of the present study was therefore to examine the association between the frequency of physical activity throughout the week, as assessed by accelerometry, and the metabolic syndrome (MetS) in physically active men and women. A secondary objective was to examine whether meeting the current physical activity guidelines, as measured using an objective method, is associated with the MetS in adults.

4.3 Materials and methods

Data source

Data are from cycles 1 and 2 of the Canadian Health Measures Survey (CHMS). The CHMS collected data from Canadians aged 6 to 79 in cycle 1 (March 2007 to February 2009) and aged 3 to 79 in cycle 2 (August 2009 to November 2011). Approximately 96% of the population is represented. Residents of Indian Reserves or Crown lands, institutions, certain remote regions, and full-time members of the Canadian Forces were excluded. Data were collected in two parts: socio-demographic and general health information were collected during an interview in the participants’ homes, and then direct physical measurements and blood samples were collected during a subsequent visit to a mobile clinic. Of the households selected across both cycles of the survey, 72.7% provided the sex and date of birth of all household members. Within each responding household one or two members were then selected to participate. Of those selected, 89.3% completed the household questionnaire, and 83.3% of those participated in the visit to the mobile clinic. The final response rate after adjusting for the sampling strategy was 53.5%. The present analysis is based on 2,324 participants (n = 1,133 from cycle 1 and n = 1,191 from cycle 2) aged 18 to 64 years with complete MetS and physical activity data. Ethics approval for the CHMS was obtained from Health Canada’s Research Ethics Board, and informed, written consent was obtained from all adult participants.
Physical activity

All ambulatory participants were provided with an Actical accelerometer during the clinic visit. Participants were asked to wear the accelerometer on an elasticized belt around their waist for a period of one week. The accelerometers were mailed back to the CHMS head office after the 7-day collection period.

The Actical accelerometer captures the acceleration of movement in all directions and records digitized values that are summed over a user-specified period of one-minute (epoch). Data are downloaded from the device as a count per minute value representing the activity intensity. Detailed data reduction and quality control for the present analysis has been published elsewhere. Briefly, non-wear time was first determined as any period of at least 60 consecutive cpm values of zero, allowing for one or two counts between 0 and 100. Total wear-time was determined by subtracting non-wear time from 24 hours. Valid persons for the present analysis were those with at least 10 hours of wear-time, on at least 4 days out of 7.

MVPA included any epoch value ≥ 1,535 cpm, the same moderate-intensity cut-point value has been used in previous analysis of CHMS data. Details of the derivation of this cut-point are described elsewhere. Briefly, the cut-point value of 1,535 was determined using decision boundary analysis of data from a study of 26 adults who wore an Actical accelerometer on their hip during a series of sessions on a treadmill with varying intensity levels. Energy expenditure was calculated for each minute where the epoch value was at or above the 1,535 moderate intensity cut-point using the following regression equation: energy expenditure in METS = 0.02663 + (0.00001107*cpm) X 60 + 1 (resting energy expenditure). This equation was developed using a sample of 24 men and women (mean age 36 years) who wore an Actical accelerometer on the hip for a series of activities of varying intensities while oxygen consumption was simultaneously measured by a portable metabolic measurement system. In this study, energy expenditure values were then converted to metabolic equivalents (MET) to account for
recent research indicating that vigorous physical activity has a greater influence on cardiometabolic health than an equivalent volume of moderate physical activity. Total weekly MET minutes was determined by summing the MET energy expenditure values for all bouted MVPA (i.e., MVPA accumulated in at least 10-minute bouts) and sporadic MVPA (i.e., MVPA accumulated in periods of 9 minutes or less) minutes. A bout of MVPA was defined as a period of at least 10 consecutive minutes above the moderate-intensity cut-point; a bout continued until 80% (i.e. 8 out of 10 minutes) was no longer above the cut-point. Since not all participants had seven valid days of accelerometry data, each total was divided by the number of valid days to obtain a daily average, and then multiplied by 7 to obtain a weekly total (in MET minutes).

In order to assess the effect of the amount of MVPA accumulated throughout the week, participants were divided into three groups: inactive (< 250 MET min/week of total MVPA, or less than half of the weekly guideline), somewhat active (250 – 499 MET min/week of total MVPA, or more than half, but less than the guideline), and active (≥ 500 MET min/week of total MVPA, equivalent to the guideline). This was done first by considering only bouted MVPA, then by considering total MVPA (bouts + sporadic). In order to assess the potential relevance of the frequency of being active based on total weekly MVPA, the active group was further subdivided into an infrequently active group (≥ 500 MET min/week of total MVPA with 1 to 4 “active” days per week) and a frequently active group (≥ 500 MET min/week of total MVPA with 5 or more “active” days per week). An “active” day was defined as accumulating at least 90 MET minutes of MVPA, which is equivalent to approximately 30 minutes of moderate intensity activity. For participants who did not have 7 valid days of accelerometer data, the number of active days over the week was determined using an equivalent percentage of valid days. For example, 4 out of 7 active days active equals 43%, which is roughly equivalent to 3 active days for participants with 6 days of valid wear time (50%), 3 active days for participants with 5 days of valid wear time (60%), and 2 active days for participants with 4 days of valid wear time (50%). To assess the
validity of this approach, we determined the sensitivity and specificity by recalculating the physical activity level (inactive, somewhat active, infrequently active, frequently active) based on 5 days of randomly selected data for respondents who had 7 valid days (n=1,224). The estimation of active days per week was both highly sensitive (>75%) and specific (>89%).

**Metabolic syndrome**

The 2009 Joint Interim Statement was used to determine the presence of the MetS. MetS was present if three or more of the following conditions were met: high blood pressure (≥ 130/85 mmHg) or drug treatment; high triglycerides (≥ 1.7 mmol/L for men and women) or drug treatment; low high density lipoprotein (HDL) cholesterol (< 1.0 mmol/L for men, < 1.3 mmol/L for women) or drug treatment; high fasting blood glucose (≥ 5.6 mmol/L) or self-reported diabetes or drug treatment; and high waist circumference (≥ 102 cm for men, ≥ 88 cm for women). Although other waist circumference cut-offs are available, the cut-offs used in the present analysis are those recommended by Health Canada.

Detailed descriptions of the measurement procedures for each of the MetS components are available elsewhere. Briefly, waist circumference was taken at the mid-point between the last rib and the top of the iliac crest, as per World Health Organization protocol, using a Gulick tape measure, and recorded to the nearest 0.1 cm. Resting blood pressure was measured using an automated device (BpTRU™ BP-300 device, BpTRU Medical Devices Ltd., Coquitlam, British Columbia) following a 5-minute rest period. The BpTRU™ recorded a minimum of 6 measurements taken automatically, one minute apart. The average systolic and diastolic blood pressure were calculated using the last 5 out of 6 measurements. Venous blood samples were collected following a 10-hour fasting period: triglycerides and HDL-cholesterol were measured in serum in both cycles, however blood glucose was measured in plasma in cycle 1, and serum in cycle 2. Blood samples were analyzed at the Health Canada Laboratory (Bureau of Nutritional Sciences, Nutrition Research Division). Glucose, HDL-cholesterol and triglycerides were all
measured on the Vitros 5,1FS (Ortho Clinical Diagnostics). Results below the limit of detection were included in analysis by imputing a value of the limit of detection divided by two. Finally, prescription and over-the-counter medications taken in the last month were reported by participants at the household interview, and confirmed at the clinic visit.\textsuperscript{21,22} Drug identification numbers were then used to identify the corresponding code from the Anatomical Therapeutic Chemical classification system.\textsuperscript{23}

**Covariates**

Age, sex, and education (post-secondary graduate, yes/no) were included as covariates. Smoking status and diet were also considered as covariates; however, they were not included in the final models as they were not associated with the MetS and therefore did not meet the criteria for confounding in our study.

**Statistical analysis**

Conventional descriptive statistics were used to describe the sample. Average MET minutes of MVPA were determined for bouts and total MVPA by physical activity group. Differences in the relative odds of the MetS and its individual components were compared across physical activity groups using logistic regression. Regression analyses were controlled for age, sex, and education. A second model was used in assessing the difference between the two active groups that adjusted for the covariates and total weekly MET minutes of MVPA.

All analyses were completed using SAS v9.2 and SUDAAN v10. All results were weighted using the activity monitor sub-sample weights for the combined cycle 1 and cycle 2 data. Statistics Canada developed a sub-sample (and consequently sub-sample weights) for the activity monitor data to compensate for any bias due to the high rate of respondents who did not provide at least 4 days of valid data.\textsuperscript{9,10} Standard errors, coefficients of variation and 95% confidence intervals (CI) were calculated using the bootstrap technique. The combined cycle 1
and 2 CHMS study design requires that 24 degrees of freedom be specified in the software (11 degrees of freedom in cycle 1 plus 13 degrees of freedom in cycle 2).9,10

4.4 Results

Population characteristics are in Table 4.1. The mean age was 41.0 years and 48.4% of the participants were male. Approximately 16.4% of the sample had the MetS. The prevalence of the individual MetS components ranged from 14.8% (high fasting glucose) to 29.8% (high waist circumference).

Table 4.1. Participant characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n=2,324)</th>
<th>Males (n=1,058)</th>
<th>Females (n=1,266)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>41.0 ± 0.3</td>
<td>40.7 ± 0.5</td>
<td>41.1 ± 0.5</td>
</tr>
<tr>
<td>Sex (%)</td>
<td></td>
<td>48.4</td>
<td>51.6</td>
</tr>
<tr>
<td>Race (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>79.5</td>
<td>81.2</td>
<td>77.9</td>
</tr>
<tr>
<td>Other</td>
<td>20.5E</td>
<td>18.8E</td>
<td>22.1E</td>
</tr>
<tr>
<td>Current daily smoker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>14.7</td>
<td>15.7</td>
<td>13.7</td>
</tr>
<tr>
<td>No</td>
<td>85.3</td>
<td>84.3</td>
<td>86.3</td>
</tr>
<tr>
<td>Post-secondary graduation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>65.2</td>
<td>64.7</td>
<td>65.7</td>
</tr>
<tr>
<td>No</td>
<td>34.8</td>
<td>35.3</td>
<td>34.3</td>
</tr>
<tr>
<td>Income quartile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower income quartile</td>
<td>19.4</td>
<td>15.0</td>
<td>23.5*</td>
</tr>
<tr>
<td>Lower-middle income quartile</td>
<td>23.1</td>
<td>23.8</td>
<td>22.4</td>
</tr>
<tr>
<td>Upper-middle income quartile</td>
<td>25.3</td>
<td>25.8</td>
<td>24.8</td>
</tr>
<tr>
<td>Upper income quartile</td>
<td>30.3</td>
<td>34.2</td>
<td>26.7*</td>
</tr>
<tr>
<td>No income reported</td>
<td>2.0</td>
<td>1.2E</td>
<td>2.7E</td>
</tr>
<tr>
<td>Cardiometabolic risk factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waist circumference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (cm)</td>
<td>89.3 ± 0.7</td>
<td>94.3 ± 0.9</td>
<td>84.5* ± 0.9</td>
</tr>
<tr>
<td>High waist circumference (%)</td>
<td>29.8</td>
<td>25.2</td>
<td>34.0*</td>
</tr>
<tr>
<td>Blood pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean systolic (mmHg)</td>
<td>109 ± 0</td>
<td>112 ± 0</td>
<td>106* ± 1</td>
</tr>
<tr>
<td>Mean diastolic (mmHg)</td>
<td>71 ± 0</td>
<td>73 ± 0</td>
<td>69* ± 1</td>
</tr>
<tr>
<td>Variable</td>
<td>Total (n=2,324)</td>
<td>Males (n=1,058)</td>
<td>Females (n=1,266)</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>High blood pressure (%)</td>
<td>19.4</td>
<td>21.6</td>
<td>17.3</td>
</tr>
<tr>
<td>HDL-cholesterol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mmol/L)</td>
<td>1.39 ± 0.02</td>
<td>1.23 ± 0.02</td>
<td>1.54* ± 0.03</td>
</tr>
<tr>
<td>Low HDL-cholesterol (%)</td>
<td>29.2</td>
<td>25.8</td>
<td>32.4</td>
</tr>
<tr>
<td>Triglycerides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mmol/L)</td>
<td>1.28 ± 0.03</td>
<td>1.44 ± 0.05</td>
<td>1.14* ± 0.03</td>
</tr>
<tr>
<td>High triglycerides (%)</td>
<td>22.5</td>
<td>29.1</td>
<td>16.2*</td>
</tr>
<tr>
<td>Fasting glucose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mmol/L)</td>
<td>5.01 ± 0.03</td>
<td>5.19 ± 0.04</td>
<td>4.84* ± 0.02</td>
</tr>
<tr>
<td>High fasting glucose (%)</td>
<td>14.8</td>
<td>20.2</td>
<td>9.7*</td>
</tr>
<tr>
<td><strong>Metabolic syndrome (%)</strong></td>
<td>16.4</td>
<td>16.8</td>
<td>16.1</td>
</tr>
</tbody>
</table>

Data presented as mean (± SE) for continuous variables or prevalence (%) for categorical variables; \(^i\) Interpret with caution (coefficient of variation between 16.6 and 33.3%); * Significantly different from estimate for males (p<0.05)

Average MVPA levels and the proportion adhering to the physical activity guidelines are shown in Table 4.2. When based on bouted MVPA alone, 23.9% of the sample adhered to the guidelines of ≥500 MET minutes/week; this increased to 51.0% when based on total (bouted + sporadic) MVPA. Within those who adhered to the physical activity guidelines, the average weekly MVPA energy expenditure was lower in the infrequently active group than in the frequently active group (1367 vs. 2237 MET minutes/week for bouted MVPA, 823 vs. 1601 MET minutes/week for total MVPA, p<0.0001).
Table 4.2. Average MET minutes/week of MVPA by physical activity groups, according to bouted moderate-to-vigorous physical activity or total (bouted + sporadic) moderate-to-vigorous physical activity

<table>
<thead>
<tr>
<th>Physical activity group</th>
<th>n</th>
<th>% of total n</th>
<th>Average MET minutes/week (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bouted moderate-to-vigorous physical activity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inactive</td>
<td>1457</td>
<td>64.8</td>
<td>382 (345 - 419)*</td>
</tr>
<tr>
<td>Somewhat active</td>
<td>317</td>
<td>11.3</td>
<td>855 (799 - 911)*</td>
</tr>
<tr>
<td>Active</td>
<td>550</td>
<td>23.9</td>
<td></td>
</tr>
<tr>
<td>Infrequently active</td>
<td>354</td>
<td>15.6 (65.0)</td>
<td>1367 (1267 - 1467)*</td>
</tr>
<tr>
<td>Frequently active</td>
<td>196</td>
<td>8.3 (35.0)</td>
<td>2237 (2041 - 2432)</td>
</tr>
<tr>
<td><strong>Total moderate-to-vigorous physical activity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inactive</td>
<td>565</td>
<td>25.8</td>
<td>128 (119 - 137)*</td>
</tr>
<tr>
<td>Somewhat active</td>
<td>529</td>
<td>23.2</td>
<td>368 (355 - 381)*</td>
</tr>
<tr>
<td>Active</td>
<td>1230</td>
<td>51.0</td>
<td></td>
</tr>
<tr>
<td>Infrequently active</td>
<td>601</td>
<td>24.6 (48.0)</td>
<td>823 (769 - 878)*</td>
</tr>
<tr>
<td>Frequently active</td>
<td>629</td>
<td>26.4 (52.0)</td>
<td>1601 (1507 - 1694)</td>
</tr>
</tbody>
</table>

MET = metabolic equivalent
* Significantly different from estimate for frequently active group (p < 0.0001)

The odds ratios (OR) (95% CI) for the MetS and its component risk factors by physical activity level is shown in Table 4.3. After adjusting for covariates, the relative odds for the MetS was 3.10 (95% CI: 1.56-6.15) times higher in the inactive group compared to the active group (i.e. those meeting the guidelines of ≥ 500 MET minutes/week of MVPA in bouts of at least 10 minutes). For each MetS component risk factors, an increase in the relative odds was also seen for the inactive group compared to the active group. When total MVPA (bouted + sporadic) was used to determine adherence to the 500 MET minute/week guideline, the relative odds of the MetS for the inactive group was 4.43 (95% CI: 2.36-8.69) compared to the active group. Because the odds ratios for the total MVPA were noticeably higher than they were for the bouted MVPA, all additional analyses were based on total MVPA.
Table 4.3. Odds ratios (95% confidence interval) for the metabolic syndrome and its component risk factors according to physical activity groups (inactive, somewhat active, and active)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Physical activity group</th>
<th>MVPA (bouts)</th>
<th>MVPA (total)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Prevalence (95% CI)</td>
<td>OR* (95% CI)</td>
</tr>
<tr>
<td>Metabolic syndrome</td>
<td>Inactive</td>
<td>21.5 (16.2 - 26.9)</td>
<td>3.10 (1.56 - 6.15)</td>
</tr>
<tr>
<td></td>
<td>Somewhat active</td>
<td>&lt;9.3</td>
<td>0.86 (0.39 - 1.93)</td>
</tr>
<tr>
<td></td>
<td>Active (meets guidelines)</td>
<td>&lt;12.1</td>
<td>1.00</td>
</tr>
<tr>
<td>High blood pressure</td>
<td>Inactive</td>
<td>22.8 (20.0 - 25.6)</td>
<td>1.54 (0.95 - 2.5)</td>
</tr>
<tr>
<td></td>
<td>Somewhat active</td>
<td>&lt;15.7</td>
<td>0.79 (0.41 - 1.53)</td>
</tr>
<tr>
<td></td>
<td>Active (meets guidelines)</td>
<td>&lt;18.9</td>
<td>1.00</td>
</tr>
<tr>
<td>High waist circumference</td>
<td>Inactive</td>
<td>34.3 (28.7 - 40.0)</td>
<td>1.88 (1.32 - 2.67)</td>
</tr>
<tr>
<td></td>
<td>Somewhat active</td>
<td>&lt;33.0</td>
<td>1.24 (0.79 - 1.95)</td>
</tr>
<tr>
<td></td>
<td>Active (meets guidelines)</td>
<td>19.9E (14.1 - 25.7)</td>
<td>1.00</td>
</tr>
<tr>
<td>High glucose</td>
<td>Inactive</td>
<td>17.9 (14.4 - 21.5)</td>
<td>1.94 (1.22 - 3.09)</td>
</tr>
<tr>
<td></td>
<td>Somewhat active</td>
<td>&lt;12.7</td>
<td>1.07 (0.58 - 1.99)</td>
</tr>
<tr>
<td></td>
<td>Active (meets guidelines)</td>
<td>&lt;12.5</td>
<td>1.00</td>
</tr>
<tr>
<td>High triglycerides</td>
<td>Inactive</td>
<td>26.4 (22.3 - 30.5)</td>
<td>1.84 (1.06 - 3.2)</td>
</tr>
<tr>
<td></td>
<td>Somewhat active</td>
<td>13.8E (9.5 - 18.0)</td>
<td>0.91 (0.54 - 1.54)</td>
</tr>
<tr>
<td></td>
<td>Active (meets guidelines)</td>
<td>&lt;22.7</td>
<td>1.00</td>
</tr>
<tr>
<td>Low HDL-cholesterol</td>
<td>Inactive</td>
<td>31.5 (26.2 - 36.8)</td>
<td>1.64 (1.09 - 2.48)</td>
</tr>
<tr>
<td></td>
<td>Somewhat active</td>
<td>&lt;41.0</td>
<td>1.48 (0.86 - 2.54)</td>
</tr>
<tr>
<td></td>
<td>Active (meets guidelines)</td>
<td>&lt;30.5</td>
<td>1.00</td>
</tr>
</tbody>
</table>

* adjusted for age, sex, education level, and total accelerometer wear time (min)

Note: If the coefficient of variation of the estimate is greater than 33%, the estimate is indicated as being less than the upper limit of the 95% CI.

75
Differences in the relative odds of the MetS between the infrequently active and frequently active groups, both of whom accumulated enough total weekly MVPA to meet current physical activity guidelines, are shown in Table 4.4. After controlling for the covariates, the relative odds for the MetS was 1.73 (95% CI: 0.87-3.41) times higher in the infrequently active group compared to the frequently active group (see Model 1); however, this was not a statistically significant difference (p = 0.1104). After further adjustment for total weekly MVPA, which was higher in frequently active group than in the infrequently active group, the relative odds for the MetS was no longer increased in the infrequently active group (0.85, 95% CI: 0.42-1.72, Model 2 in Table 4.4). Similar observations were made for the individual MetS components. The only exception was for high triglycerides, wherein the relative odds was higher in the infrequently active group than in the frequently active group after controlling for the covariates, although this was no longer true after further adjusting for total MVPA.
Table 4.4. Odds ratios (95% confidence interval) for the metabolic syndrome and its component risk factors according to weekly frequency of moderate-to-vigorous physical activity (infrequently versus frequently active)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Physical activity‡ group</th>
<th>Prevalence (95% CI)</th>
<th>OR Model 1 (95% CI)</th>
<th>OR Model 2 (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic syndrome</td>
<td>Infrequently active</td>
<td>&lt;14.1</td>
<td>1.73 (0.87 - 3.41)</td>
<td>0.85 (0.42 - 1.72)</td>
</tr>
<tr>
<td></td>
<td>Frequently active</td>
<td>&lt;7.3</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>High blood pressure</td>
<td>Infrequently active</td>
<td>14.1E (9.6 - 18.7)</td>
<td>1.04 (0.57 - 1.91)</td>
<td>1.15 (0.55 - 2.39)</td>
</tr>
<tr>
<td></td>
<td>Frequently active</td>
<td>&lt;15.1</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>High waist circumference</td>
<td>Infrequently active</td>
<td>23.6E (16.5 - 30.7)</td>
<td>1.38 (0.88 - 2.16)</td>
<td>1.07 (0.68 - 1.68)</td>
</tr>
<tr>
<td></td>
<td>Frequently active</td>
<td>15.8E (11.4 - 20.1)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>High glucose</td>
<td>Infrequently active</td>
<td>&lt;15.8</td>
<td>1.53 (0.9 - 2.61)</td>
<td>1.38 (0.65 - 2.94)</td>
</tr>
<tr>
<td></td>
<td>Frequently active</td>
<td>7.5E (5.1 - 10.0)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>High triglycerides</td>
<td>Infrequently active</td>
<td>19.1E (13.4 - 24.8)</td>
<td>1.78 (1.07 - 2.95)</td>
<td>1.37 (0.68 - 2.79)</td>
</tr>
<tr>
<td></td>
<td>Frequently active</td>
<td>&lt;16.8</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Low HDL-cholesterol</td>
<td>Infrequently active</td>
<td>27.6E (18.4 - 36.8)</td>
<td>1.4 (0.79 - 2.49)</td>
<td>0.96 (0.46 - 2.02)</td>
</tr>
<tr>
<td></td>
<td>Frequently active</td>
<td>21.6E (15.2 - 28.1)</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Model 1 adjusted for age, sex, education level, and total accelerometer wear time (min)
Model 2 adjusted for age, sex, education level, total accelerometer wear time (min), and total MVPA (MET-min per week)
‡ Physical activity groups were determined considering total MVPA (all minutes of bouted and sporadic MVPA)
E Interpret with caution (coefficient of variation from 16.6% to 33.3%)
Note: If the coefficient of variation of the estimate is greater than 33%, the estimate is indicated as being less than the upper limit of the 95% CI.
4.5 Discussion

Our primary objective was to determine whether the frequency of physical activity throughout the week was associated with the MetS in physically active adults. The main finding was that the frequency of physical activity throughout the week was not independently associated with the MetS or its component risk factors among active adults. Conversely, the weekly volume of MVPA was strongly associated with the MetS.

The results of the present study support the recently revised World Health Organization, Canadian, UK, and US physical activity guidelines that recommend that adults accumulate at least 150 minutes of MVPA throughout the week. Those who were inactive were 3 to 4 times more likely to have the MetS compared to those who were active. This was true regardless of the nature in which the MVPA was accumulated (i.e. bouted or total MVPA). Similar results were recently reported by Glazer et al. (2013) who evaluated the relationship between meeting the physical activity guidelines and several cardiometabolic risk factors in a cross-sectional analysis of accelerometer data from men and women in the Third Generation Cohort of the Framingham Heart Study (n = 2,109). The authors found that those who met the guidelines through bouted (≥ 10 minutes) or total MVPA had lower waist circumference and triglyceride values and higher HDL-cholesterol values.

To our knowledge this is the first study to use accelerometers to investigate the relationship between the weekly patterns of MVPA and health in adults. While previous physical activity guidelines recommended that adults should accumulate at least 30 minutes of MVPA on most days of the week, the current guidelines do not impose any recommendation of frequency of MVPA throughout the week because research on this topic is sparse. Although the initial model in our analysis suggested that the relative odds for MetS were higher for the infrequently active group compared to the frequently active group, this was no longer the case after controlling
for the total weekly volume of MVPA, which was much higher in the frequently active group. Thus, our results support the notion that the frequency of MVPA throughout the week is not as important as the total volume of MVPA. Similar results were seen in a previous study by Lee et al. (2004). The authors prospectively evaluated the risk of premature mortality in “weekend warriors” (≥1,000 kcal of MVPA per week on 1 or 2 days) and regularly active (≥1,000 kcal per week on 3 or more days) men compared to sedentary men (<500 kcal per week). In that study, the relative risk of premature mortality was 15% and 36% lower for weekend warriors and regularly active men, respectively. Similar to the present study, these results were not significantly different from one another. However, in a stratified analysis, “weekend warriors” did not have a lower mortality risk compared to sedentary men, if they had at least one major cardiovascular risk factor at baseline. This suggests that infrequent physical activity throughout the week may only be of benefit to individuals without major cardiovascular risk factors, although this could not be confirmed in the present study due to the cross-sectional nature of the data and the lack of power to conduct stratified analyses.

Research on the acute physiological and metabolic changes that persist following physical activity suggest that more regular physical activity might be more beneficial to health than equivalent amounts of irregular physical activity. For example, HDL cholesterol and triglyceride levels are improved 24 hours post-exercise, and these improvements persist for up to 72 hours. Improvements in insulin sensitivity occur immediately following physical activity and may persist for several days. Similarly, an increase in fat oxidation is seen following physical activity, but tends to only persist up to 24 hours. The results of the present study do not support the belief that the acute effects of MVPA have meaningful long-term health benefits. This suggests perhaps that the intensity of the MVPA accrued by the participants in this study may not have been sufficient to elicit acute effects, or that the differences between groups were too small to detect in the present study. The timing of the cardiometabolic and physical activity measures also needs to
be considered. Participants were asked not to exercise for the 24 hours prior to their clinic visit when their blood samples were obtained, and the accelerometers were worn in the week following the clinic visit.

The strengths of the present study include the use of a large, nationally-representative sample of Canadian adults and the use of accelerometers, which provide an objective and unbiased measure of physical activity.\textsuperscript{17,27} A limitation is the cross-sectional nature of the data, which does not allow for assumptions to be made regarding causality. However, it is likely that MVPA preceded the cardiometabolic risk factors based on previous randomized-controlled trials and prospective cohort studies have found that MVPA has a positive influence on cardiometabolic risk factors and is effective in the prevention of MetS.\textsuperscript{7,28} Additionally, when a full 7 days of valid accelerometer data was not available, the relative number of active days to valid days was used to estimate the frequency of physical active days. This would have contributed to non-differential misclassification of the physical activity exposure groups (i.e. misclassification would have occurred equally irrespective of physical activity level), which would have biased the results towards the null.\textsuperscript{29}

In conclusion, as per the current physical activity guidelines, accumulating at least 150 minutes of MVPA throughout the week was associated with a lower odds ratio for the MetS and its risk factors for both bouted and total MVPA. Furthermore, the frequency of MVPA throughout the week did not appreciably change the relative odds of the MetS or its component risk factors. Further studies that can better identify patterns of physical activity (e.g. true “weekend warriors”) are needed to more adequately assess the potential added benefit of more regular physical activity.
4.6 References


18. Alberti KGMM, Eckel RH, Grundy SM, et al. Harmonizing the metabolic syndrome: A joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart...


5.1 Summary of key findings

This thesis explored the relationship between different patterns of MVPA throughout the week and the MetS in adults. The hope is that this research contributes to important research gaps related to the understanding of the relationship between different weekly patterns of physical activity and health in adults, and consequently provides evidence that will be useful in refining public health recommendations for physical activity.

The first manuscript aimed to determine whether equivalent volumes of sporadic or bouted MVPA had comparable influences on the relative odds of the metabolic syndrome (MetS) in Canadian adults. The main finding was that sporadic MVPA was as strongly associated with the MetS and its component risk factors as bouted MVPA. We found that the relative odds of the MetS decreased by 11% for each additional MET hour/week of sporadic MVPA and by 9% for each additional MET hour/week of bouted MVPA (one MET hour/week is equivalent to ~20 minutes of moderate activity or ~10 minutes of vigorous intensity). The results of this and other studies1-4 provide important findings on the role that sporadic MVPA plays in health and have important implications for public health guidelines and the way that MVPA can be prescribed and promoted. Current physical activity guidelines from the World Health Organization5 and several countries (e.g., Australia, Canada, US)6-8 recommend that the weekly dose of 150 minutes of MVPA be accumulated in bouts of at least 10 minutes.5-8 However, an important secondary finding of the present study is that even 1-3 minutes bursts of sporadic MVPA were important in predicting MetS. These and other findings1-4 suggest that the weekly dose of MVPA can be accumulated sporadically in periods of 9 minutes or less. Given that only 15% of Canadian adults9
and <10% of American adults\textsuperscript{10} meet the current guidelines, and that a lack of time is the most-
often cited reason for physical inactivity,\textsuperscript{11} the current study supports promoting sporadic MVPA
as another way for individuals to accumulate a sufficient weekly volume of MVPA. Sporadic
MVPA could be accumulated through life-style embedded activities such as stair climbing and
household chores.\textsuperscript{12}

The second manuscript had two objectives: a) to examine the association between the
frequency of physical activity throughout the week and the MetS in physically active men and
women; and b) to examine whether meeting the current physical activity guidelines is associated
with the MetS in adults. The main finding was that the frequency of physical activity throughout
the week was not independently associated with the MetS or its component risk factors among
physically active adults. To my knowledge this is the first study to evaluate this relationship in
adults using directly measured physical activity data, although at least one other study similarly
found no significant association between self-reported physical activity frequency and mortality
in a large cohort study.\textsuperscript{13} Conversely, this and other studies showed that the total weekly volume
of MVPA was strongly associated with the MetS, coronary heart disease,\textsuperscript{14} obesity,\textsuperscript{15,16} type 2
diabetes,\textsuperscript{16} and high blood pressure.\textsuperscript{16} This has important public health implications, as it supports
the current physical activity guidelines that suggest a total volume of MVPA (150 minutes
weekly) without a specified frequency which allows for flexibility to accommodate any schedule
or lifestyle, e.g. 30 minutes on five days per week, or 50 minutes on three days per week, or 75
minutes on 2 days per week, etc.

The lack of evidence on the relationship between different patterns of MVPA and health
outcomes is primarily the result of the limitations of evaluating MVPA via questionnaire.
Conversely, the evidence from questionnaires for a dose-response relationship between the total
volume of MVPA and the primary prevention of coronary artery disease, stroke, hypertension,
colon cancer, breast cancer, type 2 diabetes, and osteoporosis is unequivocal.\textsuperscript{17} The results of each
of the manuscripts in this thesis provide additional support to this: that the pattern in which MVPA is accumulated is unimportant provided a sufficient amount of energy is expended. Neither the weekly frequency, nor the daily pattern of accumulated MVPA (whether bouted or sporadic) altered the association between MVPA and the MetS in Canadian adults aged 18 to 64. Rather, the relative odds for the MetS were significantly lower with higher levels of energy expenditure through MVPA. An important consideration, however, is that the MetS is not an absolute marker of health. Although the MetS encompasses several risk factors for cardiometabolic diseases such as cardiovascular disease or type 2 diabetes, the associations between MVPA and the individual risk factors were not as strong, nor as consistent as those for MetS; therefore, additional research is needed to further understand the relationship between the patterns of MVPA accumulation and cardiometabolic risk factors and other chronic conditions.

5.2 Strengths and limitations of this thesis

This is the first time that the relationship between directly-measured physical activity data and directly-measured MetS has been studied in a large, nationally-representative sample of Canadian adults. This allows the results of this thesis to be generalized to the majority of the Canadian population (approximately 96% of Canadians are represented in the Canadian Health Measures Survey, CHMS). Several studies have been monitoring physical activity in Canadian adults over the last few decades. These surveys have provided important information on the physical activity levels of Canadians and the relationships between physical activity levels and several health outcomes, although these surveys have relied on self-reported data. Although informative, several biases are possible with self-reported data which can influence the interpretability of the results. For example, participants might be more likely to over-report levels of physical activity because it is seen as a “socially desirable” behavior (social desirability bias), or participants might have difficulty remembering all of the activities they did (recall
bias). Additionally, the mode of self-reported data collection also has an influence on the accuracy of reporting. For instance, analysis of body mass index data from the Canadian Community Health Survey indicates that participants tend to under-report their weight and body mass index to a greater extent when interviewed by telephone than when interviewed in person.

The CHMS is the first survey in Canada to objectively measure physical activity levels of Canadian adults through the use of accelerometers. Accelerometer data allows for a more comprehensive physical activity profile as they are programmed to record the acceleration of movement representing the intensity of each minute of activity. In fact, it would have been very difficult, if not impossible, to assess the physical activity patterns as done in this thesis research without these objective accelerometer measures.

While the CHMS is an important source of new information on the health and health behaviours of Canadians, the use of its data is not without important limitations. Although the CHMS has a relatively large sample size, analyses are limited by the small number of degrees of freedom which are determined as the number of primary sampling units (collection sites) – number of strata (regions). The number of degrees of freedom was particularly important when building the regression models: the number of variables that could be included in the model was limited by the degrees of freedom. In each manuscript we did consider additional variables as possible confounders (such as time spent in light physical activity and time spent sedentary were also considered for manuscript 1, and smoking status and diet were also considered for manuscript 2); however, preliminary analysis indicated that these variables were not related to the MetS and they were therefore not included as covariates. It must be acknowledged though that the inability to control for other known or potential confounders such as other sedentary or physical activity variables results in the possibility for residual confounding, and therefore the associations between the physical activity variables and the MetS
might actually be stronger (for positive confounders) or weaker (for negative confounders) than what was found in this thesis.

The regression analyses were also limited by the final sample size of the population of interest. The population of interest for this thesis was adults aged 18 to 64 years with valid MetS data (including fasting glucose) and valid accelerometer data (at least 4 days with at least 10 hours of wear time). In each manuscript, this resulted in a relatively small sample size for this population based research. The small sample size did not allow the candidate to assess interactions or sex-specific associations.

The use of accelerometers in measuring physical activity is also not without limitations. Accelerometers are unable to accurately capture non-step-based activities (e.g. swimming, cycling, and weightlifting),\textsuperscript{12,29} and are unable to account for the added energy expenditure associated with load-bearing activities or added incline, thereby underestimating total physical activity.\textsuperscript{12,26} Furthermore, the cut-points and equations to estimate energy expenditure in this thesis are based on studies with small sample sizes.\textsuperscript{26,30} The use of different cut-points for MVPA or a different equation to predict energy expenditure may have resulted in the over- or under-estimation of physical activity levels. The identified limitations in estimating energy expenditure would have contributed to non-differential misclassification of the physical activity exposure groups (i.e. misclassification would have occurred equally irrespective of physical activity level), which would have biased the results towards the null.\textsuperscript{24}

Other limitations in the current thesis include the cross-sectional nature of the data, and timing of the cardiometabolic and physical activity measurements. Cross-sectional data does not allow for conclusions to be drawn regarding causality because the temporal sequence of exposure and outcome cannot be established with certainty. However, it is likely that MVPA preceded cardiometabolic risk according to other criteria for causality, such as the consistency, the strength and the dose-response nature of the associations, and the biological plausibility of the findings.\textsuperscript{24}
The association between directly-measured physical activity and cardiometabolic risk factors observed in the present thesis is consistent with those observed in other similar studies. Additionally, the associations observed in the present thesis were statistically significant and the relative odds decreased in a dose-response pattern. Finally, the associations are biologically plausible: research has consistently shown that an acute exercise session has a positive influence on HDL cholesterol and triglyceride levels, insulin sensitivity, fat oxidation, and blood pressure.

The timing of the physical activity and cardiometabolic measurements does need to be considered, and led to certain assumptions being made. In the CHMS blood samples and other physical measurements were taken at the clinic visit, while the accelerometers were provided to participants to wear for one week following the clinic visit. The accelerometer data is assumed to be representative of each participant’s regular physical activity patterns as each participant was instructed not to change their behaviours while wearing the accelerometer. This approach is consistent with other large-scale population studies such as the National Health and Nutrition Examination Survey in the U.S. Furthermore, reliability studies have suggested that as few as 3 to 4 days of physical activity monitoring is sufficient to estimate habitual physical activity levels. Participants were asked not to exercise the day of the clinic appointment, but physical activity prior to that could not be determined. Physical activity participation within 24 to 72 hours of the clinic visit (or lack thereof) may have influenced the cardiometabolic measurements, based on the evidence of the acute effects of exercise provided above.

Certain assumptions were also made regarding the physical activity data when a full 7 days of valid accelerometer data was not available. In both manuscripts, if less than 7 days of valid data were available the total volume of MVPA was determined by calculating the average daily MVPA from the available valid days and subsequently multiplying the average by 7 to obtain a weekly total. This approach was consistent with other accelerometer research in
Canada\textsuperscript{3,9,34} and the U.S.\textsuperscript{4,10} However, this assumption is particularly important in the second manuscript because the relative number of active days to valid days was used to estimate the frequency of active days. This would have contributed to non-differential misclassification of the physical activity exposure groups, which would have biased the results towards the null.

5.3 Public health implications

The findings from the manuscripts in this thesis have important public health implications, particularly in relation to physical activity patterns that are promoted in the physical activity guidelines and considered when developing physical activity programs. Both manuscripts provide additional support to the well-accepted notion that there is a dose-response relationship between physical activity and several chronic conditions and associated risk factors,\textsuperscript{17} and support the current message that “More physical activity provides greater health benefits”.\textsuperscript{6} Perhaps more importantly, the results of this thesis contribute to important research gaps that have been identified relating to the potential health benefits of different patterns of MVPA throughout the week. For example, the results of manuscript one suggest that MVPA does not need to be accumulated in 10-minute bouts, as is currently advised in the guidelines. That an equivalent amount of sporadic MVPA has a comparable relationship to the MetS as bouted MVPA might be useful in public health messaging to increase physical activity levels when time is identified as a common barrier to physical activity.\textsuperscript{11} For many people, sporadic MVPA could potentially be more easily accumulated throughout the week through brief activities such as taking the stairs, doing household chores, short walking trips, exercising during a T.V. commercial break, etc. The results of manuscript two are also incredibly relevant to address time as a barrier to physical activity participation. Again, that the frequency of physical activity throughout the week does not change the association with MetS and its risk factors suggests that individuals can obtain health
benefit by following patterns of MVPA that best suit weekly schedules (for example, 50 minutes on three days, or 30 minutes on 5 days, or 75 minutes on two days, etc.).

5.4 Future research

The findings of this thesis have added to the limited amount of research that exists on the associations between different patterns of MVPA throughout the week and MetS in Canadian adults, but also provide directions for future research. Manuscript one is the first study to evaluate sporadic physical activity in Canadian adults. Sporadic MVPA was defined as any MVPA accumulated in less than 9 consecutive minutes. Although it was shown that sporadic MVPA in bursts as short as 1-3 minutes were important in predicting the MetS, additional research is still needed to determine if a minimum bout length exists, for example is it sufficient to accumulate MVPA in as little as one minute at a time, or is a bout of 3 minutes or 5 minutes required? Additional research is also needed to determine whether the associations between sporadic MVPA and MetS are the same within older Canadian adults (ages 65+), for whom the current physical activity guidelines are the same as adults aged 18 to 64 years. Manuscript two was also the first study to evaluate the weekly frequency of MVPA in Canadian adults. Additional research is needed where true “weekend warriors” (i.e. MVPA on consecutive days) can be more accurately identified to more adequately assess the potential added benefit of more regular physical activity. In both cases, experimental study designs are also required to confirm the causality of the associations, and to be able to determine the biological mechanisms involved. For example, previous randomized-controlled trials that compared the effect of accumulated 10-minute bouts of MVPA to an equivalent single session of MVPA on fitness and various cardiometabolic measurements35-38 should be repeated using shorter bouts (e.g., 3 minutes, 5 minutes).
5.5 Summary of MSc research experiences

Through the completion of the MSc coursework, independent study, and practical work experiences the candidate became equipped with the background and skills needed to design and carry out a research project using the Canadian Health Measures Survey data. She critically reviewed the literature to identify important research gaps, and developed novel research questions forming the basis for this thesis research. The candidate was responsible for developing the framework and analytical approach for each of the manuscripts herein. The candidate also prepared all of the data for analysis in each manuscript, which included the manipulation of large Canadian Health Measures Survey datasets and the derivation of the final physical activity variables from the raw accelerometer data (described in more detail in Appendix D). Finally, the candidate completed all of the statistical analyses for each manuscript, making appropriate use of both survey and bootstrap weights to accommodate the complex survey design of the Canadian Health Measures Survey. The candidate also critically evaluated her own work and considered key epidemiological concepts in identifying the major strengths and limitations of the survey design, the analysis and the consequent interpretation of the results. The candidate was also provided the opportunity to gain experience presenting the findings of the first manuscript at a scientific conference (Canadian Society for Exercise Physiology, fall of 2012), and as described above, has submitted both manuscripts to peer-reviewed scientific journals. Finally, the candidate has proposed future research directions to confirm and expand on the findings included in this thesis.

The candidate completed this MSc work as a part-time student while working full-time as an analyst for the Canadian Health Measures Survey at Statistics Canada. Overall, the candidate has gained important knowledge and skills that she will continue to hone and develop through her continued employment with the Canadian Health Measures Survey. The candidate is now better
equipped to participate in the conceptualization of new research projects and analytical products, and in the critical review of analytical products submitted for institutional review within the agency. Furthermore, the candidate has a better understanding of the strengths and limitations of the Canadian Health Measures Survey data and the analytical capabilities of the SAS and SUDAAN software in the context of those limitations.

5.6 Conclusions

The research in this thesis has determined that sporadic MVPA was associated with the MetS to a similar order of magnitude as an equivalent volume of bouted MVPA in Canadian adults, and that the frequency of physical activity throughout the week was not independently associated with the MetS among active adults. The results of this thesis support the current guidelines that for health benefit adults should accumulate at least 150 minutes of MVPA throughout the week in at least 10 minute bouts. However, the results also suggest that comparable health benefit can be achieved through the accumulation of sporadic MVPA, and through both frequent and infrequent MVPA.
5.7 References


Appendix A

Canadian Health Measures Survey

Background and purpose

Both manuscripts in this thesis use data from the Canadian Health Measures Survey (CHMS). The CHMS is a national health survey conducted by Statistics Canada in partnership with Health Canada and the Public Health Agency of Canada. The purpose of the CHMS is to collect direct and indirect health measurements in order to create national data on important public health concerns such as obesity, hypertension, cardiovascular disease, exposure to infectious disease, and exposure to environmental contaminants. Additionally, direct physical and biological health measurements will provide an indication of the extent to which many diseases may be undiagnosed in Canada, and to be able to evaluate the relationship between health status and certain risk factors.1-3

The CHMS is conducted under the authority of the Statistics Act, and has been approved by Health Canada’s Research Ethics Board.1,2,4

Survey design

The CHMS covered the population 6 to 79 years of age in cycle 1 (data collected from March 2007 to February 2009) and 3 to 79 years of age in cycle 2 (data collected from August 2009 to November 2011) living in private dwellings in the ten provinces and three territories. The final sample is representative of approximately 96% of the Canadian population: residents of Indian Reserves or Crown lands, institutions, certain remote regions, and full-time members of the Canadian Forces were excluded.1,2

The CHMS used a complex, multi-stage sampling design to identify possible participants for the survey. During the first stage, a list of possible collection sites that met geographical and population constraints was determined based on information from Statistics Canada’s Labour
Force Survey. The collection sites were stratified across 5 regions and included both large and small urban centers to ensure the sample was nationally representative. Finally, certain financial and logistic constraints contributed to the final selection of collection sites. Fifteen collection sites were selected in cycle 1 and 18 collection sites in cycle 2. The second stage of the sample design involved the sampling of dwellings. Census and other administrative information were used to determine a random of possible dwellings within pre-determined age strata. A current list of household members (known as a roster) was sought from each selected dwelling to establish a list of possible survey participants. Finally, the third stage involved participant sampling. One or two people were selected from each household, with different probabilities for different age groups to ensure the sample sizes were met for each age group.¹,²,⁵

The response rate for the selected households for cycle 1 was 69.6%, meaning that a resident in 69.6% of the households provided the sex and date of birth of all household members. In each responding household, one or two members were chosen to participate in the CHMS; 88.3% of selected participants completed the household questionnaire, and 84.9% of this group participated in the mobile examination centre component of the survey. The final response rate for cycle 1 was 51.7%.¹ The response rates for the combined cycle 1 and 2 data were similar, with 89.3% of selected participants completing the household questionnaire, and 83.3% of those completing the visit to the mobile examination centre. The overall response rate for cycle 1 and 2 combined was 53.5%.⁶

Data Collection

Data collection took place in two parts: 1) a questionnaire completed at the participant’s home; and 2) a subsequent visit to a mobile clinic. The household questionnaire was administered by a Statistics Canada-trained interviewer. The questionnaire collected information on socio-demographic information, medical history, current health status, and health behaviours. At the mobile clinic visit, direct physical measurements were taken by Health Measures Specialists and
blood samples were collected by laboratory technologists from each respondent. At the mobile clinic, an Actical accelerometer was provided to all ambulatory participants to wear on an elasticized belt over the right hip during all waking hours for one week.\textsuperscript{1} Accelerometers were initialized to begin collection at midnight following the clinic visit and were mailed back to Statistics Canada after the 7-day collection period.\textsuperscript{1} The data included in the analyses for the present thesis are described in detail below, with the exception of the accelerometer data which is described in detail in Appendix C.

\textit{Waist circumference}

Waist circumference was measured to the nearest 0.1 cm as per the World Health Organization protocol: the measurement was taken at the mid-point between the last floating rib and the top of the iliac crest, at the end of a normal expiration, using a Gulick tape measure.

\textit{Blood pressure}

Resting blood pressure was measured electronically using a BpTRU\textsuperscript{TM} BP-300 device (BpTRU Medical Devices Ltd., Coquitlam, British Columbia). After resting quietly for 5 minutes, a minimum of 6 measurements were then taken automatically, one minute apart, and the average systolic and diastolic blood pressure was determined using the last 5 of the 6 measurements.

\textit{Blood measures (triglycerides, glucose, and high density lipoprotein cholesterol)}

Venous blood samples were collected following a 10-hour fasting period: glucose levels were measured in plasma, while triglycerides and high density lipoprotein (HDL)-cholesterol were measured in serum. Blood samples were analyzed at the Health Canada Laboratory (Bureau of Nutritional Sciences, Nutrition Research Division). Glucose, HDL-cholesterol and triglycerides were all measured on the Vitros 5,1FS (Ortho Clinical Diagnostics). Results below the limit of detection were included in analysis by imputing a value of the limit of detection divided by two
(the limit of detection is a value that is provided by the laboratory and is based on the testing method for each analyte).

**Medication use**

For medication use, respondents provided all prescription and over-the-counter products taken in the past month. Any product reported at the household was confirmed at the clinic, and new drugs or health products were collected at the clinic. Whenever possible, the Drug Identification Number was collected for each medication or health product, otherwise a DIN was assigned to the product from Health Canada’s Drug Product Database. At Statistics Canada the Drug Identification Numbers were coded using the Anatomical Therapeutic Chemical classification system which was provided to data users.

**Covariates**

Both age and sex were collected when the roster of all household members was confirmed for participant selection. Age and sex were also confirmed at the clinic visit. During the household questionnaire adult participants were asked to provide the highest level of education completed. A dichotomous variable was created for analysis indicating whether the participant holds a post-secondary degree or diploma (post-secondary graduate, yes/no). Smoking status was determined based on answers to a series of smoking questions. A dichotomous variable was created for analysis identifying current daily smokers and non-smokers. Dietary information on the following food items was obtained through a food frequency questionnaire: brown bread, fruit, lettuce, spinach, salt-water and fresh-water fish, shellfish, and nuts. For each food item, participants were asked “How often do you eat (food item)? (For example: twice a day, three times a week, once a month)” and a yearly frequency was calculated.
Data quality

Staff certification and training

The HMS that administered all direct physical measurements all held Bachelor degrees in Kinesiology or a related field, and were certified as either a Certified Personal Trainer® or a Certified Exercise Physiologist® by the Canadian Society for Exercise Physiology. All blood draws were completed by laboratory technologists/phlebotomists. Survey-specific training of standardized survey protocols was provided by content-specific experts to all HMS and laboratory staff prior to the start of each cycle, and re-training took place at mid-cycle.

Quality control and quality assurance

Each HMS completed periodic randomly assigned replicate tests of the waist circumference and other anthropometric measurements, and re-training was provided as necessary. Replicate testing was also completed by each HMS during training compared to a “Gold Standard” specialist in anthropometric measurements.

All mobile clinic staff members were observed periodically throughout the collection period to provide a direct evaluation of protocol adherence, interaction with respondents and overall data collection quality. The observers (senior staff or content-specific experts) completed observation reports and re-training was completed when necessary.

Replicate lab samples and commercial control samples were sent to the CHMS external labs to assess the accuracy and precision of laboratory testing. Field blanks were also sent to the CHMS external labs to ensure that samples were not being contaminated by the MEC environment and processes.

Data analysis

In order for the data to be nationally representative, a set of survey weights is provided by Statistics Canada for each participant. The survey weight corresponds to the number of people
represented by the respondent in the population as a whole, and is calculated as the inverse of the probability that the participant was selected for the survey, adjusting for non-response to various stages of the survey.\textsuperscript{2,6} In addition to the survey weights, bootstrap weights are provided and are necessary to calculate the variance (and the resulting standard error) on each estimate taking the survey design into account.\textsuperscript{1,2}

An important limitation of the survey design that must be considered in all analyses is the degrees of freedom. For the CHMS, the number of degrees of freedom is calculated as the number of primary sampling units (collection sites) minus the number of strata (regions). The degrees of freedom are equal to 11 for cycle 1 (15 collection sites across five regions)\textsuperscript{1} and 13 for cycle 2 (18 collection sites across 5 regions).\textsuperscript{2} The number of degrees of freedom for the combined cycles 1 and 2 is therefore 24.\textsuperscript{6} The number of degrees of freedom is particularly important in regression analysis as the number of covariates in the model is limited by the degrees of freedom: the maximum number of covariates that can be included in the model is the number of degrees of freedom minus 1.
References


Appendix B

Canadian Health Measures Survey Consent Forms
Cycle 1 consent form for adults

Canadian Health Measures Survey

Consent Form
CONFIDENTIAL WHEN COMPLETED

Date (yyyy/mm/dd): □ Reference Year □ Reference Month □ Reference Day
Identification Number: □ CLINICID
Name: □ Respondent Name
Age at clinic exam: □ CON_AGE
Gender: □ Gender M □ Gender F

I have read and understood the information provided to me in the Information and Consent Booklet for the Canadian Health Measures Survey. By marking the boxes below and signing this form, I am choosing to consent ("Yes") or not consent ("No") to the following:

- participating in the physical measures test, including providing samples of my blood and urine
- receiving a copy of my Report of Laboratory Tests
- allowing Statistics Canada to test my blood for the Hepatitis B and C viruses and to contact me, as well as the appropriate provincial authorities, if the result is positive
- storage of my blood and urine for use in future health studies
- storage of my DNA for use in future health studies

I have had time to decide on participating in the clinic portion of the survey. I understand that even though I have consented to some or all of the items on this form, I can still withdraw from any part of this survey or subsequent studies at any time.

*Respondent Name

Signature of participant ___________________________ Date ________________

Name of witness (please print) ___________________________

Signature of witness ___________________________ Date ________________

For office use only:
Entered by: ___________________________ Verified by: ___________________________

Statistics Canada Statistique Canada *BarCode
Cycle 2 consent form for adults

Canadian Health Measures Survey

Consent Form
CONFIDENTIAL WHEN COMPLETED

Date (yyyy/mm/dd): *CurrentDate
Identification number: *CLINICID
Name: *RespondentName
Age at clinic exam: *CON AGE
Gender: *Gender

I have read and understood the information provided to me in the Information and Consent Booklet for the Canadian Health Measures Survey. By marking the boxes below and signing this form, I am choosing to consent ("Yes") or not consent ("No") to the following:

- participating in the physical measure tests
- receiving a copy of my test results (such as the Report of Laboratory Tests and the lung function test results)
- allowing Statistics Canada to test my blood and urine for diseases and contaminants that are reportable in this province and to contact me, as well as the appropriate provincial authorities, if the results are positive. The list of reportable diseases and contaminants for this province has been provided to me
- storage of my blood and urine for use in future health studies
- storage of my DNA for use in future health studies

I have had time to decide on participating in the clinic portion of the survey. I understand that even though I have answered "Yes" to some or all of the items on this form, I can still withdraw from any part of this survey or subsequent studies at any time.

*RespondentName

Signature of participant

*CurrentDate

Date

*CurrentHMSIDName

Name of witness

Signature of witness

*CurrentDate

Date

For office use only:

Entered by: *CurrentHMSIDName

Verified by: 

Canada

Statistics

Canada

Statistique

Canada

*BarCode
Appendix C

Accelerometer Data

As described in Appendix A, all ambulatory participants in the Canadian Health Measures Survey (CHMS) were provided with an accelerometer to wear for a period of one week following the clinic visit. After one week, accelerometers were returned to Statistics Canada in a prepaid envelope where the data were downloaded and processed. The following sections explain the accelerometer data, the data processing completed by Statistics Canada, and the additional data reduction that was completed by the candidate for this thesis.

Canadian Health Measures Survey Accelerometer Data Processing

The Actical accelerometer measures the acceleration of movement and recorded it as a digitized value summed over a period of 1 minute (epoch), resulting in a count per minute value. The data was also translated into a step count value for each minute. The data for each participant was downloaded and saved as a “.AWC” file (Excel) and then read into SAS, keeping 10,080 data point rows per file (7 days x 1440 minutes = 10,080). All individual data files were then concatenated into one file for further processing.

Several steps were then taken to ensure the quality of the accelerometer data, including: verification of initialization errors, and checking for spurious data and plateaus. The CHMS accelerometer data reduction procedures were harmonized with those used in the U.S. National Health and Nutrition Examination Survey.\textsuperscript{1,2} Each accelerometer was initialized manually by clinic staff to begin collection at the first occurrence of midnight following a participant’s clinic visit. The start date, start time, and epoch length set at initialization were verified, and corrections were made where possible, otherwise files were dropped. The data was also assessed for spurious data and plateaus. A spurious data point was defined as a cpm value greater than 20,000 cpm, while a plateau was defined as period of more than 5 consecutive minutes with equal cpm values.
above zero.\textsuperscript{1} Data files with greater than 15 spurious data points were determined to be invalid and deleted, while files with 1-14 spurious data points or with more than 5 plateau occurrences were identified and inspected manually to determine validity.\textsuperscript{1,3,4} Occurrences of spurious data points were replaced with an average value of the surrounding data points. For example, if three consecutive minutes had values of 7000, 23000, and 8000, the spurious data point (23000) would be replaced by the average of the other two data points: \((7000 + 8000) / 2 = 7500.\) At this stage in data processing, a “per-minute” SAS file was output containing the cleaned, per-minute data for each respondent.

The next step completed by the CHMS was to determine valid wear time. Total daily accelerometer wear time was determined by identifying non-wear time and subtracting it from 24 hours. Non-wear time was defined as periods of at least 60 consecutive minutes of zero counts, with an allowance for one or two minutes of counts between 0 and 100.\textsuperscript{1,2,5} A valid day was defined as having at least 10 hours of wear-time; a valid person was defined as having at least 4 valid days of data.\textsuperscript{1,2,5} Additional data reduction summarizing the accelerometer data was completed by the Canadian Health Measures Survey prior to the dissemination of data, however the analysis for the present thesis required access to the per-minute data file described above, therefore the additional data reduction by the CHMS is not described herein. The additional data reduction completed by the candidate is described below.

**Additional Data Reduction Completed by the Candidate**

Only participants identified by Statistics Canada as having at least 4 valid days of data were included in this thesis as per recommended guidelines.\textsuperscript{1,2} The candidate obtained the cleaned per-minute data described above for each of these valid respondents to complete the data reduction necessary for this thesis.

Moderate-to-vigorous physical activity (MVPA) included any epoch value \(\geq 1,535\) cpm, the same moderate-intensity cut-point value has been used in previous analysis of CHMS data.\textsuperscript{6}
Details of the derivation of this cut-point are described elsewhere. Briefly, the cut-point value of 1,535 was determined using decision boundary analysis of data from a study of 26 adults who wore an Actical accelerometer on their hip during a series of sessions on a treadmill with varying intensity levels. Energy expenditure was calculated for each minute where the epoch value was at or above the 1,535 moderate intensity cut-point using the following regression equation: energy expenditure in metabolic equivalents (METs) = 0.02663 + (0.00001107*count per minute) X 60 + 1 (resting energy expenditure). This equation was developed using a sample of 24 men and women (mean age 36 years) who wore an Actical accelerometer on the hip for a series of activities of varying intensities while oxygen consumption was simultaneously measured by a portable metabolic measurement system. We chose to express MVPA in METs because this allowed us to merge the moderate and vigorous activity minutes, and when doing so, to account for the fact that more energy is expended for each minute of vigorous activity than for each minute of moderate activity, and the ratio of moderate-to-vigorous activity may be different in sporadic and bouted MVPA.

Total weekly MET hours (or MET minutes) were determined by summing the MET hour (or MET minute) values for all bouted MVPA (i.e., MVPA accumulated in at least 10-minute bouts) and sporadic MVPA (i.e., MVPA accumulated in periods of 9 minutes or less) epochs. A bout of MVPA was determined as a period of at least 10 consecutive minutes above the moderate-intensity cut-point; a bout continued until 80% (i.e. 8 out of 10 minutes) was no longer above the cut-point. Since not all participants had seven valid days of data, each total was divided by the number of valid days to obtain a daily average, and then multiplied by 7 to obtain a weekly total. Thus, the final derived physical activity variables for each participant consisted of MET hours/week of bouted MVPA and MET hours/week of sporadic MVPA. As this was an observational study, all participants had a bouted MVPA and a sporadic MVPA value, and these were not mutually exclusive groups.
Additional data reductions required for analyses are described in more detail in each of the manuscripts (Chapter 3 and Chapter 4).
References


