PHYSICAL ACTIVITY, SEDENTARY TIME, SLEEP DURATION, AND SELF-RATED HEALTH IN OLDER ADULTS: A COMPOSITIONAL ANALYSIS

by

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Abstract

Purpose: The purpose of this study was to determine the relationship between movement behaviours that make up a day and self-rated health (SRH) in adults aged 60-79, while adjusting for time spent in all other behaviours. This required the application of a compositional data framework to the analysis, which is an emerging method in physical activity epidemiology.

Methods: This study was conducted using cycles 1-3 of the Canadian Health Measures Survey. SRH, sleep duration, and covariates were self-reported, and sedentary time (ST), light-intensity physical activity (LIPA), and moderate-to-vigorous intensity physical activity (MVPA) were measured using an Actical accelerometer. Traditional descriptive statistics were computed for the outcome and covariates, while compositional descriptive statistics were displayed for the movement behaviours. Logistic regression analyses were run to determine the association between the overall composition of movement behaviours and SRH, as well as the association between each movement behaviour and SRH. The odds of reporting 'poor' or 'fair' SRH were modeled.

Results: The distribution of time spent in sleep, ST, LIPA, and MVPA is associated with SRH ($p<0.001$). Relative to the other movement behaviours, both sleep duration (OR= 0.17) and MVPA (OR=0.81) were associated with better SRH. ST was associated with poorer SRH (OR=12.4). No statistically significant association was found for LIPA.

Conclusion: SRH in older adults was positively associated with sleep duration and MVPA, and negatively associated with ST. Future research on physical activity should consider the effects of each movement behaviour on health outcomes, while taking into account the other behaviours.

Co-Authorship

This study is the work of Nicole Haywood under the supervision of Dr. Mark Rosenberg and Dr. Kristan Aronson, using data collected from the Canadian Health Measures Survey. Data management, statistical analysis, interpretation of the results, and writing of the thesis was performed by Nicole Haywood with the guidance of Dr. Mark Rosenberg. Dr. Kristan Aronson provided feedback on the general concepts contained within, and contributed to revising the manuscript.

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CHMS	Canadian Health Measures Survey
LIPA	Light-intensity physical activity
MEC	Mobile examination centre
MVPA	Moderate-to-vigorous physical activity
PA	Physical activity
RDC	Research Data Centre
SD	Sleep duration
SRH	Self-rated health, self-reported health status
ST	Sedentary time

Chapter 1

Introduction

Introduction

1.1 Background

In 2015, for the first time the number of Canadians over the age of 65 exceeded the number of children aged 0-14. There were 5.8 million Canadians in this older age group, representing 16.1% of the total population[1]. It is estimated that by 2036, older Canadians will constitute 23-25% of the country's population[2]. This demographic shift has implications for Canadian society in the realms of healthcare, economic strain, education, employment, and social engagement[3]. Although seniors comprised 15.7% of the population in 2014, 46% of public sector health-dollars were spent on this demographic[4]. The elderly have unique healthcare needs. As well as chronic disease, rates of functional limitations and disabilities increase with advancing age. 41.7% of Canadians over the age of 65 have at least one of the major chronic diseases - cancer, cardiovascular disease, diabetes, and chronic respiratory diseases, and 11.6% of this demographic self-report having two or more of the above conditions[5]. The Canadian healthcare system focuses heavily on treating diseases as they arise; however, a stronger emphasis on health promotion for seniors is a vital tool to help this demographic maintain good health and quality of life.

An important focus area of health promotion is physical activity (PA), which confers many well-known health benefits, including reduced risk of early mortality, and incidence of cardiovascular disease (CVD), some cancers, and depression[6-8]. In addition, regular PA may delay disability and functional decline in seniors[11]. In contrast to PA, sedentary time (ST) is an independent risk factor for adverse health outcomes such as obesity and type II diabetes, as well as early mortality[10-12]. By adding sleep duration to PA and ST, the 24 hours in a day can be divided into time spent in each of these movement behaviours. Non-ideal sleep duration has been linked to adverse health outcomes such as CVD, diabetes, and obesity[13-15].

Self-reported health status (SRH) is a commonly used metric in population health surveys. It is a subjective measure that results from a cognitive process in which individuals consider information they know about their own health, and then choose a rating from 'excellent' to 'poor' to describe their health status[16]. SRH is a good predictor of future mortality, independent of covariates such as objective health status[17-18]. It is also predictive of future morbidity and chronic disease incidence[19], as well as of physician service use[20]. SRH is a useful metric because it reflects both known and unknown biological, psychological, social, and functional elements[16].

It is well known that PA is strongly correlated with SRH in all age groups, including the elderly[21-24]. Some research has also suggested an association between sedentary time (ST) and SRH[25]. However, many of the studies that examine PA and/or ST in the elderly rely on self-reported PA data. Non-differential measurement error from inaccurate memory, as well as the more serious issues of recall and response biases plague self-reported PA data[26-27]. For example, social desirability bias may influence participants to overestimate their amount of PA. Finally, there are statistical issues regarding the analysis of movement behaviour data. Considering that there are only 24 hours in a day, it is reasonable to argue that PA, ST, and sleep are in fact co-dependent behaviours - time spent in one behaviour necessarily displaces time available to engage in the other two. Due to this, some researchers have argued that we should conceptualize the movement behaviours as compositional variables having collective associations with an outcome, and an emerging area of research in PA epidemiology is the application of compositional analysis to properly account for the co-dependence of movement behaviour data[28-30]. This thesis takes up the challenges of using a compositional analysis to analyze the relationship between PA, ST, sleep, and SRH.

1.2 Rationale

This thesis examines the relationship between PA, ST, sleep duration, and SRH in older adults. The conceptual framework proposes that SRH is both affected by and may affect the distribution of daily time spent in each movement behaviour. Several possible mechanisms for these relationships are described below. For example, sufficient sleep, more PA, and less ST influence objective health status through mechanisms such as reduced insulin resistance and increased aerobic fitness/capacity[7]. In turn, objective health status seems to be an important component of SRH. Another possibility is that sufficient sleep, more PA, and less ST lead to a change in self-perception, and this is reflected in SRH. Conversely, it might be that disability and functional decline is reflected in lower SRH, and this influences the composition of daily movement behaviours by impacting one's ability to engage in PA.

In addition, sociodemographic, behavioural, and psychosocial characteristics act as confounding factors on the pathway between the movement behaviours and SRH. Because SRH is an overall measure of health and well-being it is made up of many components. In terms of indicators of objective health status, it is somewhat controversial if the many components should be considered as confounders, or on the causal pathway between the movement behaviours and SRH. On the one hand, it is entirely plausible that movement behaviours affect objective health status, which in turn is reflected in SRH. However, it is known that SRH is a complex measure that can predict future mortality independent of objective health status. This makes it clear that SRH is not simply a reflection of objective health status, so perhaps movement behaviours acting to influence SRH through objective health status are only part of the overall causal pathway.

1.3 Objectives and hypotheses

The objectives of this study are:

1. To examine the relationship between PA, ST, sleep, and SRH, while taking into account the co-dependency of the independent variables. The central purpose of this thesis is to examine how the proportion of daily time spent in PA, ST, and sleep is related to SRH in older Canadian adults. This represents an innovative approach to the study of PA and ST, which are often assessed independently of each other. It is hypothesized that PA and sleep duration will be associated with better SRH, while ST will be negatively related to SRH.

2. To explore socio-demographic differences in the relative time spent in each of the movement behaviours.

These objectives were achieved using data from the Canadian Health Measures Survey (CHMS), a repeated cross-sectional nationally representative survey of Canadians aged 3-79. More information on the CHMS can be found in Appendix C. Data on PA and ST was assessed via accelerometer, while sleep duration and the outcome of SRH were self-reported.

1.4 Scientific and public health relevance

The study of the effects of PA on health has spanned over a century, and the positive health benefits of PA are well-known. However, the majority of this research has failed to fully take into account the co-dependent nature of PA, ST, and sleep duration. Without properly accounting for this co-dependency, study results can be affected by which movement behaviours are included in the analysis, which obfuscates the effect on the outcome of the behaviour under study. Following the procedure published by Chastin et al (2015), this thesis will apply appropriate statistical techniques to the study of the composition of movement behaviours and a general indicator of overall health, SRH. This contributes to the scientific advancement of the physical activity epidemiology field.

In terms of public health, seniors are a key demographic for health promotion programming due to population growth in this group and their high levels of health care use. This thesis is a useful tool for health promotion, in that it could contribute to the development of integrated movement behaviour guidelines for older adults. These guidelines already exist for Canadian children[31], and a set tailored for seniors would be a useful health promotion tool to encourage healthy aging. Currently, public health recommendations for adults focus on PA, with vague guidance around breaking up extended periods of ST[32]. The research presented in this thesis could also inform public health campaigns around PA (i.e., is it more beneficial to encourage people to maintain levels of MVPA or should we focus on reducing sedentary behaviour and getting people more active in any form?).

1.5 Thesis Organization

This thesis adheres to the regulations outlined in the Queen's University School of Graduate Studies and Research "General Forms of Theses" for a manuscript based thesis[33]. It is divided into four chapters. Chapter 2 reviews the literature that is relevant to the context of the study, and includes a discussion of physical activity, sedentary time, and sleep as they relate to health status and outcomes in older adults. Theories of the construct of self-rated health are also explored. Chapter 3 presents the manuscript meeting my thesis objectives, and is entitled "Physical activity, sedentary time, and sleep duration and self-rated health in older adults: A compositional analysis." This chapter also includes an overview of the study data source and methods. This manuscript will be submitted to the *Journal of Aging and Health*, and is formatted according to their specifications. Chapter 4 provides a summary and discussion of the key findings, strengths and limitations, public health and scientific implications, directions for future research, and conclusions. Appendices providing additional information on statistical methods, power calculations, and specific information on the Canadian Health Measures Survey are also included.

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Chapter 2

Literature Review

2.1 Overview

This literature review will provide an overview of the concept of SRH, including various theories on what it captures, and how it is related to other health status indicators. This review will also examine the measurement of sleep duration, ST, and PA. It will summarize and critique the existing research on SRH and each of the daily movement behaviours, focusing on work done with older populations. Finally, statistical issues in PA research will be identified, and an overview of compositional analysis will be provided.

2.2 Self-rated health

2.2.1 Definition

Self-reported or self-rated health status (SRH) is a commonly used indicator in both clinical epidemiology and population health. It is a subjective measure of health that is thought to reflect an individual's integrated perception of the domains of health, including biological, psychological, and social dimensions. The World Health Organization considers SRH to be a reflection of population health and healthy life expectancy within countries[1]. It is assessed either by a questionnaire or by a single question which asks subjects to rate their own health, usually on a four or five-point scale from poor to excellent. SRH has been used as a health indicator in epidemiological studies since the 1950s, and has been found to predict future health outcomes independent of physical, socio-demographic, and psychosocial indicators[2-5]. It is widely considered to be a valid indicator of health status.

2.2.2 Theories of Self-rated health

As stated above, studies have demonstrated a strong association between SRH and a number of outcomes, including future mortality, morbidity, health care use, and nursing home entry[4, 6-8]. These relationships are generally attenuated, but persist even after adjusting for a wide variety of sociodemographic variables and physical and mental health indicators. The most commonly studied association is that between SRH and mortality, where research has shown poor SRH to be associated with increased risk of mortality[3, 9-11]. The reasons underlying this relationship are, however, unclear. This is partly due to the fact that the construct of SRH is poorly understood. Attempts to illuminate the construct of SRH have included studies on its determinants, as well as presentations of conceptual models.

Although it may be tempting to assume that SRH simply reflects objective health status, empirical research has shown it to be more complex. Even after accounting for a wide range of physical and mental health indicators, including physiological measures, some variance in SRH remains unexplained. One theory to explain this claims that SRH is a more inclusive and accurate measure of health status than the covariates used[3,12, 13]. It is simply not possible to collect information on every single disease, disability, and functional impairment that a person may have. In addition, surveys generally do not gather information on disease severity and prognosis, and individuals may weight their self-ratings of health based on these factors[13]. Similarly, SRH may capture physical health risk factors that are undetectable or not known[14]. For example, it has been demonstrated that people may not be aware of diagnosable risk factors – one study showed that 17.4% of Canadians with high blood pressure were not aware of it[15].

Another theory is that SRH reflects one's self-concept and lifestyle factors, including social and material conditions that are known to have adverse effects on health[16]. Although studies have attempted to control for various factors, residual confounding is still a possibility, and this theory postulates that uncontrolled-for psychosocial and socio-demographic factors at least partially explain the relationship between SRH and mortality. It is important to note that SRH represents an individual's own perception, so cognitive processing plays a role. Some personality factors, such as a weak sense of mastery or fatalism, have been shown to be correlated with SRH[17]. Hypochondria and preoccupation with health are also associated with SRH[18]. This theory also suggests that SRH reflects dispositional optimism or pessimism, and that it can influence future health behaviours[3, 6]. However, it is important to note that while health behaviour, social resources, and optimism are associated with mortality, their effects are not independent of their influences on the individual. Therefore, these factors could explain the effect of SRH on mortality risk only if they reflected change in objective health status that takes place between the self-rating and death. This is not supported by the majority of findings that show the association between SRH and mortality is strongest for shorter rather than longer follow-up periods[19-21]. Finally, contextual factors, such as culture, affect how individuals rate their own health[22]. In truth, SRH probably captures and is influenced by many factors. To this end, Jylha has proposed a model that integrates both social and biological pathways to explain how individuals rate their own health[13].

In her paper, Jylha theorizes that "the basis of self-rated health lies in the biological and physiological state of the individual organism," and that contextual factors influence the processing of information used to inform this rating[13]. She proposes that individuals consider information on formal health status, such as number of physician-diagnosed diseases and prescription medications. Additional input information includes subjective experiences of symptoms and body sensations, which is reflective of overall functioning and may indicate sub-clinical disease. Contextual influences include cultural and historical definitions of 'health,' comparative groups (for example, how healthy are age-group peers?), previous health experiences, health expectations, and cultural conventions in expressing positive and negative opinions[13]. In addition, individuals may incorporate family history into their self-ratings of health by using this information to judge how likely they are to suffer from heritable diseases. Jylha emphasizes that SRH is a dynamic evaluation, in which individuals may judge the trajectory of their health and not only their current level of health.

Jylha proposes that sociodemographic factors correlated with SRH influence it by acting through pathways which affect objective health status and functioning. She proposes that factors such as education and social status do not directly describe health status, but affect the likelihood of physical and mental health conditions that individuals use as the basis for self-ratings of health[23]. She further suggests that

SRH may reflect the presence or absence of resources that can attenuate decline in health, such as social support or personal characteristics and resources. Finally, Jylha argues that 'non-health' individual and social characteristics may influence SRH by shaping the framework of evaluation[13].

Overall, SRH is an inclusive measure of health status. As evidenced by the persistent relationship of SRH with mortality even after adjusting for a variety of confounders, SRH seems to capture something more than the factors that it encompasses. This can be reflected in the theory of holism, which states that "organic or unified 'wholes' have value and being which is inherently different from, and cannot be reduced to, the sum of their individual parts"[138]. This concept lends support to the validity and usefulness of SRH as a health status indicator.

2.2.3 Relationship with mortality and other health indicators

Numerous studies have shown a strong and consistent relationship between SRH and risk of all-cause mortality[3, 6, 9, 24, 25]. This relationship exists in both genders, and all age groups and ethnic groups studied. However, it is strongest in younger age groups, males, and those of higher socioeconomic status[21, 26, 27]. The odds ratio of mortality for those individuals who rate their health as 'poor' compared to those who rate their health as 'excellent' has been calculated as being 1.61-1.92, controlling for a variety of other health status indicators and mortality risk factors[6, 25]. However, there is some evidence to suggest that knowledge of one's objective health status is an important factor in the relationship between SRH and mortality. Idler et al. showed that in a group of people with circulatory disease, SRH was an independent predictor of mortality only in the subgroup that was aware of their diagnosis[28]. In the group that was unaware of their disease, the association was not statistically significant. Other studies have also shown that the relationship between SRH and mortality is strongest when the cause of death is a condition which the person is likely to have been aware of, for example, diabetes[29].

Studies have also illustrated associations between SRH and other health indicators. Latham et al. found that SRH is a significant predictor of the onset of coronary heart disease, diabetes, stroke, lung disease, and arthritis, but not cancer[4]. Additional studies have also found statistically significant relationships between SRH and chronic diseases, including stroke and type II diabetes[30, 31]. One possible explanation for these findings is that the predictive relationship between SRH and mortality works through morbidity. Other studies have found associations between SRH and health service use, including physician service use and overall healthcare expenditure[5, 32]. Finally, SRH is known to be related to decline in functional health status[3, 33]. Specifically, studies have found that poor SRH is predictive of decline in gait speed, for example[34]. Thus, it makes sense that it is also predictive of nursing home entry[35].

Studies looking at correlates of SRH have found that various sociodemographic variables, as well as indicators of physical and mental health and functioning are associated with SRH. For example, Borim et al. found that educational attainment, income, physical health, and an indicator of mental health/happiness were associated with SRH in an older population[36]. In a study of two large occupational cohorts in Europe, Singh-Manoux et al. found that physical indicators of health such as number of recurring health problems, symptom score, physical mobility, and measures of minor psychiatric morbidity explained the majority of the variance in SRH[20]. Differences in SRH have also been reported with regards to sex, marital status, ethnicity, employment, smoking status, and mental health indicators, such as depression [3, 37-40].

Research on this topic has primarily been carried out as secondary data analyses conducted on existing datasets that were not designed to answer questions specifically related to SRH. However, these datasets tend to have large, representative samples, which reduces the risk of selection bias. In addition, the variable of SRH is not subject to misclassification. The relationship between SRH and mortality has been studied in a number of different populations, including young adults, the old-old, occupational cohorts, emergency department patients, and in people with mild to moderate cognitive decline[20, 41-44]. Although there are relative differences by subgroup, the consistency of the association provides strong support for the idea that SRH is indeed predicative of mortality, and is therefore an acceptable proxy for overall health status.

2.2.4 Self-rated health and aging

Individuals tend to rate their health more poorly as they age, though this decline is more pronounced in those aged 75 years and older[45]. However, the observed decline in SRH is less pronounced than the decline in objective physical health and functioning in aging populations. This is called the paradox of aging, and is reflected in the fact that the correlation between objective health status and SRH weakens with advancing age[46]. The paradox of aging states that although SRH tends to be poorer in older age groups, it does not match the steeper decline in functional health status that occurs with advancing age. Thus, a significant proportion of older individuals who are ill or disabled still rate their health as good or better. One hypothesis to explain this finding is that older individuals may rate their health against what is 'expected,' or against the perceived health of their peers, instead of against perfect health[46]. When comparing SRH assessments using global versus comparative question wording, it has been found that global SRH decreases substantially with age, but when asked to rate their own health compared to age-group peers, older persons maintain a higher SRH than would be expected based on their objective health status[46]. This finding agrees with the paradox of aging, and suggests that SRH in older adults may be based more on health expectations and comparisons with the 'average' for their age.

The association of SRH with mortality also weakens with advancing age. One study showed that hazard ratios for mortality based on SRH decline by about half between age 50 and 80[47]. This concurs with the paradox of aging described above, where SRH correlates less strongly with objective health status in older populations. It has also been suggested that acute health problems which threaten survival (for example, pneumonia) may come on more suddenly in older people, and thus may not have been taken into account in the initial SRH assessment[13]. This agrees with the finding that SRH is most strongly related to mortality with shorter follow-up durations[19-21].

2.3 Physical activity

2.3.1 Definition, measurement, and rates in older Canadians

PA is defined as "any bodily movement produced by skeletal muscles that requires energy expenditure"[48]. This energy expenditure can be measured in kilocalories. Metabolic equivalents (METs) are used to estimate the metabolic cost of physical activity. One MET is equivalent to a person's energy expenditure at rest[49]. PA can be categorized by intensity into light, moderate, and vigorous physical activity. Light PA is considered to be any activity that causes an individual to expend 1.6-2.9 METs; for moderate PA this is 3-5.9 METs, and for vigorous PA it is greater than or equal to 6 METs. Moderate and vigorous PA is often combined into MVPA, which has a threshold of greater than or equal to 3 METs[49].

People obtain PA doing a variety of activities – these activities can be categorized as occupational, exercise, leisure-time, household, and active transportation[48]. This thesis uses accelerometer data and so will consider all PA domains; however, studies often use self-reported exercise or leisure-time physical activity (LTPA) as an independent variable. Exercise refers to planned, structured, and repetitive activities performed for the purpose of improving physical fitness[48]. Physical fitness is a set of attributes that people have or achieve relating to their ability to perform PA[50]. There are four domains of physical fitness: health-related, skill-related, physiological fitness, and motor skills[50]. Finally, LTPA is any PA that is not an essential activity of daily living, and that is performed at the discretion of the individual[51].

The Canadian Society for Exercise Physiology recommends that adult Canadians, including seniors, should accumulate at least 150 minutes of MVPA per week, in bouts of 10 minutes or more[52]. The guidelines also recommend strength training major muscle groups twice a week. Objectively measured PA data from cycle 3 of the Canadian Health Measures Survey (CHMS) has shown that approximately 22% of Canadian adults aged 18-79 meet these guidelines; however, only 12% of seniors aged 60-79 do so[53]. Additional results from cycle 3 of the CHMS showed that women aged 60-79 accumulate an average of 23 minutes of MVPA per day, while men in the same age group accumulate 27 minutes per day[53].

Before the use of accelerometers in PA research, PA data was self-reported. This method requires participants to report how often and for how long they engaged in a variety of activities. Each activity is assigned a metabolic cost in terms of METs, and the total metabolic cost is calculated based on reported frequency and duration of the activity. The Canadian government has conducted surveillance on PA levels of Canadians for many years. For example, the Canada Fitness Survey (CFS) was conducted in 1981 and 1988, and was followed by the Physical Activity Monitor every 1-2 years starting in 1995. Data from these surveys show a trend towards increasing PA levels throughout the 1980s and 1990s, with 18.8% of adults over the age of 65 accumulating at least 3 MET-hours per day in 1981; in 2000 this figure was 30.7%, a statistically significant difference[54]. Another national survey, the Canadian Community Health Survey (CCHS), has been collecting data since 2001. A 2007 study based on the 2005 CCHS found that 43% of adults over the age of 65 were either active or moderately active[55]. This study also found statistically significant sex differences, where 50.2% of older men were active or moderately active, compared to 37.5% of women[55]. Objectively measured PA data in a national Canadian survey started with the use of the Actical accelerometer in the first cycle of the CHMS, which has been conducted every 2 years starting in 2007. Other methods of direct PA measurement include calorimetry, heart-rate monitoring, and pedometry.

Generally, objectively measured PA data is seen as more reliable than self-reported data. However, self-reported PA measures do have some strengths: they are practical to administer to large groups, cost-efficient, and they place a relatively small burden on and do not interfere with the usual habits of participants. However, self-reported PA data has been demonstrated to be prone to both over and under-estimation. These problems can be attributed to inaccurate recall, misunderstanding of the survey questions, and social desirability bias[56]. With reference to the elderly, problems with memory and cognition can also affect self-reported PA measures. On the other hand, direct measures of PA which assess energy expenditure or body movement are not prone to response and recall biases, and are generally seen as more accurate than self-reported data. However, they are more expensive, intrusive, and time-consuming than self-report. Additionally, there is some evidence to suggest that individuals may alter their behaviour when they know it is being monitored[57]. Accelerometers and pedometers do not accurately capture swimming, cycling, or upper-body activities, and do not account for the extra effort required for walking uphill or carrying a load. Also, the most commonly used accelerometers have been verified for use in the general adult population, and there are no intensity cut-points that are specific to older adults.

As can be expected based on the issues raised above, direct and indirect measures can produce markedly different estimates of PA in study participants. A systematic review of PA measures in older people found that the average correlation coefficient between direct and indirect measures of total PA was 0.38[56]. In another review, surveys using self-reported PA data estimated that 20-30% of older Canadian adults were sufficiently active; however, a survey based on objectively measured PA data found that only 4.5% or 13.1% were, depending on the guidelines used[58]. Aside from the biases and errors noted above, one potential reason for this is that current Canadian PA guidelines require MVPA to be obtained in bouts of ten minutes or more. If an older person walked briskly for 9.5 minutes, this would not be counted towards the PA total for compliance with guidelines. However, accelerometry is the most widely used method for total PA measurement because it does capture moment-to-moment activity. One final issue to note with accelerometry is that although it is objective, there is a subjective component in establishing epoch lengths (the unit of time to be classified as active or not) and intensity cut-points.

2.3.2 Physical activity and self-rated health

Physical inactivity is considered to be a leading risk factor for global mortality and non-communicable diseases[59]. Sufficient, regular PA reduces the risk of premature mortality, coronary heart disease, stroke, diabetes, hypertension, colon cancer, breast cancer, type II diabetes and depression[60-62]. The risk reduction between least active and most active groups for all-cause mortality is estimated to be about 33%[63]. There appears to be a dose-response relationship between PA and improved health outcomes, such that accumulating more PA leads to a higher reduction in risk[62]. Additionally, more intense PA has been found to be more protective of health than lower intensities[62]. However, significant risk reduction has also been shown with modest amounts and intensities of PA[61, 61, 64]. In older adults, PA is also important for preventing loss of muscle strength and maintaining balance, important components of physical functioning[65]. Research has also shown a positive association between PA and successful aging, which encompasses absence of disease and disability, high functional capacity, and active engagement with life[66]. In addition, studies have also shown that regular PA can prolong independent living, reduce disability, and improve quality of life for older people[67-69]. Several biological mechanisms have been proposed for the health-protective effects of PA. Research has shown that routine PA improves body composition, enhances lipid lipoprotein profiles, improves glucose homeostasis and insulin sensitivity, reduces blood pressure, reduces systemic inflammation, decreases blood coagulation, improves coronary blood flow, improves cardiac function, enhances endothelial function, and reduces levels of C-reactive protein[61,68,70].

Studies examining the relationship between SRH and PA have found a correlation between the two variables as well as a positive association between them, meaning that PA is associated with increased odds of reporting good or better SRH[71-73]. This association has been found in different countries with diverse ethnic groups[74-76], and in populations with disease or disability[77,78]. Studies specific to older adults have demonstrated comparable findings[71,79,80]. Similar to the relationship between PA and objective physical health described above, there is evidence of a dose-response relationship, suggesting that both higher amounts and intensities of PA confer stronger odds of reporting good or better SRH[72-74]. However, even LIPA has been shown to be associated with SRH in older adults[71]. One study found that compared to people who reported no LTPA, those in the lowest quintile for this activity domain had an odds ratio for sub-optimal SRH of 0.69, which decreased to 0.49 in the highest quintile of LTPA[73]. A similar result was reported in another study using the International Physical Activity Questionnaire, with an odds ratio for reporting poor SRH of 0.62 for inadequately active versus inactive older participants, and 0.48 for active versus inactive[76]. Modeled the opposite way, a Swedish study found an odds ratio of 1.60 for good SRH among those who accumulated at least six hours of PA per week in all domains, compared to those who accumulated two hours or less[74].

There are a few issues in comparing SRH and PA research. Some studies on this topic have considered specific domains of PA, such as LTPA, as well as total PA, and adherence to PA guidelines.

There may be significant differences between total PA and adherence to guidelines, and I would expect total PA to be more strongly associated with SRH. It should be noted that much of the research in this area has relied on self-reported PA data, which may introduce selection and recall bias. Finally, it should be noted that although PA and SRH are correlated, it is not clear which direction a causal relationship may take. Although some studies have examined PA as a predictor of SRH, at least one has considered SRH as being a predictor of PA[81]. At this time the available evidence does not overwhelmingly support one view or the other.

There are several mechanisms by which PA might affect SRH. Because objective health status seems to be a significant component of SRH, the ways that PA improves physical health are also potential pathways through which it could affect SRH. Thus, mechanisms such as improved cardiovascular function and glucose homeostasis reduce the risk for chronic disease, which is reflected in SRH. However, the correlation between objective health status and SRH weakens with age, and it is known that objective health status is not the only determinant of SRH[46]. Other potential mechanisms for the positive relationship between PA and SRH include quality of life indicators, such as the role of PA in preventing functional decline, preserving cognitive function, and reducing depressive symptoms[83]. Finally, there is some evidence to suggest that PA predicts self-efficacy, which can impact self-ratings of health[82,84].

2.4 Sedentary behaviour

2.4.1 Definition and rates in older Canadians

Sedentary time (ST) refers to time spent expending 1.0 - 1.5 METs while in a sitting or lying position, but does not include time spent sleeping[49]. Sedentary activities include watching TV, reading, playing video games, and using the computer. ST can be accumulated at work (occupational), during motorized transportation, or during leisure time. Screen time is a specific domain of ST that encompasses time spent watching television, on the computer, or on a gaming console[85]. ST has increased substantially over the past few generations, as more occupations involve sedentary work, and as personal computer and cellphone use have exploded. The increase has been so marked that ST has been studied and has emerged as a risk factor for adverse health outcomes.

Measurement of ST can be done through self-reported surveys tools which carry social desirability and recall biases similar to those encountered with self-reported PA[86]. In addition, research has shown that self-reported measures tend to underestimate total ST when compared with measured ST[86]. However, self-reported ST data can provide context and identify specific sedentary behaviours which may have differential effects on health outcomes. For example, ST spent socializing with others could have a positive effect on health[86]. ST can also be measured objectively through the use of accelerometers, which measure acceleration, or inclinometers which measure positional angle and slope[85]. A final issue in research on ST is the need to properly control for time spent in the other movement behaviours, PA and sleep. This will be addressed more thoroughly below.

Currently, there are no Canadian guidelines specific to ST for adults, although recommendations do exist for younger age groups[87]. The U.K. and Australia do have ST guidelines for adults, in which they recommend limiting prolonged ST and breaking up extended periods of sitting as often as possible[88,89]. However, in our modern Westernized society the vast majority of waking time is spent sedentary. Furthermore, based on current evidence, older adults are the most sedentary age group[86]. Results from the 2012-2013 CHMS showed that adults aged 60-79 accumulated an average of 608 minutes (10.1 hours) of ST per day, compared to 576 minutes per day in the 18-39 year-old age group[53].

2.4.2 Sedentary time and self-rated health

Very little research has been done on ST and SRH. The studies that do exist tend to examine ST as the absence of PA, instead of a unique behaviour. Therefore, this brief review will take SRH as an indicator of overall health and quality of life. Sedentary behaviour has been linked to multiple negative health outcomes, including all-cause mortality, as well as incidence of cardiovascular disease, cardiovascular and cancer mortality, and incidence of some types of cancer and type II diabetes[90-93]. One longitudinal study examining mortality found that more sedentary adults ($\geq$10 hours/day) had a 29%

greater risk of future mortality than less sedentary adults (≤6 hours/day)[93]. This same study found no association between ST and mortality for highly active adults; however, other studies have found associations between ST and health outcomes independent of PA level[91,94,95]. There is also some evidence to suggest that patterns of ST accumulation may be important. A recent study found a dose response relationship for the length of sitting bouts related to the hazard of mortality, where participants with the longest sitting bouts had a hazard ratio of 1.96 compared to those who sat for the shortest periods of time[96]. It has been proposed that ST increases the risk of mortality and chronic disease by affecting cardiometabolic risk factors. Studies have found association between prolonged ST and markers such as BMI, waist circumference, HDL cholesterol, triglycerides, insulin, diastolic blood pressure, and 2-hour post-load glucose[97,98]. The specific pathways through which ST may affect health outcomes include its effects on adiposity, sex hormones, metabolic function, and systemic inflammation[99].

Prolonged ST carries specific risks for older adults. Research has shown that this behaviour is linked to geriatric-specific health outcomes, such as limitations in activities of daily living, falls, muscle strength, and quality of life indicators[100]. There is mixed evidence on the effects of ST on cognitive function and mental health. Some studies have shown that ST is associated with better cognitive function, while others report the opposite[100]. In this scenario it is likely that context is important, because cognitively engaging sedentary activities such as reading or doing puzzles may be associated with better cognitive performance[100].

2.5 Sleep

2.5.1 Definition and duration in older Canadians

Sleep is part of the normal circadian rhythm in humans. It is characterized by closed eyes, a recumbent position, and relative perceptual disengagement from and unresponsiveness to the environment[101]. The US National Institute of Mental Health defines sleep and wakefulness in this way: “sleep and wakefulness are endogenous, recurring, behavioral states that reflect coordinated changes in the dynamic functional organization of the brain and that optimize physiology, behavior, and health[102].

There are two main types of sleep: rapid eye movement (REM) sleep, and non-REM sleep. Non-REM sleep can be further divided into four stages, which roughly parallel a depth-of-sleep continuum[101].

Sleep is essential for human health and survival. Studies of sleep deprivation have illustrated that shorter sleep duration causes the activation of immune-related mechanisms in the body, which leads to increases in inflammatory markers[103]. Sleep deprivation also decreases antioxidant defense responses, and is associated with increased activity of the sympathetic nervous system, affecting stress hormone release[103,104]. It also induces changes in the expression of circadian clock-related genes[103]. Finally, sleep deprivation is associated with decreased insulin sensitivity and impaired cognition[105,106].

Measurement of sleep duration in population studies is largely self-reported, although a few studies have used a 24-hour wear time protocol for accelerometry. Results from the CHMS showed that Canadian adults aged 65-79 reported sleeping an average of 7.24 hours per night, compared to 7.12 hours for adults aged 18-74[107]. While this difference seems small, only 54.2% of older adults met sleep duration guidelines, compared to 64.8% of those aged 18-64[107]. Thirty-one percent of older adults slept fewer hours than recommended, and 14.7% reported sleeping longer[107]. In terms of sleep quality, seniors who slept the recommended amount reported more refreshing sleep and less difficulty going to sleep and staying asleep, compared with those who slept fewer hours than recommended. Finally, 30% of seniors reported at least some difficulty staying awake during normal waking hours[107].

2.5.2 Sleep duration and self-rated health

The National Sleep Foundation recommends that adults aged 18-64 accumulate 7-9 hours of sleep per night, and adults aged 65 and older get 7-8 hours[108]. On a population level, sleeping 7-8 hours per night has been shown to be associated with the lowest risk of cardiovascular morbidity[109]. Non-ideal sleep duration is also associated with increased risk of metabolic syndrome, diabetes, hypertension, coronary heart disease, some types of cancer, and impaired neurobehavioural performance[110-112]. Increased risk of adverse outcomes may be associated with both too little and too much sleep.

Studies on sleep duration and SRH have found increased odds of reporting poor SRH with sleep duration both more and less than 7-8 hours, adjusting for a variety of confounders including age and indicators of objective health status[113-116]. Associations are stronger for the more extreme ends of the distribution sleep duration, compared to the reference of 7-8 hours[114]. Studies report odds ratios of 1.36-2.29 for reporting poor SRH with less than 5 hours of sleep, and 1.32-1.98 with more than 9 hours of sleep[114,115]. Both short and long sleep duration may affect SRH by impairing mood and cognitive functioning, or by increasing fatigue[114]. Additionally, it is known that non-ideal sleep duration is linked to physiological changes described above, which increase the risk of chronic disease. Finally, long sleep duration in particular may indicate an undiagnosed medical condition such as heart failure or sleep apnea[114].

2.6 Conceptual models

The overall conceptual model for this thesis is presented in Figure 2.1. This conceptual framework proposes that SRH is both affected by and may affect the distribution of daily time spent in each movement behaviour. Several possible mechanisms for these relationships are described below. For example, sufficient sleep, more PA, and less ST influence objective health status through mechanisms such as reduced insulin resistance and increased aerobic fitness/capacity[61]. In turn, objective health status seems to be an important component of SRH. Another possibility is that sufficient sleep, more PA, and less ST lead to a change in self-perception, and this is reflected in SRH. Conversely, it might be that disability and functional decline is reflected in lower SRH, and this influences the composition of daily movement behaviours by impacting one's ability to engage in PA.

In addition, sociodemographic, behavioural, and psychosocial characteristics act as confounding factors on the pathway between the movement behaviours and SRH. Because SRH is an overall measure of health and well-being it is made up of many components. In terms of indicators of objective health status, it is somewhat controversial if the many components should be considered as confounders, or on the causal pathway between the movement behaviours and SRH. On the one hand, it is entirely plausible that movement behaviours affect objective health status, which in turn is reflected in SRH. However, it is known that SRH is a complex measure that can predict future mortality independent of objective health status. This makes it clear that SRH is not simply a reflection of objective health status, so perhaps movement behaviours acting to influence SRH through objective health status are only part of the overall causal pathway.

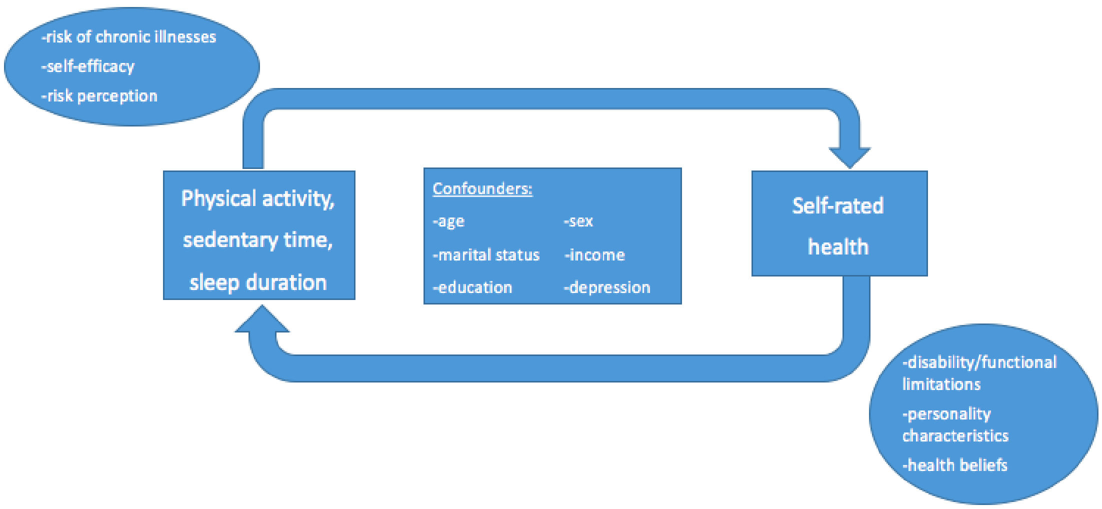

Figure 2.1: Conceptual model of thesis

Most of the research done on SRH and the movement behaviours takes the conceptual view that the movement behaviours influence SRH, not the other way around. Although the cross-sectional nature of these studies means that determining temporality is not possible, this is a plausible explanation for the relationship between sleep, PA, ST, and SRH. Assuming that this conceptual framework is correct, the mechanisms through which the movement behaviours act to impact SRH are presented in Figure 2.2.

2.7 Relationships between the movement behaviours

Research on PA and ST has demonstrated a weak to moderate negative correlation between total PA and ST. This includes both total ST, as well as specific domains such as TV viewing, screen time, and occupational ST[117,118]. The negative correlation was found between ST and all PA, as well as LIPA and MVPA, but was strongest for LIPA and ST. These results suggest that increasing ST displaces LIPA,

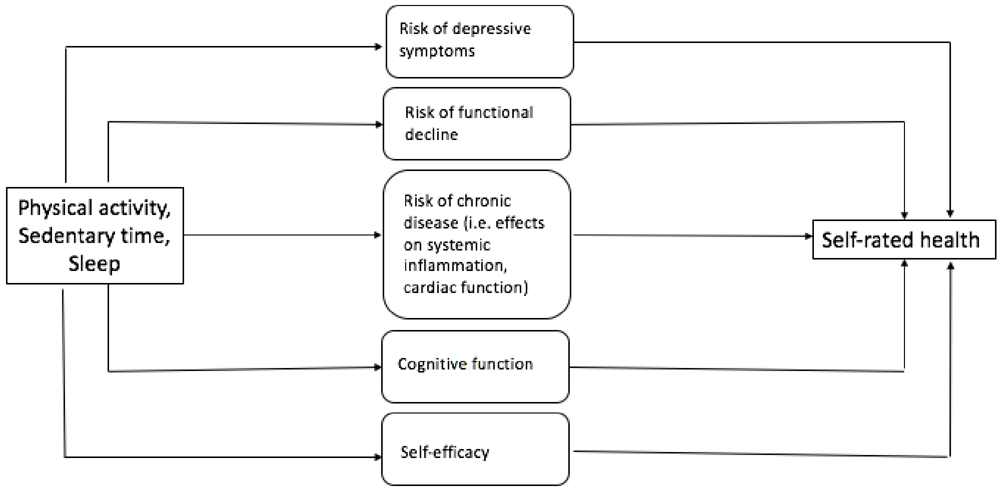

Figure 2.2. Potential mechanisms for the effects of PA, ST, and sleep on SRH

which makes sense, as ST is more likely to displace LIPA than MVPA[117]. In terms of sleep, studies have found a modest correlation between PA and sleep quality and duration, with higher amounts of PA being linked with improved sleep quality[119,120]. The reasons for this are probably physiological and mental – for example, people who exercise more may be more tired at night, and thus sleep more soundly.

The evidence for the effects of ST on sleep is scant. One study calculated a weak negative correlation between ST and sleep efficiency[121], and a review concluded that ST is associated with an increased risk of insomnia and disturbance[122]. It should be noted that the majority of studies examining these relationships have not properly accounted for the codependent nature of this type of data.

2.8 Covariates

Sociodemographic correlates of PA include age, sex, marital status, income, and educational attainment[123]. Income and education attainment are positively related to PA; one study found that participants in the wealthiest quintile were 4.5 times more likely to be adequately physically active, compared to the poorest quintile[124]. Other correlates of PA in adults include perceived barriers, self-efficacy, and motivation[123,125]. Health and health-behaviour factors such as smoking status, chronic disease, functional limitations, obesity, depressive symptoms, and psychological distress are also correlated with PA[124,126]. Finally, aspects of the social and physical environment, such as accessibility of parks and trails, are also correlated with PA levels[123]. A longitudinal study found that in older adults, increasing age, female sex, having ever smoked, chronic illness, arthritis, obesity, and depressive symptoms were associated with a lower likelihood of maintaining PA over the 8 year study[124].

Sociodemographic correlates of sedentary time include age, gender, marital status, employment status, ethnicity, education, and income[118,127,128]. ST increases with increasing age, and women are overall more sedentary than men[118]. Some studies have observed a trend towards higher leisure ST in cohabiting and married couples, while having children is associated with lower ST[127]. Inverse to the associations observed for PA, lower levels of income and education are correlated with higher levels of ST[118]. Health and health-behaviour correlates of ST include obesity, functional limitations, mood, and smoking status[128]. Finally, environmental correlates include proximity of green space, neighbourhood walkability and safety, and weather[127].

Sociodemographic correlates of sleep duration include age, socioeconomic status, and marital status, where non-ideal sleep duration is associated with lower socioeconomic status, unemployment, and being unmarried[129-131]. Total sleep duration tends to decrease with age due to physiological changes in circadian rhythms, homeostatic regulation, and endocrine function[129]. Health and health behaviour correlates include smoking status, obesity, chronic diseases such as diabetes, and depressive symptoms[130]. Also, it is known that certain types of medications can affect sleep quality duration[131]. Overall, research suggests that low sociodemographic characteristics, adverse lifestyle factors, poor psychological conditions, and certain disease morbidities are associated with abnormal sleep duration[129].

2.9 Compositional nature of movement behaviour data

Considered together, sleep, sedentary time, and physical activity are co-dependent behaviours. This is because daily time is constrained into 24 hour periods. Therefore, time spent in one behaviour necessarily displaces time available to engage in the other two. Given that sleep, ST, and PA account for 100% of total daily time, traditional statistical approaches that quantify independent associations may be inappropriate for analyzing all these behaviours simultaneously. For example, including multiple movement behaviours in the same model often leads to collinearity problems in multivariate analyses[132]. Additionally, behaviours that are uncorrelated may not be independent, as the usual correlation coefficient is not an accurate measure of pair-wise relationships in this type of data[133]. In light of these constraints, some researchers have argued that we should conceptualize the movement behaviours as compositional variables having collective associations with an outcome.

Past studies have recognized the co-dependent nature of PA and ST and have attempted to correct for this in different ways. One ingenious study created a summative time use variable for PA, ST, and sleep, and found that increasing the proportion of daily time in favour of PA was associated with better SRH[134]. More recently, isotemporal substitution and compositional analysis have emerged as appropriate techniques for movement behaviour data[133]. In this framework, conclusions about one movement behaviour can be drawn while taking into account time spent in the other behaviours. By assuming that key information is captured in the distribution of relative time spent in the different movement behaviours, one can apply this compositional framework to the analysis of physical activity data. To make results more meaningful and interpretable, numbers can be translated from fractions into units of time per day, without changing the results.

2.10 Thesis rationale

This thesis will study the combined effects of time spent sleeping, sedentary, and physically active on an overall indicator of health and well-being. In examining the relationship between PA, ST, sleep duration, and SRH in the elderly, it is important to note age-related changes in each of these variables. First, levels of PA tend to decline with age[135]. Conversely, ST increases with age[136]. However, elderly adults do spend a significant amount of time engaged in LIPA (193 minutes per day), so it is important to determine how the intensity of PA might influence health in this population[53]. Finally, sleep duration and quality decrease with age, and sleep problems become more prevalent. All three of these factors – declining PA and sleep, and increasing ST - are potentially health-degrading, so it is important to consider their combined effect on health. Few studies have looked at the relationship between these movement behaviours and SRH in older adults specifically, and none have done so using compositional analysis to account for the co-dependency of the movement behaviour data. A compositional framework allows one to determine the optimum distribution of movement behaviours for SRH in older adults. While it seems to correct only for a methodological issue, this type of approach represents an important shift in how we model multiple movement behaviours throughout the day.

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Chapter 3

Physical activity, sedentary time, sleep duration and self-rated health in older adults: A compositional analysis

3.1 Abstract

Objectives: The purpose of this study was to determine the relationship between the movement behaviours that make up a day and self-rated health in adults aged 60-79, while adjusting for time spent in all other behaviours.

Methods: This study was conducted using cycles 1-3 of the Canadian Health Measures Survey. Traditional descriptive statistics were computed for the outcome and covariates, while compositional descriptive statistics were displayed for the movement behaviours. Logistic regression analyses were run to determine the association between each movement behaviour and SRH.

Results: The distribution of time spent in sleep, ST, LIPA, and MVPA is associated with SRH ($p<0.001$). Relative to the other movement behaviours, both sleep duration (OR= 0.17) and MVPA (OR=0.81) were associated with better SRH. ST was associated with poorer SRH (OR=12.4). No statistically significant association was found for LIPA.

Discussion:

SRH in older adults was positively associated with sleep duration and MVPA, and negatively associated with ST. Future research on physical activity should consider the effects of each movement behaviour on health outcomes, while taking into account the other behaviours.

3.2 Introduction

Physical activity (PA) as it relates to health outcomes has been studied extensively. It is known that regular PA is protective against many chronic diseases, including cardiovascular disease (CVD), certain types of cancer, type II diabetes, and even mental health conditions such as depression[1-5]. It is also known that increasing the duration and intensity of PA confers greater health benefits, in a dose-response fashion[6,3]. Canadian guidelines currently recommend a minimum of 150 minutes of moderate-to-vigorous physical activity (MVPA) per week for good health[7]. However, objectively measured PA data from the Canadian Health Measures Survey showed that only ~15% of Canadian adults aged 18-79 meet these recommendations[8]. Women aged 60-79 accumulated an average of 12 minutes per day of MVPA, while men in the same age group accumulated 17 minutes per day[9].

There is much data to support the finding that adults in Western countries spend the majority of their day engaged in sedentary behaviours. Canadians aged 60-79 averaged 602 minutes per day of sedentary time (ST) in 2015[9]. Prolonged ST is associated with increased risk of CVD, type II diabetes, early mortality, and other health conditions[10-12]. However, this risk may be modified depending on the pattern of accumulation of ST. For example, extended periods of unbroken ST may confer increased risk[13]. This is reflected in Canada's Physical Activity Guidelines, which recommend breaking up extended periods of sitting[7].

Sleep is the other behaviour in the daily composition of time. Sleep is part of the normal circadian rhythm in humans. It is characterized by closed eyes, a recumbent position, and relative perceptual disengagement from and unresponsiveness to the environment[14]. Sleep is essential for human health and survival. The National Sleep Foundation recommends that adults aged 18-64 accumulate 7-9 hours of sleep per night, and adults aged 65 and older get 7-8 hours[15]. On a population level, sleeping 7-8 hours per night has been shown to be associated with the lowest risk of cardiovascular morbidity[16]. Non-ideal sleep duration is also associated with increased risk of metabolic syndrome, diabetes, hypertension, coronary heart disease, some types of cancer, and impaired neurobehavioural performance[17-19]. Increased risk of adverse outcomes may be associated with both too little and too much sleep[18,19].

Each 24-hour period can be divided into sleep duration, ST, and PA. The constrained nature of daily time means that PA, ST, and sleep duration are not entirely independent of each other. This implies that these movement behaviours are co-dependent, which presents several problems in traditional statistics: first, it presents collinearity problems in multivariate regression, and second, it creates inconsistencies with correlation coefficients in measuring the association between two behaviours. Therefore, a statistical approach that takes into account the compositional nature of the data is essential. In order to overcome the methodological issues described above, Chastin[20] has proposed applying a compositional framework to movement behaviour data. In terms of descriptive statistics, this approach allows for more accurate measures of central tendency, as well as meaningful measures of co-dependence between the movement behaviours. By isometrically log-transforming the movement behaviour data, traditional regression analyses can be run, which allow estimation of the relationship between the overall composition and outcome, each component of the composition and the outcome, and the effect of changing the composition on the outcome.

The outcome studied in this investigation is self-rated health (SRH), which is often used as an indicator of overall health and well-being. It is a subjective measure of health that is thought to reflect an individual's integrated perception of the domains of health, including biological, psychological, and social dimensions[21]. SRH has been used as a health indicator in epidemiological studies since the 1950s, and has been found to predict future health outcomes such as mortality, morbidity, and future healthcare use, independent of physical health, socio-demographic, and psychosocial indicators[22-25]. It is widely considered to be a valid indicator of health status.

The purpose of this study was to investigate the combined effect of time spent engaged in PA, ST, and sleep on a general indicator of health in adults aged 60-79. Specifically, the association between the daily composition of movement behaviours and SRH was examined, as well as the individual effect of each movement behaviour on SRH. These measures allowed us to obtain effect estimates for each behaviour on SRH, fully adjusted for time spent in the other behaviours.

3.3 Methods

3.3.1 Data source

This study uses data collected in the Canadian Health Measures Survey (CHMS), a nationally representative cross-sectional survey of Canadians aged 3-79 living in private dwellings[26]. Data collection for cycles 1-3 was carried out from March 2007 - December 2013. The CHMS is representative of approximately 96% of the Canadian population, but excludes institutionalized persons, prisoners, full-time members of the Canadian Armed Forces, residents of Aboriginal reserves, and residents of some remote and northern regions. Households are selected to participate in the survey through a complex, multi-stage cluster sampling strategy[26]. Data collection for the CHMS consists of two components. First, a trained interviewer conducts a household interview to gather sociodemographic and lifestyle information for one or two people in the household, then those respondents are asked to attend a mobile examination centre (MEC) where trained personnel take physical measures of health. In Cycle 1, 69.3% of contacted households agreed to provide their household composition. Of those, 88.3% of selected individuals agreed to respond to the household questionnaire, and of those, 84.9% attended the Mobile Health Clinic for the second part of the survey[27]. Similar response rates were achieved in Cycles 2 and 3.

The current study is restricted to those survey participants aged 60-79 at the time of sampling (some participants turned 80 years old during their participation in the study). It is based on 2335 adult participants with valid accelerometer and SRH data. Exclusions included 909 age-eligible participants because they lacked sufficient accelerometer, sleep, SRH, or covariate data. The CHMS is a voluntary survey, and all participants gave written informed consent. Ethics approval for the CHMS was obtained from Health Canada's Research Ethics Board. Additional clearance specific to the analyses in this thesis was obtained from the Queen's University Health Sciences Research Ethics Board. Data were accessed through the Statistics Canada Research Data Centre at Queen's University, Kingston, Ontario.

3.3.2 Measurement of physical activity, sedentary time, and sleep duration

Following the MEC visit, participants were given an Actical accelerometer on an elasticized band to wear on their right hip during all waking hours for one week. The accelerometer was initialized to start collecting data at midnight following the clinic visit, and the devices were returned to Statistics Canada in a prepaid envelope. The accelerometer measures acceleration in all directions, and this data is stored as counts per minute (cpm). Statistics Canada staff use standard cut-points to categorize each minute of wear-time as sedentary or physically active. Sedentary time (ST) was classified as any minute where the cpm is less than 100. Light intensity physical activity (LIPA) was defined with a cpm of 100-1592, and MVPA was defined as any minute that had a cpm greater than 1592. Non-wear time was defined as 60 consecutive minutes of 0 cpm, with an allowance of 1 - 2 minutes of less than 100 cpm. In accordance with past work on the CHMS, a valid day required at least 10 hours of wear-time, and the analysis that follows required participants to have at least four valid days of accelerometer data.

Sleep duration was assessed by a single self-reported question in which participants were asked: "How many hours do you usually sleep on a weeknight?" This number was recorded to the nearest half-hour. Because participants did not wear an accelerometer for 24 hours per day and instead self-reported sleep duration, the sum of the data for all movement behaviours did not add to exactly 1440 minutes, or 24 hours. In order to deal with this issue, the movement variables were normalized to allocate missing time to each movement behaviour in the same proportions that were recorded by the accelerometer. The same procedure was applied to participants with data greater than 1440 minutes, where the extra time was deleted in the proportions spent in each measured movement behaviour (except sleep). Self-reported sleep duration was assumed to be accurate and was not normalized. After this procedure, the number of minutes per day spent in all movement behaviours summed to 1440. These data were then transformed into proportions of daily time. Due to a lack of methods to deal with zeroes in log-based compositional analysis, respondents with any proportion equal to 0 were excluded.

The movement behaviour variables were further modified via an isometric log-ratio transformation for use in logistic regression in order to fully adjust the models for time spent in the other behaviours. Because there are four variables (sleep duration, ST, LIPA, MVPA), each movement behaviour was transformed into three variables that represent rotations in the orthonormal plane in a composition of four parts. For example, three isometrically log-transformed variables were derived from sleep duration, where each variable represents the proportion of sleep relative to the other movement behaviours. To compute the three variables, three, two, and then one of the remaining movement behaviours were included in the isometric log-ratio transformation.

3.3.3 Measurement of self-rated health

Self-rated health (SRH) was assessed by a single question asking respondents to rate their health on a scale from 1-5 (excellent to poor). The question read: "In general, how would you rate your own health?" SRH is considered to be an ordinal variable, where the difference between poor and fair may not be the same as that between fair and good. Because this is a categorical variable, SRH was dichotomized into poor and fair health, versus good, very good, and excellent SRH. Past research has dichotomized SRH as above, or as poor/fair/good versus very good/excellent. For this study, the dichotomization was chosen where approximately 13% of the sample had the outcome of poor or fair SRH.

3.3.4 Confounders

Factors that are associated with any of the movement behaviours and SRH were identified from the literature and considered as covariates. Age (continuous)[28, 29], sex (male or female)[28, 30], ethnicity (white or non-white)[31], marital status (married/common-law, separated/divorced, widowed, and single, never married)[32], job status (worked at a job in the past 12 months yes/no)[33], and educational attainment (less than high school, high school graduate, post-secondary graduate)[28, 29, 33] were included as sociodemographic factors. Household income was also considered[28, 33], but it should be noted that only 77% of participants provided a number for total household income. Therefore, using data from a previous series of income questions, Statistics Canada imputed values for total household income. The imputation process has been demonstrated to be more accurate for income categories instead of raw numbers, so income quintiles were used. Rural versus urban residence was also considered[29]. This was accomplished using the 2013 Postal Code Conversion File+, which is based on 2011 Canadian census geography[34]. This file was used to classify postal codes as urban or rural, based on population size and density.

A measure of objective health status was used to characterize the objective health status of the sample. Participants were asked a series of questions regarding the presence or absence of "physician-diagnosed" chronic illnesses. These questions were used to derive a variable indicating the presence or absence of major chronic diseases (yes/no). The qualifying chronic conditions included heart disease, cancer, diabetes, emphysema, chronic obstructive pulmonary disease, chronic bronchitis, high blood pressure, and stroke[35]. Finally, smoking status was derived based on a number of questions about current and past habits, and was categorized into current smoker (daily or occasional), former smoker (daily or occasional), and non-smoker (less than 100 cigarettes in lifetime)[29]. Confounders included in the final models were age, sex, income, educational attainment, and smoking status.

3.4 Statistical analysis

Out of 3244 adults aged 60-79 in the original sample, 2335 were eligible for analysis: 680 participants were excluded because they did not have at least 4 days of valid accelerometer data, and a further 165 were excluded because their average daily proportion of MVPA was exactly 0. True zeroes cause problems in compositional analysis that is based on log ratios, because a compositional component equal to zero has an undefined logarithm[36]. Another 64 participants were excluded because they lacked data on important covariates such as educational attainment.

All tests in the analysis were run using Statistics Canada's activity monitor sub-sample weights for combined cycles 1-3 of the CHMS. Variance estimates were obtained using the bootstrap method with the bootstrap weights provided by Statistics Canada. Basic descriptive statistics were computed to characterize the sample. Descriptive statistics for the movement behaviour variables take into account the compositional nature of this data. Compositional geometric means for the proportion of daily time spent in each behaviour were computed, then transformed back into minutes per day for easier interpretation. Arithmetic means for sleep duration, ST, LIPA, and MVPA were also computed for comparison.

Chi-square analyses were carried out to test for bivariate relationships between covariates and SRH. Due to the co-dependent nature of the compositional movement behaviour data, coefficients of correlation are not appropriate nor accurate reflections of pairwise relationships for these variables. Instead, a variation matrix that depicts all possible pair-wise log-ratio variances was calculated. Values close to 0 indicate that the two behaviours are highly proportional, and vary together. Higher values reflect low proportionality. Traditional correlation analysis to test for a relationship between the composition of movement behaviours and covariates/the outcome is not easily interpretable or meaningful, so graphical representations of differences in movement behaviour proportions by group were created instead. These figures, called 'relative behaviour profiles,' reflect the relative differences in geometric means for each behaviour by sub-group. They are obtained by taking the log-ratio of the compositional geometric mean of a behaviour for a sub-group divided by the compositional geometric mean for the whole sample. The figures show the relative differences between compositions by groups. Positive bars represent a higher group mean relative to the overall compositional mean for that component, and negative bars represent a lower group mean compared to the overall compositional mean.

Finally, binary logit models were created to characterize the relationship between SRH and the daily composition of movement behaviours, as well as each individual movement behaviour. The bootstrap method was used to calculate variances around effect estimates. The isometric log-ratio transformed movement behaviour variables were used as the main exposure in these analyses. Covariates were included *a priori* based on past findings from the literature. Separate models for the relationship between each movement behaviour and SRH were created. In each model, the three isometrically log-ratio transformed variables derived from each movement behaviour were included. The chi-square p-value for the likelihood ratio test was interpreted to determine whether the composition of movement behaviours as a whole was associated with SRH. Then, the odds ratio for only the first isometrically-transformed movement behaviour variable in each model was interpreted. An odds ratio greater than 1 indicated that that specific movement behaviour was positively related to SRH, while an odds ratio less than 1 meant that that movement behaviour was negatively related to SRH. P-values for the OR estimate were used to determine whether the association was statistically significant.

3.5 Results

Descriptive characteristics are presented in Table 1. The mean age was 66.9 years, 51.1% were female, 48.9% were male, and 54.5% had completed a post-secondary diploma or degree. About half rated their own health as 'very good' or 'excellent', while 13% rated it as 'poor' or 'fair.' Just over 45% had a diagnosis of a major chronic disease.

Descriptive statistics for the compositional movement behaviours are presented in Table 2. After transforming the data into proportions of daily time, the compositional geometric means for time spent sleeping, in sedentary behaviour, LIPA, and MVPA were 0.3476, 0.4914, 0.1555, and 0.00542 respectively. Translating the proportions back into minutes per day gives 500.5 minutes spent sleeping, 707.6 sedentary, 223.9 engaged in LIPA, and 7.8 minutes engaged in MVPA.

A variation matrix showing the codependence between movement behaviours is presented in Table 3.3. The value of the log-ratio is used to determine co-dependency. Lower values indicate higher co-dependency, meaning that these behaviours tend to vary together. Sleep duration and ST are the most co-dependent behaviours, while MVPA is the least proportional to any other behaviour. SB and LIPA and sleep duration and LIPA are moderately co-dependent.

Chi-square analysis indicated that educational attainment, the presence or absence of major chronic conditions, and income were related to SRH (all $p<0.0001$), while smoking status was borderline ($p=0.067$). Respondents with less than a high school education rated their health more poorly (23% poor/fair SRH, 36% very good/excellent SRH), while post-secondary graduates rated their health highly (10% poor/fair SRH, 53% very good/excellent SRH). Respondents who reported the presence of a major chronic illness also rated their health more poorly (19% poor/fair SRH, 36% very good/excellent SRH), while those without a chronic condition rated their own health more highly (7% poor/fair SRH, 64% very good/excellent SRH). For income, there was a trend – as income increased, the proportion of respondents rating their health as very good/excellent increased, and the proportion of those who rated their health as fair/poor decreased (lowest income quintile: 25% poor/fair SRH, 36% very good/excellent SRH; highest income quintile: 9% poor/fair SRH, 59% very good/excellent SRH).

Table 3.1 – Participant characteristics

Variable	**Mean/percentage (n=2335)**	**Males**	**Females**
Age (years)	66.9	66.8	66.9
Sex (%)		48.9	51.1
Ethnicity (%)			
White	85.8	86.5	84.9
Non-white	14.2	13.4	15.1
Marital status			
Married/common-law	71.3	81.5	61.4
Separated/divorced	12	10.1	13.7
Widowed	11.6	4.1	18.8
Single, never married	5.2	4.2	6.1
Education (%)			
Less than high school	23.6	24.6	22.7
High school graduate	21.8	19.2	24.4
Post-secondary graduate	54.5	56.2	53
Worked at job during past year (%)	37.7	44.0	31.7
Has a major chronic condition (%)	53.2	54.1	52.4
Smoking status (%)			
Current daily or occasional smoker	13.4	15.2	11.7
Former daily or occasional smoker	43.3	52	35
Non-smoker	43.3	32.9	53.3
Income, net $CDN per year (%)			
$0-19,999	8.7	6.7	10.5
$20-39,999	25.4	24.2	26.6
$40-59,999	23.4	23.7	23
$60-79,999	14.8	14.8	14.8
$80,000 +	27.8	30.6	25.1
Residency (%)			
Urban	76.6	75.3	77.9
Rural	23.4	24.7	22.1
Self-reported health status (%)			

Poor/fair	13.3	14.7	12
Good	37.8	38.14	37.5
Very good/excellent	48.9	47.2	50.6

Table 3.2 Mean minutes per day spent in each movement behaviour

	Sleep	**ST**	**LIPA**	**MVPA**
Geometric mean (minutes/day)	500.5	707.6	223.9	7.8
Arithmetic mean (minutes/day ± SD)	429	600	200.9	14.9

Table 3.3 – Variation matrix for movement behaviours

	Sleep	**ST**	**LIPA**	**MVPA**
Sleep	0	2.26 E-6	0.0002286	0.00365
ST	2.26 E-6	0	0.000356	0.00332
LIPA	0.0002286	0.000356	0	0.00354
MVPA	0.00365	0.00332	0.00354	0

Relative behaviour profiles showing the relative differences in geometric means for each behaviour by sub-group are shown in Figures 3.1-3.4. It can be seen in Figure 3.1 that younger participants spent a higher proportion of time engaged in LIPA and MVPA, and a lower proportion of time sleeping and sedentary as compared to the entire sample. Figure 3.2 shows that as educational attainment increases, the proportion of time spent engaged in MVPA increases. Figure 3.3 shows that individuals with a diagnosed chronic disease spent a lower proportion of time engaged in LIPA and MVPA, and a slightly higher proportion of time sleeping, as compared to the entire sample. The opposite is observed for healthy individuals. For self-rated health, Figure 3.4 shows the observed trend to be that as

SRH improves from ‘poor’ to ‘excellent,’ the relative proportion of ST decreases, while time spent sleeping and engaged in LIPA and MVPA increases.

Figure 3.1a Relative behaviour profile: Age groups

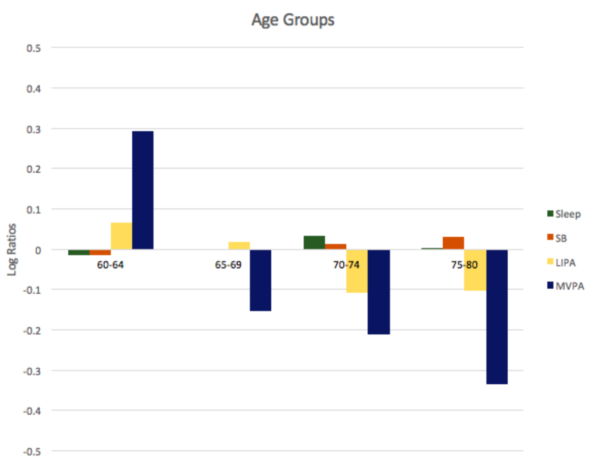


Figure 3.1b Relative behaviour profile: education

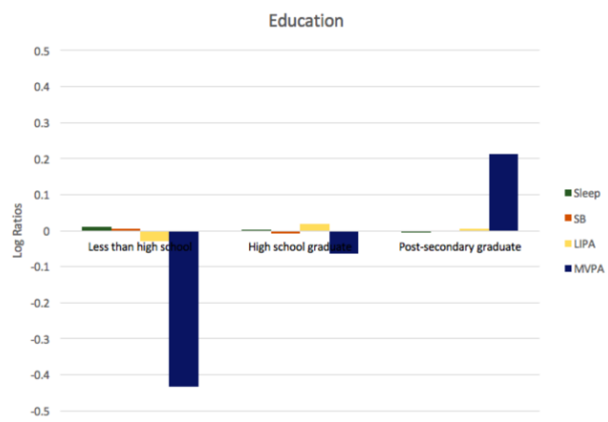


Figure 3.1c Relative behaviour profile: Chronic disease

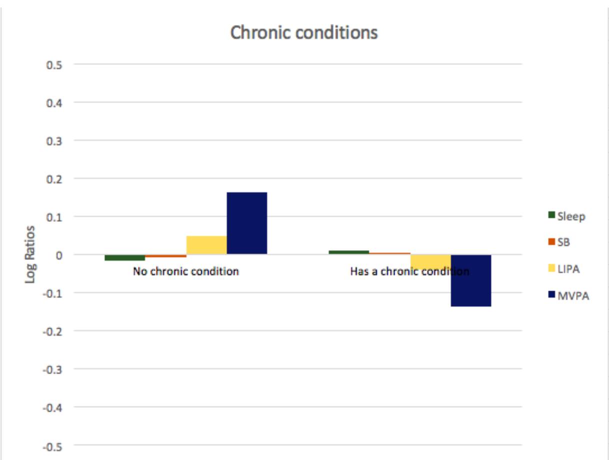
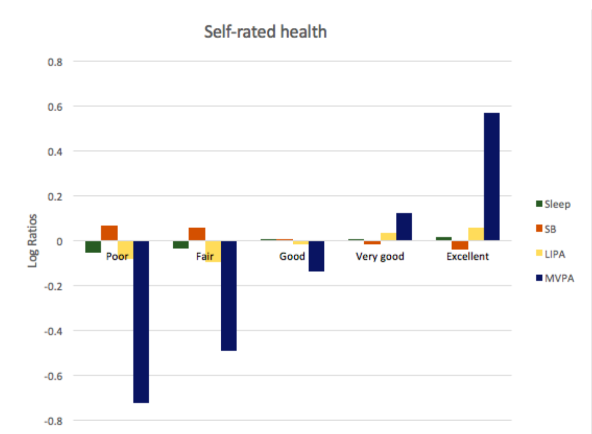


Figure 3.1d Relative behaviour profile: SRH



Logistic regression models were adjusted for educational attainment, income, smoking status, and chronic illnesses, as these covariates were associated with SRH in bivariate analysis. Age and sex were forced into the models. Interaction by sex was tested, but was not statistically significant. Regression results indicated that the entire composition of a day is related to SRH. The p-value was <0.05 for all the likelihood ratio tests for each movement behaviour model. Although odds ratios were computed, they are not easily interpretable in this analytical framework. However, a simple interpretation is: time spent sleeping relative to the other behaviours was positively associated with SRH. Time engaged in MVPA relative to other behaviours was also positively associated with SRH. ST relative to the other movement behaviours was negatively associated with the SRH outcome. LIPA was not associated with SRH in this analysis. These results are presented in Table 3.4.

Table 3.4 – Compositional behaviour model for SRH

	Odds ratios (of having poor SRH)			
	Log-likelihood p-value	**Crude**	**Full model**	**Maximum likelihood p-value**
Sleep duration	<0.0001	0.162	0.171	0.0005
ST	<0.0001	12.2	12.4	<0.0001
LIPA	<0.0001	0.715	0.638	0.0796
MVPA	<0.0001	0.780	0.804	0.0088

*full models adjusted for age, sex, education, income, smoking status

3.6 Discussion

This is one of the first studies to look at physical activity and SRH in older adults while taking into account the co-dependency of the movement behaviours[37], and to our knowledge is the first to do so using a compositional framework. This means that the effect estimates are fully adjusted for time spent in all other movement behaviours. Our analyses showed that the overall distribution of daily time was found to be related to SRH. In addition, statistically significant associations were found between sleep duration and MVPA and better SRH, while a negative association was found between ST and SRH. LIPA was not associated with SRH in this analysis.

Previous studies have also reported a positive relationship between MVPA and SRH, and a negative relationship between ST and SRH[29,38-40]. Past studies have also reported a negative association between non-ideal sleep duration and SRH[41,42]. Although LIPA was not associated with SRH in this study, several past studies have found a positive relationship between LIPA and better SRH[31]. Although this study found a negative relationship between LIPA and poor SRH, it was not statistically significant. It is thought that the movement behaviours influence SRH by affecting risk factors for physical, mental, and cognitive health and functioning. For example, engaging in regular PA can reduce the risk of depression, which is reflected in one's SRH. However, previous studies have failed to properly adjust for the co-dependence of the movement behaviours. A major strength of this study is the use of a compositional framework for the analysis, which properly accounts for this co-dependence[20]. Additionally, the use of accelerometers to capture movement behaviour data lends strength to this study, in that it avoids the pitfalls of self-reported physical activity data. Finally, the large sample size and nationally representative data set provided sufficient power to detect meaningful associations.

The use of SRH as an outcome has both strengths and limitations. First, SRH appears to capture something that objective health status does not, as is indicated by its independent relationship with a variety of morbidity and mortality outcomes[22-25]. Also, there is some evidence to suggest that people have trouble self-reporting physician-diagnosed conditions, and SRH avoids this problem[43] because it is not limited by individual knowledge of one's objective health status. A limitation of using SRH is that it is correlated with and affected by covariates that the present study did not measure. For example, self-efficacy is an important correlate of SRH and PA, and could confound the relationship between these two variables[44,45].

Analysis of model fit using the receiver operating curve showed moderate fit (c=0.70). This raises the possibility of residual confounding, as contextual factors such as social capital were not included. Additionally, several potentially influential observations were identified, but were ultimately included because they had large weightings and were meant to represent large segments of the population. A major limitation of this study is the nature of the cross-sectional data. This means that we cannot determine causality – does PA cause people to rate their health more highly, or are people with better SRH more likely to engage in the health-promoting movement behaviours? Other limitations include the fact that sleep duration was self-reported instead of objectively measured. This meant that a normalizing procedure involving assumptions had to be applied to the movement behaviour data. In the future, 24-hour accelerometer wear-time protocols might be useful to address this issue. Another limitation is that the Actical accelerometer cut-points were validated in younger and middle-aged adults, and might not be appropriate for seniors. This could have resulted in the misclassification of some physical activity data, such that LIPA and MVPA were underestimated. This would have biased the results towards the null. In addition, accelerometers are best at measuring ambulatory activity, and thus might underestimate total activity. However, walking is the most commonly reported exercise activity reported by older Canadians, so this likely was not a significant issue in this study[46]. This study does not take into account patterns of physical activity and sedentary time accumulation, which may moderate the effects of the totals on health[13, 47].

In excluding a number of survey participants with insufficient accelerometer wear time, a bias may have been created. Excluded participants were older, sicker (had higher prevalence of chronic conditions), heavier (higher BMI), more likely to be current smokers, and had a poorer distribution of SRH. Analysis of the sparse accelerometer data (using only valid days with >10 hours of wear time) showed that the excluded participants also had a lower compositional geometric mean for MVPA, and a higher compositional geometric mean for ST than included participants. Thus, a potential selection bias might have been created by the necessary exclusion of participants without sufficient accelerometer wear-time. However, Statistics Canada treats those participants with less than 4 valid days of accelerometer data as non-respondents to the physical activity monitor section of the CHMS, and adjusts the sampling weights of respondents accordingly to compensate for any bias[26].

This study was based on a sample of ambulatory, community-dwelling adults aged 60-79. Age-related changes in SRH, especially the weakening of the correlation between objective health status and SRH, should encourage caution in generalizing these results to other age groups[48]. Additionally, these results might not be generalizable to hospitalized or institutionalized patients.

3.7 Conclusion

In conclusion, this study assessed the relationship between sleep duration, ST, LIPA, MVPA and SRH. The overall distribution of daily time was found to be related to SRH. In addition, statistically significant associations were found between sleep duration and MVPA and better SRH, while a negative association was found between ST and SRH. An association between LIPA and SRH was not found. These relationships are fully adjusted for time spent in the other behaviours.

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Chapter 4

Discussion

4.1 Summary

Objectives of this study were to determine if there was an association between the proportion of daily time spent engaged in sleep, ST, LIPA, and MVPA and SRH, as well as the specific effect of each movement behaviour on the outcome. These objectives were achieved using data from the Canadian Health Measures Survey, with a nationally representative sample of Canadian adults aged 60-79. Sleep duration and SRH were self-reported, and ST, LIPA, and MVPA were objectively measured using accelerometry. The objectively measured movement behaviours were normalized so that sleep duration, ST, LIPA, and MVPA summed to exactly 1440 minutes. The movement behaviour variables were further modified via an isometric log-ratio transformation for use in logistic regression in order to fully adjust the models for time spent in the other behaviours. Binary logit models were used to assess the relationships of interest. Results showed that the overall composition of movement behaviours was associated with SRH; additionally, sleep duration and MVPA were positively associated with this outcome, while ST was negatively associated with SRH. No statistically significant association was found for LIPA.

4.2 Strengths

This study was conducted on a large, nationally representative sample of Canadian adults. This limits the potential for selection bias, and allows generalizability of the results to ambulatory, community-dwelling older adults. Further strengths include the use of accelerometer data for movement behaviours, which gives an objective measure of PA and ST. This eliminates the risk of response and recall bias in regards to these behaviours, which may cause people to both over and under-estimate PA and/or ST[1]. In addition, the correlation between self-reported and objectively measured PA data is moderate, and it is generally accepted that objective measures are more accurate[2]. The use of accelerometer data also produces a to-the-minute assessment of the time spent in light and moderate-to-vigorous activity. This allows for an examination of the effect of different intensities of PA on the outcome.

The use of SRH in this study has both strengths and limitations. First, as a self-reported measure, SRH is not prone to misclassification. Additionally, SRH appears to be a more inclusive measure of health status than we can directly measure, as is indicated by its independent relationship with a variety of morbidity and mortality outcomes[3-6]. Also, SRH is a good general indicator of overall health. It seems to reflect one's quality of life, along with physical, mental, and cognitive well-being and functioning[7]. Finally, there is some evidence to suggest that people have trouble self-reporting physician-diagnosed conditions, and SRH avoids this problem[8] because it is not limited by formal knowledge of one's objective health status.

The major strength of this thesis is its novel approach to PA research. A compositional analysis analyzes the relative distribution of time between behaviours, which takes into account the co-dependent nature of the movement behaviour data[9]. This is one approach to dealing with the constrained nature of this type of data. The compositional analysis produces accurate means for the movement behaviours, as well as valid measures of co-dependency between them[10]. Finally, using the compositional framework for regression analysis means that all effects estimates are fully adjusted for time spent in all the other movement behaviours[10].

4.3 Limitations

4.3.1 Internal validity

Internal validity refers to the extent to which inferences based on the study sample are accurate[11]. Essentially, it asks if the results are a reflection of the truth in the study sample. Internal validity is assessed by examining the role of chance, bias, and confounding in explaining study results. Threats to internal validity include systematic errors which are not due to chance alone, such as information and selection biases. Residual confounding is the other major threat to internal validity.

There is always a possibility that study results have been obtained due to chance, and that they do not reflect a real association. Type I errors result when the null hypothesis is true, but is rejected[11]. The type I error rate or significance level (alpha) is the probability of rejecting the null hypothesis given that it is true[11]. The threshold for statistical significance is usually set at alpha=0.05, which means that, given that the null hypothesis is true, there is a 5% chance that the results are due to chance. In the present study, the significance for the association between the overall daily composition of movement behaviours and SRH was <0.0001, meaning that there is less than a 0.1% chance that this result was due to chance if there was actually no relationship. The same interpretation applies to the association between sleep duration, ST, and MVPA and SRH. With a significance of 0.08, however, the association between LIPA and SRH was interpreted to be not statistically significant. It should be noted that multiple testing of a hypothesis has the potential to inflate the type I error, however that is not likely to be an issue in the current study.

Bias is another threat to internal validity. Selection bias occurs when there are systematic differences between included and excluded participants, such that the study sample is not representative of the population under study[11]. Another type of bias is non-response bias, which results when study respondents differ from non-respondents in meaningful ways[11]. In the current study, a significant number of survey respondents were considered non-respondents and excluded due to lack of valid days of PA data from insufficient accelerometer wear-time. These participants were older, sicker (had higher prevalence of chronic conditions), heavier (higher BMI), more likely to be current smokers, and had a poorer distribution of SRH than included participants. Analysis of the sparse accelerometer data (using only valid days with >10 hours of wear time) showed that the excluded/non-responding participants also had a lower compositional geometric mean for MVPA, and a higher compositional geometric mean for ST. This suggests that a bias might have been created by the necessary exclusion of participants lacking sufficient accelerometer data. However, Statistics Canada treats those participants with less than 4 valid days of accelerometer data as non-respondents to the physical activity monitor section of the CHMS, and adjusts the sampling weights of respondents accordingly to compensate for any bias[12]. The other opportunity for non-response bias comes from the participation rate in the CHMS. In Cycle 1, 69.3% of contacted households agreed to provide their household composition. Of those, 88.3% of selected individuals agreed to respond to the household questionnaire, and of those, 84.9% attended the Mobile Health Clinic for the second part of the survey[13]. Similar response rates were achieved in Cycles 2 and 3. Although this response rate is comparable to other large surveys, it does introduce the potential for non-response bias. However, it is only considered a bias if the relationship under study is in some way different in the non-respondents versus the respondents. There is no evidence to suggest that this is the case in the current study.

Sensitivity analysis is "a method to determine the robustness of an assessment by examining the extent to which results are affected by changes in methods, models, values of unmeasured variables, or assumptions"[11]. It is used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. This technique can be used to assess the impact of missing data on study results, as well as estimate the impact of unmeasured confounding. Unfortunately, a sensitivity analysis was not possible in the current study due to the compositional nature of the movement behaviour variables.

Information error is random error in the measurement of a study variable. Information bias occurs when this error is systematic in nature[11]. There are several opportunities for information bias to be introduced in this study. The fact that sleep duration was self-reported introduces the potential for measurement error for this variable. Some studies have found that adults systematically over-estimate their sleep duration, and so this error could be considered information bias[14]. Newer studies are moving towards 24-hour accelerometer protocols, where participants do not take the accelerometer off to sleep. This protocol may be tested in the next cycle of the CHMS. Another issue with accelerometers is that they tend to underestimate total activity, as they do not capture swimming, cycling, or upper-body activities, and do not account for the extra effort required for walking uphill or carrying a load[15]. However, walking is the most commonly reported exercise activity reported by older Canadians, so this likely was not a significant issue in this study[16].

Another instance of potential information bias in this study has to do with the classification of PA intensity. Compared to the Actigraph, another accelerometer used in PA research, limited research using small sample sizes has been done validating the Actical accelerometer in relation to cut points for physical activity intensity[17]. Furthermore, due to changes in body composition and basal metabolic rate, established cut-points may not be appropriate for use in older adults. One past study completed a laboratory-based calibration of the Actical accelerometer with adults aged 45 and up, and came up with a cut-point of 1065 cpm to distinguish between light and moderate intensity PA[18]. In the current study, the corresponding cut-point used was 1592 cpm. If existing cut-points are too high for older adults, misclassification of LIPA and MVPA may have occurred. If the movement behaviours predict SRH, this information bias would have the effect of attenuating the results towards the null.

The covariates considered in this study were all self-reported. Behaviours that affect health, such as smoking, may be prone to information bias through social desirability bias. Social desirability bias is a type of response bias that causes respondents to answer questions in a way that will be viewed favourably by others[11]. For example, study participants may under-report the frequency of smoking and drinking behaviours, and over-report their consumption of fruits or vegetables. In this study, smoking status may have been affected by social desirability bias. It should also be noted that household income was imputed, as only 70% of respondents provided their annual income[13]. Thus Statistics Canada staff used answers from a series of income questions to impute a household income value. This imputation process is more accurate for percentiles than for raw numbers[18], so income quintiles were used in the current analysis.

A final important threat to internal validity is residual confounding. This occurs when a confounder has not been adequately adjusted for in the analysis[11]. A limitation in using SRH as the outcome in this study is that it is correlated with and affected by covariates that the present study did not measure. For example, social capital and self-efficacy are important correlates of SRH and PA, and could confound the relationship between these two variables[19]. Residual confounding can lead to either over- or under-estimation of study results.

4.3.2 External validity

External validity is the extent to which the results of a study can be generalized to other populations[11]. This study was based on a nationally representative sample of older Canadian adults, which was derived by Statistics Canada using a complex, multi-stage cluster sampling scheme[12]. The overall response rate for each CHMS cycle is about 55%, leaving open the potential for non-response bias[13]. Additionally, the CHMS is not designed to be representative of certain populations, including full-time members of the Canadian Forces, prisoners, residents of Aboriginal reserves, and residents of some remote and northern regions. Also, participants in the CHMS were ambulatory and community-dwelling, so the results of this thesis might not be generalizable to severely disabled, hospitalized, or institutionalized patients. Finally, age-related changes in SRH, especially the weakening of the correlation between objective health status and SRH, should encourage caution in generalizing these results to other age groups[20].

4.4 Causality

The question of causality, does *x* cause *y*, is often assessed with Bradford-Hill's criteria. These criteria include strength of association, consistency, specificity, temporality, dose-response, plausibility, coherence, experiment and analogy [11]. These criteria are usually applied to a body of evidence, as causation cannot be determined with a single study. However, for the sake of discussion those criteria applicable to this study will be discussed below.

The first Bradford-Hill criteria to be addressed here is plausibility. Does the relationship under study make sense, considering our current knowledge of the topic? Is there a biological mechanism for the relationship? Examining the potential causality that engagement in health-promoting movement behaviours such as MVPA causes people to rate their health more highly, several mechanisms can be identified. First, it is known that engagement in regular, sufficient exercise affects physiological risk factors for disease[21,22]. Thus, mechanisms such as improved cardiovascular function and glucose homeostasis reduce one's risk of having a chronic illness, which is reflected in their SRH. Other potential causative mechanisms for the positive relationship between MVPA and SRH include the role of MVPA in preventing functional decline, preserving cognitive function, and reducing depressive symptoms[23]. Finally, there is some evidence to suggest that engagement in MVPA predicts self-efficacy, which can impact self-ratings of health[24].

Conversely, people with better SRH may be more likely to engage in the health-promoting movement behaviours. This is plausible because SRH encompasses factors such as physical functioning, which may affect one's ability to perform MVPA[7]. Additionally, SRH is affected by personality factors and health beliefs, and these factors may affect the likelihood that someone will engage in health-promoting behaviours[7].

The only necessary criterion for causation is temporality: the exposure must precede the outcome[11]. The cross-sectional nature of this study makes determining temporality difficult. Since the survey questions asked about current SRH, sleep, and covariates, and accelerometers measured current activity levels, temporality is a key issue. Does engagement in health-promoting movement behaviours such as MVPA cause people to rate their health more highly, or are people with better SRH more likely to engage in the health-promoting movement behaviours? The data from this study cannot answer this question.

Other important Bradford-Hill criteria are strength of association, dose-response, and consistency[11]. These criteria essentially say that there is more likely to be a causative effect if there is a large effect size, a dose-response relationship where more of the exposure is linked to a stronger effect, and if many studies find similar results. Although the effect sizes are not readily interpretable in this study, the odds ratios for sleep and ST on SRH are quite far from the null of 1, while the odds ratio for MVPA on SRH differs from the null by about 19%. The direction of these odds ratios is in keeping with past research, but it is difficult to compare the effect sizes because the effect size in the current study is not easily interpretable. However, past studies found that the odds ratio for reporting poor SRH with non-ideal sleep duration is 1.30-2.30[25,26]. Effect estimates for MVPA on reporting poor SRH are 0.48-0.69[27,28]. This study did not assess the possibility of a dose-response relationship, but past research has identified this type of association between ST and SRH, as well as MVPA and SRH[28,29].

4.5 Future research directions

This study is among the first to apply a compositional analysis approach to physical activity data. It is the first we know of that uses this framework with a dichotomous outcome. When using the compositional framework with linear regression, it is possible to evaluate the effect of time displacement from one movement behaviour to another. This suggests that a future research direction could be developing statistical techniques to be able to do the same with logistic regression with a dichotomous outcome. For example, a question to be addressed could be 'what is the change in the log-odds by replacing 30 minutes of ST with 30 minutes of MVPA?'

As some past research has suggested that the pattern of accumulating PA and ST is important, future research might look at these patterns within a compositional framework. This thesis was limited to studying the effects of total ST, LIPA, and MVPA on SRH. Also, using compositional analysis (or other methods) to disentangle the effects of ST and PA on health outcomes would be useful. Research on the movement behaviours should be done considering each daily component *relative* to the others. Compositional analysis would accomplish this.

Lastly, further research on the determinants of SRH would be useful. If we as public health researchers are going to continue using it as an overall indicator of health, we should better understand what it captures. To this point, studies have been able to account for less than 50% of the variance in SRH with predictor variables such as age, gender, employment status, physical and mental functioning, and physical and mental well-being[30,31]. Although research has also studied social capital and support factors and SRH[19], integrating these variables with more traditional health and demographic indicators might be useful in mapping out the factors underlying SRH.

4.6 Public health implications

Results from this study show that there is a serious lack of PA of all intensities, but especially MVPA, in older adults. This requires targeted public health action. Study results also provide an impetus for public health action to reduce ST in older adults. Finally, results of this study contribute to the formulation of integrated physical activity, sedentary time, and sleep guidelines for older adults. Such guidelines already exist in Canada for children and youth[32], and for adults in countries such as Australia and the U.K.[33,34].

4.7 Conclusion

This study assessed the association between the proportion of daily time spent engaged in sleep, ST, LIPA, and MVPA and self-rated health in a nationally representative sample of 60-79 year olds. The overall composition of the daily time budget in relation to the movement behaviours was statistically significantly associated with SRH. Additionally, both sleep and MVPA were positively associated with SRH, and ST was negatively associated with this outcome.

4.8 References

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Appendix A

Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board Initial Ethics Clearance

QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS RESEARCH ETHICS BOARD (HSREB)

HSREB Initial Ethics Clearance

August 29, 2016

Ms. Nicole Haywood
Department of Public Health Sciences
Queen's University

ROMEO/TRAQ: #6019030
Department Code: EPID-550-16
Study Title: How self-rated health is related to physical activity, sedentary time, and sleep: A compositional analysis
Co-Investigators: Dr. M. Rosenberg, Dr. K. Aronson
Review Type: Delegated
Date Ethics Clearance Issued: August 29, 2016
Ethics Clearance Expiry Date: August 29, 2017

Dear Ms. Haywood,

The Queen's University Health Sciences & Affiliated Teaching Hospitals Research Ethics Board (HSREB) has reviewed the application and granted ethics clearance for the documents listed below. Ethics clearance is granted until the expiration date noted above.

- Thesis Proposal – July 8, 2016
- Department Thesis Committee Approval Form

Documents Acknowledged:

- CORE Certificate – N. Haywood

Amendments: No deviations from, or changes to the protocol should be initiated without prior written clearance of an appropriate amendment from the HSREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

Renewals: Prior to the expiration of your ethics clearance you will be reminded to submit your renewal report through ROMEO. Any lapses in ethical clearance will be documented on the renewal form.

Completion/Termination: The HSREB must be notified of the completion or termination of this study through the completion of a renewal report in ROMEO.

Reporting of Serious Adverse Events: Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information.

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

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

Yours sincerely,

Albert J. Clark.

Chair, Health Sciences Research Ethics Board

The HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations, Canadian General Standards Board, and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP). Federalwide Assurance Number: FWA#:00004184, IRB#:00001173

HSREB members involved in the research project do not participate in the review, discussion or decision.

Appendix B

Course on Research Ethics Certificate of Completion

PANEL ON
RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

This document certifies that

Nicole Haywood

has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)

Date of Issue: **10 November, 2014**

Appendix C

Power Calculations

The power calculated to evaluate the associations between each movement behaviour relative to the others and SRH was ~95%. These values were obtained using the statistical software G*Power[1]. The power was calculated at an $\alpha = 0.05$, with a sample size of 2300 participants, and 13% of the sample with the outcome of fair/poor SRH. The following parameter estimates from the literature were also used as inputs in the power calculations: minimum detectable difference for sleep duration on SRH=0.7[2], minimum detectable difference for ST on SRH=2.0[3], minimum detectable difference for LIPA on SRH=0.8[4], minimum detectable difference for MVPA on SRH=0.8[4]. These odds ratios from the literature are the most directly comparable to the current study, as they modeled the odds of having poor SRH.

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Appendix D
Canadian Health Measures Survey

Background and purpose

The analysis in this thesis uses data from the Canadian Health Measures Survey (CHMS). The CHMS is a national population 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 to provide national data on important public health concerns such as obesity, hypertension, cardiovascular disease, exposure to infectious disease, and exposure to environmental contaminants. Additionally, measurement of direct physical and biological indicators provides an indication of the extent to which many diseases may be undiagnosed in Canada, and can be used 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 was administered to respondents aged 6-79 years living in private dwellings in cycle 1, and those aged 3-79 in cycles 2 and 3[1,2,5]. Data collection for each cycle is carried out over approximately two years; cycle 1 data were collected from March 2007 to February 2009, cycle 2 data were collected from August 2009 to November 2011, and cycle 3 data were collected from January 2012 to December 2013. In cycles 1 and 2, respondents from the ten provinces and three territories were chosen, however in cycle 3 only residents of the ten provinces were eligible to be selected for the survey. 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[1,2,5].

The CHMS uses a complex, multi-stage sampling design to identify possible participants for inclusion in the survey. During the first stage, a list of possible collection sites that meet geographical and population criteria is determined based on information from Statistics Canada's Labour Force Survey. The collection sites are stratified across regions and include rural and urban centers of varying sizes. After selection of collection sites, the second stage of the sample design involves the sampling of dwellings. Census and other administrative information are used to determine a random sample of possible dwellings within pre-determined age strata. A letter is sent to selected households, providing information about the CHMS and informing them that an interviewer will visit their home to collect information about the household[1,5]. A current list of household members is sought from each selected dwelling to establish a list of possible survey participants. Finally, the third stage of sampling involves participant sampling. One or two people are selected from each household, with different probabilities for different age groups to ensure the target sample sizes are met for each age group[1,2,6].

The CHMS is a voluntary survey, and respondents who choose to participate give informed consent. 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 center component of the survey. The final response rate for cycle 1 was 51.7%[1]. The response rates for cycles 2 and 3 were similar.

Data collection

There were two components of data collection. The first was a household questionnaire, which was administered by a trained interviewer at the respondent's home. This questionnaire collected information on sociodemographic variables, medical history, current health status, and health behaviours. The second component of data collection was a visit to a mobile examination clinic, where direct physical measurements and blood samples were taken by trained staff. 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[1]. Accelerometers were initialized to begin data collection at midnight following the clinic visit and were mailed back to Statistics Canada after the 7-day collection period[1]. The Actical accelerometer measures the acceleration of movement and records it as a digitized value summed over a period of 1 minute (epoch), resulting in a count per minute value. 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[1,2,5]. Previously validated cut-points were used to classify wear time as sedentary (less than 100 counts per minute), light-intensity physical activity (101-1534 counts per minute), or moderate-to-vigorous physical activity (greater than 1535 counts per minute)[1,2,5]. A valid day was defined as having at least 10 hours of wear-time[1].

Covariates

Age and sex were collected during the sampling process, and were confirmed at the household interview. Other sociodemographic and health information such as marital status, ethnicity, and the presence or absence of physician-diagnosed chronic conditions was collected at the household interview. Also during the household questionnaire, adult participants were asked to provide the highest level of education completed. A categorical variable was created for analysis indicating whether the participant has less than a high-school education, is a high-school graduate, or has completed some form of schooling beyond high school[8]. Smoking status was determined based on answers to a series of smoking questions. A categorical variable was created for analysis identifying current smokers, former smokers, and never-smokers[8].

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[2,7]. Different weights are provided for the household interview component and the accelerometry component, adjusting for non-response. This analysis used the weights specific to the accelerometry component. In addition to the survey weights, bootstrap weights are provided to calculate the variance and standard error of each estimate, taking the survey design into account[1,2,5].

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 (16 collection sites across five regions)[1], 13 for cycle 2 (18 collection sites across 5 regions)[2], and 11 for cycle 3 (16 collection sites across 5 regions)[5]. The number of degrees of freedom for the combined cycles 1, 2, and 3 is therefore 24[7]. 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, in that the maximum number of covariates that can be included in the model is the number of degrees of freedom minus 1.

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