Examining the Simultaneous Influence of Individual and Neighborhood Determinants on Cardiovascular Health: A Multilevel Study in Canadian Adults

Sarah Singh, The University of Western Ontario

Supervisor: Frisbee, Stephanie J., The University of Western Ontario
A thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in Epidemiology and Biostatistics
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Abstract

Introduction: Previous studies have found that the cardiovascular health of individuals may be influenced not only by their personal characteristics, but also independently by their social relationships and the neighborhoods in which they reside. Still, it is unclear how these determinants act together to influence cardiovascular health and whether these determinants account for differences in cardiovascular health among Canadian adults.

Objective: The main objectives were: 1) to examine the status of cardiovascular health in Canadian adults and, 2) to describe how individual and neighborhood determinants can: a) act together to influence cardiovascular health and, b) account for differences in cardiovascular health among Canadian adults.

Methods: This study employed a cross-sectional design utilizing secondary data from multiple sources. Cardiovascular health was defined by the American Heart Association’s Cardiovascular Health Index – a summed score of 7 clinical and behavioral components known to have the greatest impact on cardiovascular health; ideal health in all 7 components is the healthiest outcome. Data for cardiovascular health was extracted from the Canadian Community Health Survey 2015-2016. Descriptive methods were employed to establish the distribution of cardiovascular health in Canadian adults. Multilevel Mixed Effects Regression Modelling was employed to examine the influence of individual (including interpersonal) and neighborhood determinants on cardiovascular health in a sample of Canadian adults.

Results: Study findings indicated that 27% of Canadians reported ideal health in 6-7 cardiovascular health components, 68% reported ideal health in 3-5 cardiovascular health components, and 5% reported ideal health in only 0-2 cardiovascular health components. Canadian adults were found to be healthier in clinical, as opposed to behavioral, components of cardiovascular health. Multilevel analyses indicated that individual (including interpersonal) and neighborhood determinants acted simultaneously, and even interactionally, to influence cardiovascular health. Further, the neighborhood accounted for up to 7% of the differences in cardiovascular health between individuals, with considerable differences noted between neighborhoods for the influence of determinants on cardiovascular health.
Conclusion: Interventions to improve cardiovascular health should be aimed at encouraging healthier behaviors in Canadian adults and, addressing both individual and neighborhood determinants of health simultaneously in subgroups with the poorest cardiovascular health.

Keywords

Cardiovascular health, cardiovascular disease, social determinants of health, residence characteristics, multilevel modelling, population health
Summary for Lay Audience

Maintaining ideal heart health can help us live a long and healthy life. Research has shown that exercising routinely, eating a healthy diet, and going to regular check-ups with a family practitioner, are all actions that can prevent heart disease such as heart attack and stroke. Still, our heart health is not just affected by our own actions, but also by our social connections and the environment in which we live. In our study, we examined the status of heart health in Canadian adults. We also investigated how our personal attributes and behaviors function together with our social connections and our neighborhoods, to impact heart health. The study used multiple data sources, with heart health derived from the Canadian Community Health Survey 2015-2016. Results of the study showed that only a quarter of the Canadian adult population maintained ideal heart health by way of healthy behaviors, proper lifestyle choices and avoiding early signs of heart disease, such as high cholesterol and diabetes. Further, our personal attributes such as age, education, and race, functioned together with our social connections and our neighborhoods to determine our heart health. Differences in heart health between individuals were not only due to differences between individuals, based on our personal attributes, but were also due to differences between our neighborhoods, based on neighborhood attributes. Overall, this study is important because it revealed low levels of ideal heart health in Canadian adults, which require urgent action. Additionally, the study highlighted the key roles of social connections and the neighborhood in actions towards improving heart health.
Acknowledgments

Years of hard work in research, culminating in this thesis document, would not have been possible without the opportunity to move to Canada and pursue my PhD at Western University. I am especially indebted to my supervisor, Dr. Stephanie Frisbee, who has provided me with the support and resources necessary to accomplish my research career goals. I am truly grateful for all the brilliant researchers with whom I have had the pleasure to work during this process. My supervisory committee, Dr. Stephanie Frisbee, Dr. Saverio Stranges, Dr. Anthony Tang and Dr. Piotr Wilk, has been an integral component of my thesis work, with each member providing the personal and professional support needed every step of the way. I consider all my supervisors as admirable mentors who have taught me a great deal about scientific research and about the kind of researcher I would like to be.

Thank you to the institutions that have facilitated my research during the past few years: the Western RDC, where I’ve spent many hours working with data, the Epidemiology and Biostatistics Department at Western University, the American Heart Association Epidemiology and Prevention Group, and other important organizations I’ve engaged with over the years.

I would like to thank my family, whose love and support has been essential throughout this and all my other career endeavors in the world of science. Also, I am thankful for the friends I have made over the past few years who have helped me in times of need. Particularly, I wish to thank my top role model in life – my mother, Morissa, who has stood by me my entire life and provided me with more love, encouragement and inspiration than I could ever express with words. And finally, I give all praise and glory to Jesus Christ, my personal Lord and Savior, around whom everything revolves and for whom everything exists.
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<th>Full Form</th>
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<tr>
<td>AHA</td>
<td>American Heart Association</td>
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<tr>
<td>BMI</td>
<td>Body Mass Index</td>
</tr>
<tr>
<td>CANUE</td>
<td>Canadian Urban Environmental Health Research Consortium</td>
</tr>
<tr>
<td>CANHEART</td>
<td>Canadian Health in Ambulatory Care Research Team</td>
</tr>
<tr>
<td>CCHS</td>
<td>Canadian Community Health Survey</td>
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<tr>
<td>CDC</td>
<td>Centers for Disease Control and Prevention</td>
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<tr>
<td>CIHI</td>
<td>Canadian Institute for Health Information</td>
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<td>CSD</td>
<td>Census Sub-Division</td>
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<td>CVH</td>
<td>Cardiovascular Health</td>
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<td>CVHI</td>
<td>Cardiovascular Health Index</td>
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<tr>
<td>CVD</td>
<td>Cardiovascular Disease</td>
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<tr>
<td>DA</td>
<td>Dissemination Area</td>
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<td>FSA</td>
<td>Forward Sortation Area</td>
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<td>WHO</td>
<td>World Health Organization</td>
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Preface

The purpose of this thesis is two-fold: 1) to assess the cardiovascular health of Canadian adults using a simple, yet effective, tool that focuses on health as a positive construct, and 2) to demonstrate and quantify the role of determinants, other than our own personal attributes, in shaping our cardiovascular health. The thesis purpose is accomplished through multilevel regression analysis, which is used increasingly in population health research although, not to its full extent for operationalizing the contextual influence on health.

The conceptualization of the thesis objectives stemmed from a simple observation I’ve made throughout my career in medicine and population health, “If we want to promote health then we need to clearly define it, measure it and discover what influences it.” The field of medicine has successfully adopted this stepwise approach for treating disease, yet research is slow to take the same approach towards health.

The thesis was designed to be of interest, not only to epidemiologists and biostatisticians, but also to clinicians, sociologists, public health experts and anyone with a keen interest in improving health. It is anticipated that thesis findings will be used on a larger scale to inform new policies and interventions, but also on a smaller scale to encourage new approaches to researching cardiovascular health in the Canadian population.

This thesis is an original work completed in its entirety by Sarah Singh and submitted for the degree in Doctor of Epidemiology and Biostatistics at Western University. No part of this thesis has previously been published or submitted for any other qualification at any other university.
Chapter 1

1 Introduction

This chapter begins by providing preliminary background information for the thesis research, followed by a brief description of the thesis layout.

1.1 Background

The concept of health as a state of wellness, not simply the absence of disease, has become essential to the social medicine and public health approaches that govern our society today. (1) As healthcare costs rise and population growth soars, methods to promote healthy living and improve our overall wellness are growing increasingly popular. (2) The idea of ‘staying healthy’ and maintaining health throughout the life course has become the cornerstone of disease prevention. This era of prevention has revived the questions, “What is health?”, “What impacts health?” and, “How can we track the health of the population and its subgroups?” (3) While recent developments in medicine and advances in technology have greatly enhanced our ability to address these questions, further research is needed to better understand the dynamic and complex nature of health. More specifically, research should aim to attain a better understanding of operationalizing health and to apply that understanding to disease prevention and health promotion efforts. (3)

The World Health Organization defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.” (4) Thus, health is considered a positive state of wellness, distinctly above and beyond the negative state of illness. (5) Rather than argue its utopian nature, applying this concept of health to a particular setting or context may be a more intuitive approach. Chronic diseases, including heart disease, cancer, diabetes, stroke and respiratory diseases, are the leading causes of mortality worldwide, and thus provide a unique opportunity for examining health. (6) Most chronic diseases are closely linked to multiple risk factors – elements that increase or decrease the likelihood of disease. (7) Reducing the impact of these risk factors can effectively prevent disease and, moreover, keeping them at minimum levels
can promote a better status of health.(6) In keeping with this notion, and to provide
greater context for exploring and operationalizing health, the current study will focus on a
chronic disease that is highly amenable to risk factor control and health promotion –
cardiocvascular disease.

Despite innovations in treatment, cardiovascular disease (CVD), commonly characterized
by heart attack or stroke, remains one of the largest threats to global health.(8) According
to the most recent Global Burden of Diseases Report in 2017, CVD was responsible for
an estimated 17.8 million deaths worldwide, equivalent to 330 million years of life lost
and another 35.6 million years lived with disability.(9) Consequently, CVD prevention is
now a top public health priority. (8) Reducing the burden of CVD has evolved towards
defining and promotion cardiovascular health (CVH) – the adoption of healthy lifestyle
choices and behaviors that slow or halt the development and thus, progression towards
CVD. (3) It is well established that the CVH of individuals can be improved by
maintaining a healthy diet, reducing stress, remaining physically active and engaging
with health professionals to ensure age-appropriate screening for hypertension,
cholesterol and diabetes. (10) In addition, population-level approaches to improving CVH,
such as salt reduction strategies and raised tobacco taxes, have been remarkably
successful in lowering CVD incidence and mortality worldwide. (11) Still, CVD is a
complex and long-term problem that requires multiple intervention strategies at all stages
of the life course.

To date, CVH remains a challenge for healthcare, providers and policy-makers given its
multifactorial nature. (12) Well-known determinants of CVH include genes, biology,
health behaviors, social factors, and the environment. Thus, CVH promotion can be
difficult to tackle using a one-size-fits-all approach. (12) Studies have shown that
individuals experience CVH differently based on their individual characteristics. (13, 14)
There has been a growing body of research examining the impact of social support and
social cohesion on CVH. (15) Furthermore, social aspects of our environment, including
wealth, social capital, crime and community support, can significantly affect the health of
individuals. (16) While the independent effects of both individual- and population-level
determinants on health remain a critical field of research, newer studies have begun to
postulate that their interconnections can also widely impact health. Thus, there is a rising demand for research attempting to explore these connections to better understand how our individual characteristics interact with our social environment to impact health.

The thesis will focus on a crucial question in CVH research to date – how do our individual characteristics, social connections, and the environment in which we live and work, simultaneously influence our cardiovascular health? Canada has long been at the forefront of health policy, proposing a global mandate – the ‘Ottawa Charter for Health Promotion’ at the first International Conference on Health Promotion, jointly held with WHO in 1986. However, recent efforts around CVH promotion appear to have plateaued nationally, while the burden of CVD rises, thus creating a need for further studies to enhance our understanding of CVH.

To contribute towards the local and international scientific body of literature, the thesis will expand upon two main areas of understanding: 1) the status of CVH in Canada and, 2) how individual- and population-level determinants influence and contribute to variations in CVH in a sample of Canadian adults. In exploring these complex health issues, findings from this study will inform future interventions and policies needed to both improve population CVH and reduce widening CVH inequalities.

1.2 Chapter Summary

Few studies have addressed the topic of CVH in Canadians, nor are there any known studies that aim to disentangle the complex interplay between individual- and population-level determinants of CVH. Canada provides an ideal setting for examining CVH and its determinants because the population is diverse and, despite universal healthcare, a high burden of CVD persists amongst Canadians. Differences in behaviors, family composition, social networks and neighborhoods can lead to differences in CVH among individuals and various subgroups of the population. Unfortunately, current health authorities do not appear to encompass these differences when creating CVH policies and interventions. The overall aim of this thesis is to investigate the influence of individual- and population-level determinants acting simultaneously and interconnectedly on CVH.
The thesis begins with a literature review which defines the concepts referred to throughout the study including health, cardiovascular health, and determinants of health. With the background now established, the research objectives outline the step-by-step approach employed to address the overall thesis aim. The methodology chapter then details the study design, study sample, tools, and statistical methods used to fulfil each research objective. Results of the analyses are organized and presented by research objective in the subsequent chapter. In the final chapters, the study findings are summarized and discussed in relation to other studies, with special consideration given to the implications of the findings to future policies and interventions.
Chapter 2

2 Literature Review

The concept of ‘disease’ is largely objective and rooted in the science of the human body, its physiology and pathology.(6) Traditionally, the fields of medicine and public health structure interventions and policies around disease, seeking to reduce the negative impact of disease on individuals.(6) However, the knowledge landscape has evolved and now posits ‘health’ as a positive concept that can be promoted, in the absence or presence of disease, to improve overall wellness.(1)

The following discussion begins by exploring the existing literature and examining the questions first posed in the thesis introduction: *What is health? What impacts health?* and, *How can we measure the health of the population and its subgroups?* Then, the discussion focuses on applying the concept of health promotion to tackle one of our biggest health challenges today – cardiovascular disease. As the first step in this process, the literature review will define the role of cardiovascular health (CVH) in reducing the burden of cardiovascular disease. The discussion concludes by identifying determinants that can potentially improve the cardiovascular health of individuals and populations.

2.1 Defining Health

2.1.1 The Concept of Health

‘Health’ is not simply explained in terms of one person or place.(25) Throughout the ages, health has been deemed holistic – pertaining to all aspects of wholeness; the physical, mental, social and spiritual.(26) The age of medicine ushered in the emphasis on biological mechanisms which were interrupted by bouts of illness.(25) As theories and statistical techniques have progressed, the value of health has been quantified and even monetized through constructs such as health-adjusted life expectancy.(27) Currently, modern theorists agree that health refers not only to individuals, but also to groups and communities and results from interactions between individuals and their environment. (28)
During its establishment in 1948, the World Health Organization (WHO) proposed one of the first official definitions to encompass the social aspect of health.(4) This definition of health is widely accepted today – “health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.”(4) However, at the time of its inception, the uptake of this definition was slow, as it was considered broad compared to the more specific definitions based on the biomedical model.(1) Between 1984 and 1986, the WHO updated the definition of health to “a state of complete physical, mental and social well-being, an individual or group must be able to identify and to realize aspirations, to satisfy needs, and to change or cope with the environment.”(28) The Ottawa Charter from the 1st International Conference on Health Promotion contributed to this expanded definition through the assertion that health is a construct of everyday human living.(20) This latest definition would evolve the idea of health from a condition, to a resource for development, with the responsibility now resting upon individuals, communities and governments to improve health and health equity for all. The conceptual advancement of health as both a state and a resource, has formed the basis for the first global health mandate, “Health for All by the year 2000 and beyond”, embraced by at least 147 of the 166 World Health Organization member States worldwide.(29)

Canada has been a forerunner in promoting the value and concept of health through renowned publications such as the 1974 Lalonde Report.(30) Lalonde emphasized the need to transition from the biological perspective of illness as measured by morbidity and mortality, and onto the wellbeing of the population as affected by the environment, lifestyle and healthcare system. The 1974 report indicates that while the medical approach to treating the sick is important, further investigation into the underlying causes of illness and death is necessary to enhance the health of an entire population.(30) It further states that these underlying causes are not limited to the human body but may lie within the systems and infrastructure of society and everyday living. To this end, the report proposes that the concept of health can be divided into four main sections known as ‘health fields’: human biology, environment, lifestyle and health care organization.(30) This ‘Health Field Concept’ was revolutionary in proposing an innovative structure for
comprehensively examining individual and collective aspects that contribute to the health of populations.

Over time, health has become an essential component of education, politics, and the economy, as research continues to expand the understanding of individuals’ perceptions and experiences of health. A recent global health report by The Kaiser/Pew Global Health Survey conducted in 47 countries around the world, found that countries reported varying national concerns, aside from disease, that impact the health of their citizens; including crime, terrorism, pollution and corruption are at the top of the list in Africa, Latin America, Eastern and Central Europe, and the Middle East. (31) The study concluded that there is significant variation in how health is perceived by individuals around the world, indicating a role for culture in the health of populations. (31) Another global survey conducted in 2018, assessed the personal health perceptions of 20,767 adults in 27 countries by eliciting a response to the question: Do you agree or disagree with the statement, *I am in good health.* (32) Generally, 56% agreed that they were in good health though estimates varied by country; 70% in India, 50% in Peru and 32% in Japan. (32) While survey results may be considered as culturally based, findings show there is a subjective aspect to health; rooted in individualism and also influenced by basic needs including diet, exercise, sleep, safety and healthcare.

Over the past few decades, the definition of health has not transformed radically beyond the foundation laid by the WHO, the Ottawa Charter, and the Lalonde report, although variations have been suggested. A key editorial published in the Lancet posited that health is a property of the individual and his/her ability to adapt to their environment. (33) In comparison to disease, which involves a diagnosis assigned by a medical professional, health is constantly advancing along with the individual’s change in circumstances. (33) Authors from another key publication entitled, “How should we define health?” agreed with the approach proposed by the Lancet, building upon the concept of health as the ability to adapt within the health domains, physical, mental and social, originally proposed by the WHO. (34) The proposed health domains were: physical, mental and social. (34) For the physical domain, maintaining physical health involves managing a stable level of physicality in a changing environment. The term ‘allostasis’ was
referenced, which refers to the body’s ability to achieve stability through physiological or behavioral changes. (35) For the mental domain, mental health was viewed as ‘a sense of coherence’ contributing to the ability to cope and recover in varying circumstances. For the social domain, social health included the ability of individuals to manage their daily lives and relationships. Thus, our past and current research has confirmed that health is a complex and evolving issue; suggesting that an amalgamation of concepts may be the best approach to a modern definition of the concept of ‘health.’ (34)

2.2 Measuring Health

To operationalize the concepts of health discussed above, we need to be able to measure health. Valid and reliable measures of health are key to determining distribution, evaluating interventions and formulating policy. (27, 36) However, health measurement is complicated, as measures are expected to apply across various dichotomies: individuals and populations, wellness and disability and, clinical and self-reported information. (36, 37) Arguably, measures of health and disease have been used interchangeably in the literature and focus primarily on disease surveillance and trends. (38) However, as indicated throughout this thesis, health is not simply the inverse of disease and, thus the measures should not be used interchangeably. (26)

Health is complex and it is implausible that one measure can encompass all aspects of health. (39) Currently, numerous measures of health exist; ranging from the simple question, “Do you feel healthy?” to the more complex, quality-adjusted life years (QALYs). (39) In 2018, the WHO published the “Global Reference List of 100 Core Health Indicators” which act as a standard set of 100 different measures for examining health at national and global levels. (40) Although extensive, this list of indicators is considered to be a comprehensive benchmark for assessing health around the world. For the purposes of this study, the following discussion briefly highlights four selected measures of health from the list, that are used most frequently in the scientific literature; they include: mortality, life expectancy, quality of life and summary measures of health.
2.2.1 Mortality

Although health is a positive concept, one of the most established and well-known measures of health to date is mortality. Death is a common measure of health because it is the inevitable endpoint for many neglected health issues. Thus, it is intuitive to consider death or time to death as a measure of health. Additionally, data on death is often mandated and readily available through vital statistics registries and census surveys in many countries. Crude death rates are calculated as the total number of deaths over a time period, while standardized death rates are used to compare populations of different age and sex compositions. Such measures can be extremely informative for addressing challenges key to global health policy. For example, the United Nations World Mortality Report 2019 assessed crude death rate, sex-adjusted mortality rates and infant mortality rates to examine health across countries. Findings revealed that many regions of the world will fail to meet the Sustainable Development Goal to reduce child mortality to <25 deaths per 1,000 live births by 2030. A major limitation to mortality rates is that they do not reflect the high morbidity and disability caused by health issues that do not necessarily end in death. Given the rise in chronic disease prevalence, this limitation became imperative and has been addressed by other measures of health as listed below.

2.2.2 Life Expectancy

In its simplest form, life expectancy is the number of years of life that a person (or a group of persons) can expect to live. Traditionally, life expectancy is a measure of the overall mortality level of a population and is calculated from mortality rates using life tables (survival probabilities listed by age sample). Researchers examine the observed mortality rates of a group over past years and use that information to predict mortality rates for other groups over future years. Life expectancy is calculated assuming that mortality rates remain constant over time and is therefore an approximation. In 2016, the WHO global life expectancy at birth was 72.0 years; 74.2 years for females and 69.8 years for males. Consequently, as global mortality has decreased in the past few years, life expectancy has increased. In 2017, life expectancy at birth was 80.7 years in OECD countries. The main limitation of the life
expectancy measure is similar to the mortality rate; it is not comprehensive for health, omitting information on morbidities or the quality of life lived.

2.2.3 Health Related Quality of Life

Health related quality of life (HRQOL) measures were introduced in the 1980s and focus on measuring functionality and wellness of life lived.(49) HRQOL are generic or disease-specific measures that cover various domains of health, including physical, mental and social domains, and do not provide specific details pertaining to any one health condition. Unlike mortality or life expectancy, HRQOL is self-assessed and represents an individual’s (or group of individuals’) perceived functional status, social support, or area resources over time. In this way, HRQOL may provide valuable information on morbidity, including unmet needs and the social factors associated with morbidity.(49) Common HRQOL instruments used in the literature include: EQ-5D (Euroqol 5-Dimension Measure), Health Utilities Index and, SF-36 (Self-rated Health 8-Domain Measure). Furthermore, there are numerous disease specific HRQOL instruments that were created to assess the quality of life experienced in relation to a specific disease or disability. An important limitation to the use of HRQOL is the validity of the various instruments used.(50) Within a specified context, it is challenging to determine whether HRQOL instruments are measuring the domains exactly as they were intended to, as there is no gold standard for quality of life.(50, 51) Thus, research utilizing HRQOL without some a priori knowledge of the outcomes are often prone to inferences based in bias and broad interpretation.

2.2.4 Summary Measures of Health

Summary measures were created to reflect morbidity and mortality, while also including information on quality of life and functionality. Summary measures are favored for assessing health, as compared to mortality, because it can be used for conditions that lead to a high burden of disability with low fatality rates.(38) An important summary measure is quality-adjusted life years (QALY), where 1.0 QALY is equivalent to perfect health.(52) As perfect health deteriorates, due to disability or injury for example, the value of the QALY decreases to less than 1.0. QALYs are used frequently in health
economic studies to determine the cost-effectiveness of various health care interventions.(52) Another key measure is disability-adjusted life years (DALY), which are measured in the same way as QALYs but are adjusted by weighing the severity of disabilities.(52) The valuation of weights used in these analyses are a topic of contention in using summary measures of health.(53) Debates are often centered around whose values for weights should be used: the patient, the hospital, or the administration. (53)

Therefore, challenges with existing measures of health are centered around practicability, applicability, and distinct alignment with the concept of health. Further research is needed to explore other measures of health that can fill these gaps and be appropriately and seamlessly implemented in CVH research.

2.3 Determinants of Health

2.3.1 Introducing the Thesis Theoretical Framework

Health is not solely limited to the individual but is also influenced by social relationships and by the environment, where we live, work and play – a concept embodied by the ecological model. The ecological model, developed in the late 1980’s, are “a conceptual framework designed to draw attention to individual and environmental determinants of behavior.”(54) The model proposes levels of influence on health, including personal factors, interpersonal processes, organizations, community, and public policy.(55) As the interest in social inequalities in health grows, the ecological model has drawn attention to those actionable factors that act at each level of influence to impact the health of individuals – determinants of health. The Public Health Agency of Canada defines determinants of health as a range of factors that influence the health status of individuals or populations, including but not limited to: income and social status, social support networks, education and literacy, employment/working conditions, social environments, physical environments, personal health practices and coping skills, healthy child development, biology and genetic endowment, health services, gender and culture(22, 56). Identifying health determinants are key to developing approaches for improving health.(22)
The impact of determinants on health is not always evident, especially as determinants tend to interact thus, conceptual frameworks are necessary as the theoretical foundation for studying potential impact. A recent Canadian review highlighted seven key conceptual frameworks describing how determinants influence health in the Canadian context. (57) Frameworks differed based on the intended setting for application and variables used to define levels of influence including, individual need, social connections, social context, healthcare, and governmental policy. Much of the content for these frameworks were adopted from a seminal report by the WHO Commission on Social Determinants of Health report published in 2008. (58) The report urges action towards social determinants of health for reducing health inequity worldwide and confirms the need for a joint, socio-ecological approach to addressing these determinants in individuals, populations, and the environment.

One of the earliest, most established and well-known frameworks for studying the impact of health determinants is the Main Determinants of Health model (commonly known as the socio-ecological model) proposed by Dahlgren and Whitehead, in conjunction with the World Health Organization, in 1991. (59) The model uses a rainbow-layered diagram to emphasize that individuals are a part of a larger environment and the interaction between the two are inextricable. Individuals are nested within social communities and geographic regions which form the contextual environment that constantly shapes the individual’s lifestyle choices and health. The model is not shown in this review due to copyright restrictions but can be found in the seminal publication, “Policies and Strategies to Promote Social Equity in Health”, by Dahlgren and Whitehead, 1991. (59)

The thesis will be guided by the model principle that health is not only affected by the characteristics of an individual (individual-level determinants) but also by social interactions and characteristics of the environment in which that individual lives (population-level determinants). The model suggests a hierarchical approach to classifying determinants, where the central portion of the model refers to ‘lower level’ individual determinants and, the radiating arcs that move further away from the individual represent ‘higher level’ determinants of the population. The ‘Main Determinants of Health’ model describes five ‘levels’ of determinants that could be
targeted by policies and interventions for addressing inequalities in health. The following discussion describes the Main Determinants of Health model in further detail and outlines how the model will be applied in this study.

The central portion or core of the figure represents attributes that relate to the physical and mental condition of an individual. Factors intrinsic to the individual, that is, factors that form the basis of physical attributes, were some of the first discovered to influence health. Multiple studies have demonstrated strong relationships between age, sex, race and cardiovascular disease risk and mortality. While these attributes remain non-modifiable, they provide key information on target populations for whom changes in policy may be most impactful. In this study, these intrinsic individual factors are used to define population subgroups and identify possible inequalities in health.

The layer directly surrounding the core represents individual behaviors and choices of lifestyle such as physical activity, diet, sleep, stress and alcohol use. The association between these modifiable factors and health has also been well established over the past three decades. The basis of prevention is to encourage personal change towards healthier lifestyles and behaviors that reduce risk of morbidity and mortality.

The following layer represents social and community networks, including peer relationships and community belongingness. A growing body of research suggests that social support is directly associated with improvements in individual health. In a report to the government from the Canadian Social Cohesion Network, Stanley et al recommended that policies to improve health in Canada should be developed from the point of view of social cohesion which is a modifiable factor that can act as a target for policy and intervention.

The next layer is multifaceted and represents a wide variety of living and working conditions. Key studies, have provided evidence for the impact of “physical and social environments, including aesthetic quality, walking/physical activity environment, availability of healthy foods, safety, violent crime, social cohesion, activities with neighborhoods, neighborhood problems, and social and physical disorder”, on health.
outcomes.(63, 64) Neighborhood factors represent a broad range of characteristics that are highly amenable to large-scale interventions and local policies for improving population health.(63)

The final and outermost layer represents the ‘macro-policy’ environment and contains societal elements observed at the level of the country or, in Canada, at the level of the province such as culture, government schemes and economic systems. Policies operating at the macro-policy level involve national and international efforts to create structural changes in the framework of society that can drastically impact health.(65) Another key component to the model is the arrows connecting the layers suggesting, that health is not just impacted by the characteristics of each layer but by the interaction between layers; that is, interactions between individuals and their relationships with peers, living and working conditions, access to goods and services, and policies governing the society to impact health.(65)

In conclusion, the Main Determinants of Health model is an appropriate guide for this study because it provides a simple, yet substantiated framework for investigating the multilevel (individual and population level) influence of determinants on health. For years, this framework has helped researchers to hypothesize on the patterns of influence of multiple levels of determinants acting simultaneously on health.(57) Notably, the Dahlgren and Whitehead model is simplistic and since its inception, many other socio-ecological frameworks have emerged linking individuals to their environment. However, this model was chosen as the thesis framework because it considers both health and determinants of health as intrinsically linked concepts, with determinants of health acting in a layered yet integrated pattern to influence health; a concept emphasized by the image of the rainbow intuitively symbolizing a system acting in unison.

In this thesis, The Main Determinants of Health model informs the selection of study variables representing determinants, and the multilevel methodology that will be used to address the main research question: How do our individual characteristics, social connections and the environment in which we live and work, simultaneously influence our cardiovascular health?
2.3.2 A Prominent Threat to Health – The Issue of Cardiovascular Disease

Cardiovascular diseases (CVD) are a group of disorders of the heart and blood vessels including coronary artery disease, heart failure and stroke. Although CVD mortality rates have declined in the past five decades, WHO has declared CVD the leading cause of death worldwide, with 17.8 million deaths attributed to CVD globally in 2017. (48, 66) Approximately one third of these deaths are premature, occurring in individuals 70 years and younger. (66) Most developed countries have reported similar patterns for CVD. The US reports an age-adjusted prevalence rate of 10.6% for CVD, with over 500,000 deaths (1 in 4 deaths) from CVD in 2017. (67) Additionally, in 2017, Europe reported 19.9 million new cases of CVD in 54 member countries, with an age standardized prevalence rate of 6595 per 100,000 individuals. (67)
Despite advanced treatment and publicly accessible healthcare, Canada exhibits similar trends with the prevalence of ischemic heart disease increasing from 1.5 million in 2000 to 2.5 million in 2013. (68) Though some of these findings have been attributed to an aging population, over 100,000 CVD-related deaths are reported annually. (68) Additionally, the economic burden due to CVD is expected to increase with greater hospitalization and clinical intervention in the aging population, thus pushing the projected annual cost of CVD in Canada to over $28 billion by the year 2020. (69, 70)

Risk factors are conditions, behaviors or attitudes that increase the likelihood of disease. On average, 9 in 10 Canadians have at least one risk factor for CVD including smoking, obesity, hypertension, diabetes or a sedentary lifestyle. (71-73) The growing prevalence of CVD risk factors nationwide threatens the transient decrease in CVD mortality noted in recent reports. (72) Developments in pharmacological therapy, in combination with awareness campaigns, have prompted decreases in the overall incidence of physical inactivity and smoking over the last decade. However, obesity and poor diet remain significant barriers to achieving optimal health. Consequently, CVD prevention through risk factor reduction and control have become major medical and public health priorities for Canadian health authorities. (70, 71)

2.3.4 The Groundwork for Cardiovascular Disease Prevention

Emerging only in the second half of the 20th century as a challenge to population health, CVD has slowly risen to the forefront of public health and medicine. (74) The increasing burden of CVD has given rise to broader approaches in disease management at the population level, thus prompting the rise of early epidemiologic studies in CVD. (75)

2.3.4.1 United States

The Framingham Heart Study (FHS) is one of the most influential and longest-running studies on heart disease. The FHS, which began in 1948 in Framingham Massachusetts, was one of the first studies to identify traditional risk factors, such as cigarette smoking, high cholesterol and high blood pressure, and relate these to heart disease incidence. (61) In the first study, approximately 5209 men and women aged 30 to 62 years were observed via medical examinations and lifestyle interviews. The FHS has continued to
enroll second and third generations into the investigation thus increasing the breadth of participants over time and expanding the scope to include genetic determinants of CVD. Over the past decades, the FHS has led to ground-breaking insights into the need for CVD risk factor control, the multifactorial nature of CVD and the development of CVD risk assessment profiles, using the Framingham Risk Score, to identify high-risk individuals. This work has formed the foundation of primary prevention, or risk factor control, in CVD.

2.3.4.2 United Kingdom

Further significant findings on CVD development were revealed in the Whitehall Study (WHS). Beginning in 1967, the WHS arose out of growing interests in the relationships between the social inequality, work environment, psychosocial support and health.\(^{(76)}\) The WHS I study examined the health and lifestyle of British civil servants between 1967 and 1977.\(^{(77)}\) Results were published in the 1978 issue of the Journal of Epidemiology and Community Health and ultimately revealed that those in the highest grade of employment had one third the mortality rate of those in the lowest grade of employment.\(^{(77)}\) A subsequent WHS II study published in the Lancet in 1991 showed a strong relationship between psychosocial factors and health, revealing that those with greater workloads and less social support were at greater risk for CVD.\(^{(78)}\) The WHS was one of the first to demonstrate clearly that factors outside of health care, such as stress and socioeconomic status, can directly impact the risk of CVD.\(^{(78)}\)

2.3.4.3 International

The Seven Countries Study, which began in 1957, was one of the first studies to examine rates of CVD and stroke in populations with varying diets and lifestyles.\(^{(79)}\) The study sample included individuals from the US, Italy, Greece, Yugoslavia, the Netherlands, Finland and Japan. Data on personal characteristics and lifestyle and dietary choices, were collected in men aged 40 and over residing in mostly rural regions throughout the seven included countries. Results of the study confirmed that populations consuming higher dietary fat, specifically a diet with high cholesterol and saturated fat, are at increased risk for coronary artery disease.\(^{(80, 81)}\) Additionally, at the time, the study
called for further investigation into more favorable diets such as those from Greece and Japan, which are still known to be popular weight-loss diets today. The Seven Countries Study also provided crucial evidence for the role of the cultural environment in the CVD epidemic.

These early studies in CVD distribution and risk factors, conducted in populations around the world, form the foundation for CVD prevention today. However, more research is needed to identify the role of cultural, political, and other ecological risk factors in global CVD prevention.

2.3.5 The Groundwork for Cardiovascular Disease Prevention in Canada

Canada has been a forerunner in promoting the value and concept of disease prevention through renowned publications such as the 1974 Lalonde Report. Lalonde emphasized the need to transition from the biological perspective of illness as measured by morbidity and mortality, and onto the wellbeing of the population as affected by the environment, lifestyle and healthcare system factors. The 1974 report indicates that while the medical approach to treating the sick is important, further investigation into the underlying causes of illness and death is necessary to enhance the health of an entire population. It further states that these underlying causes are not limited to the human body but may lie within the systems and infrastructure of society and everyday living. To this end, the report proposes that the concept of health can be divided into four main sections known as ‘health fields’: human biology, environment, lifestyle and health care organization. This ‘Health Field Concept’ was revolutionary in proposing an innovative structure for comprehensively examining individual and collective aspects that contribute to the health of populations.

Building on this framework, in 1987, a federal and provincial working group on CVD prevention entitled ‘Promoting Heart Health in Canada’ was developed. This group has laid the groundwork for the Canadian Heart Health Initiative (CHHI), a program created to foster health promotion through environmental, intersectoral approaches and health public policy. The working group for the CHHI focused on disseminating and
implementing interventions for chronic disease prevention and healthy living promotion throughout all Canadian provinces. The CHHI was a five-phase project conducted from 1986 to 2005 and aimed at 1) national, provincial and local collaborations, 2) growth in health research and intervention, 3) adaptation of interventions by the public health system, 4) the use of both high-risk and population approaches in health interventions and 5) promoting primary prevention-based interventions to reduce risk factors. (82) Feedback from provincial governments and data on program implementation have indicated the success of the CHHI and the need for collaborative efforts towards improving population health. (83) To this end, the Canadian government has dedicated over $300 million to the Integrated Strategy on Healthy Living and Chronic Disease which is a national project that builds on the work of the CCHI, independently within provinces. (83)

In summary, the battle to reduce CVD burden globally, and in Canada, is now decades old. Rapid developments in both CVD prevention and treatment, including pharmacological advancements in the use of statins and the timely use of stents to limit the damage caused by myocardial infarction, have promoted a slow decline in mortality rates currently. (71) However, increasing rates of obesity, greater sedentary activity, poor nutrition and the gain in the popularity of e-cigarettes among Canadians have reignited the focus and growing need for both primordial and primary prevention of CVD through health promotion. (84)

2.3.6 The Role of Health Research and Policy in Cardiovascular Disease Prevention

Over the past few decades, extensive research has been conducted in the fields of CVD prevention and CVH promotion. The concept of CVH is embedded within both primordial and primary prevention. (6, 85) Primordial prevention aims to deter the onset of CVD risk factors, whereas primary prevention aims to deter the clinical manifestations of CVD. (75) Arguably, both strategies are essential for eradicating CVD as the leading cause of mortality worldwide. (6) Health policy remains a key component to these efforts however, clinical and observational research is needed to inform policies and interventions to reduce CVD and improve CVH at both the individual and population levels. (86)
Clinical trial data has provided ample evidence for prevention at the individual level; however, there is less evidence for population level policies and interventions. (87) Additionally, while existing prevention efforts have allowed us to reduce the burden of disease, we are still far off from the prospect of health and longevity for all. (88) Further work is needed in the evolution from solely disease prevention towards health promotion. (88) Health policy plays a significant role in addressing those risk factors and health determinants that are not amenable to traditional risk factor therapies. (86) Factors such as age, sex, and race may not be adjusted through behavioral changes or medications, which leads many to underestimate the contribution of these factors to CVD prevention research or policies. (86) On the contrary, these non-modifiable factors act as key targets for the actions of health policies and interventions. The actions of health policies are often disseminated under limited resources; therefore, it is important to identify subgroups who are most in urgent need of health changes. (7)

Another key element to CVD prevention is the impact of the environment on the health of individuals, as outlined in the Dahlgren and Whitehead framework. (59) This theory suggests that policies can have significant impact on the health of individuals by optimizing the environment in which those individuals spend their time – the living and working environments. (65) Aside from increasing green spaces, methods such as providing greater resources for deprived communities or improving access to the healthcare system can lead to significant gains in CVH improvement. (89) The challenge for policy makers remains how to integrate evidence for biological, behavioral and economic changes to support CVD prevention and CVH promotion. (90) A combined approach of modifying individual health behaviors and creating targeted population-level prevention policies can have a substantial impact on CVH. (90) Further methodological research can shed light on combined approaches to CVD prevention and CVH promotion and is the stimulus for the current thesis work.
2.4 Introducing the Concept of Cardiovascular Health

2.4.1 Transitioning from Cardiovascular Disease to Cardiovascular Health

There has been substantial evidence on the association between lifestyle factors and health behaviors, and CVD.(91) Avoiding the onset, or minimizing the impact, of factors known to increase the likelihood of CVD is the cornerstone of CVD prevention today. Adequate physical activity, healthy diet, weight management and not smoking have all together been shown to reduce the incidence of heart attack and stroke by up to 80%.(91) Furthermore, adopting these healthy practices can not only prevent CVD, but also improve the overall physical and mental wellness that leads to longevity. Nevertheless, the reliance on ‘health’ as a tool to tackle the burden of CVD is often overlooked in comparison to newer medical therapies.(92) Further research is needed to support the greater need for ‘health’ to be an integral part of CVD policies and interventions moving forward.

The elements associated with CVD are extensive and can be further subdivided into various categories: biological (cholesterol, blood pressure, and body mass index), health behaviors (smoking, physical activity, and sleep), lifestyle factors (stress, work load and social support), and societal (healthcare systems and governing policies).(93) The wide-ranging nature of these elements makes CVD a challenge to address however, a focus on health promotion may be a judicious solution. As mentioned previously, the World Health Organization defines health as ‘a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.’(4) This is a broad definition of health, however, it emphasizes a key point – that health cannot solely be defined by disease. In other words, disease is neither a sufficient nor a necessary cause of health. Building on this definition, the term ‘cardiovascular health’ (CVH) can be described as a state of well-being based on health factors known to improve heart health.

Not surprisingly, the same risk factors that instigate CVD can also improve CVH if managed appropriately. Commonly known risk factors include, but are not limited to, smoking habits, diet, physical activity, obesity, age, blood pressure, blood glucose,
cholesterol, and family history of heart disease.(74) These factors are commonly known as risk factors because they result in the development of atherosclerosis which ultimately leads to CVD.(88) However, if optimized, they can also be used to measure health and/or the prevention of atherosclerotic disease.(88) For example, blood pressure that is not controlled (in normal range) can progress to hypertension which can eventually cause a stroke. However, blood pressure that is controlled can lead to healthy vascular changes that prevent the onset of a CVD event. It is important to note that CVD is multifactorial and managing just one or two risk factors may not eliminate the chances of an event.(74) Similarly, CVH involves maintaining a healthy status in multiple health factors.

CVH and CVD are indeed distinct concepts but are also part of a larger continuum conceptualized in the diagram below (Figure 2.2). (This diagram was conceived for the purpose of this thesis and not intentionally copied from any other source). The continuum begins with ideal cardiovascular health which represents an optimal state of physical well-being that is disease-free. Primordial prevention maintains this state of ideal health and prevents the initial onset of traditional CVD risk factors including, hypertension, high cholesterol, and diabetes. There are many more CVD risk factors including obesity and smoking that increase the likelihood of developing clinical CVD. Primary prevention is aimed at the population with CVD risk factors and is intended to prevent a clinical diagnosis of CVD, marked by the presence of atherosclerosis (blockage of blood vessels). Secondary prevention occurs in those with clinical CVD and is key to preventing a CVD event such as a heart attack, angina, and stroke, which results from the progression of clinical CVD. Tertiary prevention is the last line of defense on the continuum and prevents the occurrence of early death from a CVD event. The grey arrow on the diagram indicates that individuals can move freely in either direction along the continuum. Given the threats of the right side of the diagram, emphasis should be placed on the left side of the diagram – starting with ideal cardiovascular health and primordial prevention.
Figure 2.2 Diagrammatic representation of the continuum of cardiovascular health and cardiovascular disease

Given the high burden of CVD, and the important contribution of early epidemiological studies, CVD prevention through CVH promotion is foundational public health and public policy approach worldwide. (88) This has brought along a necessary shift from focusing on CVD to enhancing CVH. Leaders in the field of health policy have recognized the need for interventions that increase population impact, by providing a healthier environment that allow for healthier decisions of individuals. This has also highlighted the important role of the community as researchers reveal wide variations in CVH across subpopulations based on their social, economic and physical environments. (94) There is now a greater push for policymakers is to create the political and environmental change needed for communities to adopt healthier lifestyle and behavioral options for their residents. (95) Numerous declaration and call-to action documents worldwide have promoted the need for partnerships between section and improved infrastructure to support greater population CVH. (96, 97) A pertinent example of this is The Canadian Heart Health Strategy and Action Plan released jointly by the
Canadian Minister of Health and Chief Public Health Officer in 2009. The plan lays out a six-part nationwide strategy, proposed by health experts throughout the country, including: ‘create heart health environments, help Canadians lead healthier lives, support Indigenous populations, reform health services, build the knowledge infrastructure and develop the right service providers’. Further research is needed to highlight progress towards these goals and to inform future policy for CVH.

As we move forward with CVH promotion, it is key that we identify those elements that impact health, which brings us to an important distinction – the difference between risk factors and determinants of health. This distinction is an ongoing topic of serious debate in the health literature. However, the current consensus is that risk factors are individual attributes that increase the likelihood of disease, while determinants of health refer to the wider elements that give rise to risk factors, i.e. the causes of causes. At the individual level, these two terms often overlap however, more obvious differences are noted at the population level. This is carefully highlighted in the seminal publication by Geoffrey Rose. “Sick Individuals, Sick Populations,” wherein Rose emphasizes the need to distinguish between the “causes of cases” and the “patterns of incidence.” He later concluded that the ideal approach would likely involve both concepts; understanding not only what causes sickness, but also who falls ill and what drives rates of sickness in various populations. Therefore, in addressing CVD, using health as a tool involves not simply the reduction of risk factors but also, an understanding of determinants of health that can promote greater CVH. This is the premise of the thesis and the foundation for its objectives.

As the conceptualization of the thesis moved forward, two important questions underpinned the operationalization of health for addressing CVD: Why should we address CVD? And, what makes health the ideal tool to do so? These issues are the focus of the subsequent sections of this literature review however they may be briefly addressed as follows. As a leading cause of morbidity and mortality worldwide, CVD carries a high burden for humanity. However, research has shown that up to 80% of CVD is preventable and rates of disease are highly amenable to interventions and policies beyond traditional medical therapy. Furthermore, health is a universal concept that may be
applied to everyone, individuals, and populations, regardless of race, culture, or beliefs. There are multiple dimensions of health, including physical, mental, and social health, that can be affected by simple adjustments to behaviors and attitudes at both the individual and population levels. (28) Similarly, there are numerous determinants of health that, once identified, can inform ideal targets for future policies to improve health. (103) From a practical point of view, investing in health is also a cost effective and efficient way of addressing the issue of CVD in the long run. Health is often persistent across generations, giving the future workforce the chance at increased economic output, and easing large financial commitments to the healthcare system. (28)

2.5 A Multilevel Approach to Cardiovascular Health

In operationalizing health, another important question arises; Why don’t we all experience health in the same way? Research has shown that variations in the distribution of health outcomes, may be attributed to differences across individuals based on individual characteristics such as age, race or sex, or differences across populations based on population characteristics such as culture or geographic location. (64) In fact, variations in the distribution of health outcomes likely stem from a combination of differences in characteristics at the individual and population levels. (64) Thus, examining factors that contribute to health at both of these levels is an intuitive approach to health promotion.

The multilevel approach to health was supported in the 1982 seminal paper by Rose et al., ‘Sick Individuals and Sick Populations’, which presented two main strategies for disease prevention that are well-known to date – ‘high-risk’ (individual) and ‘population’ strategies. (104) The high-risk strategy focuses medical attention on those individuals with risk factors for example, statins for those with hypercholesterolemia or insulin for those with diabetes. (104) This method is well-known in the medical field and highly regarded because it provides an immediate and effective solution to impending heart disease. The population strategy involves identifying the underlying causes of disease and shifting the whole distribution of risk within a population. (104) This approach may produce greater gains in a larger proportion of the population but has not been popularized due to a slower impact on the health of individuals. (104) The concept of a multilevel strategy for disease prevention can also be translated to health promotion.
Population-level approaches for CVH involve addressing risk factors across groups of individuals. The use of community-based interventions for CVH have been widely successful worldwide. A recent review indicated that 10% increase in the price of tobacco worldwide has accounted for a 4% decrease in tobacco consumption.(105) Further studies have also demonstrated that a salt reduction strategy is one of the most cost-effective and efficient public health approaches for improving population health.(85) However, recent population-level approaches have found success examining more ‘upstream’ determinants such as knowledge and awareness.(85, 102) Studies in low- and middle-income countries, such as India, Iran and Pakistan, have found significant improvements in lifestyle habits and healthy behaviors by increasing knowledge on dietary factors in vulnerable populations such as women living rural and urban areas.(106)

Individual-level approaches have been the mainstay of medicine and many public health interventions; statins for high cholesterol, smoking cessation, and regular exercise are well-known methods of prevention to date.(75) Medical and pharmacological therapies have advanced significantly in the past decade to market new drugs for cholesterol and glucose control, along with new surgical procedures such as angioplasty.(75) The use of risk scores and algorithms have been regularized with individuals being categorized as high or low risk based on levels of risk factors such as age, blood pressure and cholesterol levels.(107) Despite this progress, CVH rates remain low and while risk scores were created to act as guides and/or thresholds for treatment, they tend to provide a false sense of assurance that contradicts disease prevention efforts.(107)

In describing the multilevel strategy, Rose differentiates between the ‘causes of individual cases’ and the ‘causes of incidence in a population’, and the need for different approaches to both—known as the Rose theory.(104) The ‘causes of individual cases’ theory is captured in the individual approach described above. The ‘causes of incidence’ theory indicates that in order to fully understand differing incidence rates in at least two populations, we must first understand the factors that influence these rates at the level of the population, rather than solely the characteristics of individuals within that population.(104) This is captured in the less-popularized population approach. The Rose
theory is important because it suggests a combined approach, identifying both ‘causes of individual cases” and ‘causes of incidence’, as the optimal approach for achieving greater progress on health promotion. (104) Further research is required to determine the optimal balance of individual- and population-level strategies for CVD prevention and CVH promotion.

2.5.1 The Influence of Individual- and Population-Level Determinants on Cardiovascular Health

As mentioned earlier in this review, further research is needed to generate in-depth knowledge on the determinants of CVH which can act as targets for policy and intervention in the Canadian population. Even more importantly, there needs to be a greater understanding of how varying determinants act together to collectively impact CVH. (108) In reference to Rose, one must consider the ‘causes of incidence’ to attempt a shift in the distribution of health in the population. (104) A systematic investigation into the determinants of health would not be complete with addressing all the ‘layers of health’ (as in the Dahlgren and Whitehead model) or ‘health fields’ (as in the Lalonde report). (30, 59) Subsequent discussions will now be aimed towards the determinants of CVH.

It is well understood that CVD, and consequently CVH, are multifactorial – influenced by various determinants of health. (109) The World Health Organization defines determinants of health as, ‘the range of personal, social, economic and environmental factors that determine the health status of individuals or populations.’ (5) The Dahlgren and Whitehead model is a well-known socio-ecological model that emphasizes the fact that individuals are a part of a larger society and the interaction between the two are almost inextricable. (59) Individuals are nested within social communities and geographic regions which forms a contextual environment that constantly shapes the individual’s lifestyle choices and health. The model refers to both individual level (factors are characteristics of the individual) and the population level (factors that are characteristic of the environment or groups of individuals) influences that act together to influence health. (59, 110) Research to date suggests that health and disease are not impacted by
independent, disconnected mechanisms but by determinants that interact at both the individual and population levels. (100)

According to the Canadian Council on Social Determinants, there are 12 determinants that most impact population health in Canada including: income and social status, social support, education, employment, working conditions, physical environment, biology and genetics, personal health practices, child development, gender, culture and health services. (111) While some well-known determinants are biological, many are also social, lifestyle or economic determinants that influence the distribution of health in the Canadian population. (111) Therefore, to gain a local perspective on Canadian CVH, it is important to include these determinants in any study examining the health of the Canadian population. Given the scarcity of research surrounding the impact of these determinants on CVH in Canada, the following discussions will examine the current literature on how determinants, at both the individual and population levels are known to influence CVH globally. The list below is not intended to be an extensive coverage of determinants but will highlight the major CVH determinants addressed in this study.

2.5.2 Individual-level Determinants

Individual-level determinants are those factors that are inherent to the individual and are measured at the level of the individual. (112) The Main Determinants of Health model suggests biological factors, age, race, and ethnicity as individual determinants. However, since the inception of that model there have been numerous studies highlighting the significance of social and economic factors as individual determinants. (19) Below is a list of the individual-level determinants included in this study, based on data availability and strong evidence linking these determinants to CVH.

2.5.2.1 Age

Studies have consistently shown worsening CVH with increasing age for both men and women although, a closer look into individual health behaviors reveal differing patterns. (113, 114) In a recent review, young adults aged 20-40 years were found to have a higher prevalence of normal cholesterol, blood pressure and glucose than middle-aged or older adults aged 40 years and over. (114) However, older adults were found have a
higher prevalence of healthy diet and non-smoking habits.(114-117) Age is an important factor for primordial prevention which encourages a healthy diet and adequate physical activity at a young age to prevent the onset of diabetes and hypertension in later life. The Cardiovascular Risk Young Finns Study, a sample study initiated in the 1970’s to study atherosclerosis precursors in Finnish children, was one of the first studies to show that exposure to high obesity, high cholesterol or high blood pressure in childhood may predict early signs of CVD in young adulthood.(118) Thus, the promotion of CVH earlier in life, even in utero, may prevent the onset of CVD or at the least, reduce its impact in adulthood.(118)

2.5.2.2 Sex and Gender

The term ‘sex’ for the purpose of this research is defined as a set of biological attributes related to physical functions including genetics and sexual anatomy. The term ‘sex’ should not be confused with ‘gender’ which is defined according to social role and related to identity, expression and sexual preferences.(119) A seminal publication by Clow et al has led to the promotion of Sex- and Gender- based analysis (SGBA) in research.(120) According to Clow, SGBA is a method of identifying sex and gender gaps in research evidence and aiming research questions towards explaining those gaps.(120) This is especially important for CVD which is now the leading cause of premature death in Canadian women. In 2019, the Heart and Stroke Foundation launched a campaign “Time to See Red” which is intended to promote a gender shift in the CVD research population which currently consists of 66% male participants.(121)

Most of the research surrounding CVD and CVH differences are focused on biological sex. Data over the past few decades have shown that women have higher mortality rates of coronary heart disease and stroke, although men have a higher prevalence of coronary heart disease.(9) Research has suggested that this may be due to differences in lifestyle, life expectancy and clinical presentations of CVD in men and women.(122) In a recent analysis using data from the Paris Prospective Study, women were twice as likely as men to have healthier health behaviors, except for total cholesterol and physical activity.(123) Results were independent of levels of poverty and deprivation however, women in that study sample were also found to be more depressed and less educated than men.(123)
There are several dimensions for measuring gender including gender identity (an individual’s sense of their own gender) and gender expression (the manner in which an individual’s gender is manifested).(119) Sexual orientation may be classified under the term ‘gender expression’ and refers to the gender of attraction.(119) Unlike biological sex, sexual orientation may vary over time and individuals, and may be represented as lesbian, gay, bisexual or heterosexual.(119) While the proposed gender proxies are simple to conceptualize, they are challenging to differentiate and identify with measurements tools.

Few studies have examined the association between gender and CVH, with most studies conducted in the US. A 2013 study was one of the first to examine the association between cardiovascular biomarkers and sexual orientation in young US adults.(124) Results show that women who were lesbian or bisexual had higher BMI, and heavier smoking and drinking as compared to heterosexual women.(124) Similarly, men who identified as homosexual or bisexual had higher blood pressure and pulse rates as compared to heterosexual men.(124) Two recent Canadian studies were found to exclusively examine the link between gender and cardiovascular health. Using data from the Canadian Community Health Survey, Steele et al found that, in women, bisexual and lesbian reported heavier smoking and drinking as compared to heterosexual women. (125) The second study by Veenstra et al also used data from the Canadian Community Health Survey and examined the interaction between income and gender and its effects on hypertension.(126) Results of that study showed that wealthier bisexual adults were more likely to report hypertension than poorer bisexual adults.(126)

National surveys such as the National Health Interview Survey in the US and the Canadian Community Health Survey in Canada have begun to collect data on gender in the past few years. However, the questions differ across surveys; with some surveys asking respondents about gender identity and others asking about gender expression. There is currently no known consensus on which measure best validates the concept of gender in self-reported surveys.(127) Therefore, it is contingent upon survey developers to ensure test question validity and measure the different dimensions of gender separately, with special consideration giving to terminology and populations.(120) Given
the emerging significance of gender in CVH, this study will include the variables that represent the construct of gender in the survey data.(127)

2.5.2.3 Race/Ethnicity

The term ‘race’ refers to biological traits, including skin color and bone structure, that are inherited, while ‘ethnicity’ refers to shared cultural practices among a group of individuals with similar heritage or ancestry.(128) Race/ethnicity is often used as a combined term to encompass aspects of both physical traits and cultural influences, especially for the proposes of self-reporting.(129) The impact of race and/or ethnicity on health is multidimensional with our response to any race/ethnicity differing based on societal, peer and personal perspectives.(129, 130) Social prejudice and discrimination largely influence the role of race/ethnicity in the health of individuals and tend to underlie racial disparities in health.(130)

The relationship between race/ethnicity and cardiovascular health varies widely by country. In the US, research shows that Hispanic and non-Hispanic Black adults reported higher levels of physical inactivity as compared to non-Hispanic White adults.(131) In contrast, Canadian data from national surveys revealed that most ethnic visible minorities (excluding Latin Americans), compared to White ethnicity, reported overall higher levels of physical inactivity and lower body mass index and smoking, after adjusting for sociodemographic characteristics.(132) Due to its complex nature, race/ethnicity may also be on of the mechanism pathway through which other social determinants, such as immigration or income, act upon health.(133) The thesis will adjust for other social determinants on the pathway and utilize a Canadian standard definition of race/ethnicity according to its categorization in national survey data, which is based on the Employment Equity Act of Canada (a legislation defining visible minorities based on national needs and estimates).(134)

2.5.2.4 Immigration

With 3.4% of the world population migrating in 2017, up from 2.8% in 2000, the health of migrants is a major global issue today.(135) Immigration status has long been considered a determinant of health, giving rise to the term ‘healthy immigrant effect’
which is a phenomenon where the health of immigrants are healthier than existing residents of the country, despite the migrants’ countries of origin.(136) A possible explanation may be immigrant self-selection, which has been shown to be a contributing factor to immigrant health in the US, Canada, UK and Australia.(136)

A recent US study by Lê-Scherban et al investigated whether there was an association between CVH and immigrant status, and how this association differed by age.(137) Results showed that immigrants living in the US for a short duration of time, as compared to those who were born to an immigrant family in the US, reported experiencing better overall health.(137) Similar findings were noted in Canada by Tu et al who examined the CVH of over 800,000 immigrants to Ontario, Canada over a 15-year period.(138) The study found that the risk of a CVD event was greater in long-term immigrants as compared to immigrants living in Ontario for less than ten years.(138) Additionally, the incidence of CVD events was 30% lower in immigrants living in Ontario for less than ten years than in long-term immigrants.(138) This relationship was maintained after adjustment for socioeconomic status, indicating that the length of immigrant status may be a contributing factor.

2.5.2.5 Alcohol and Illicit Drug Use

It is well established that increased consumption of alcohol and illicit drug use is associated with poor CVH.(139) Drugs are known to affect every part of the circulatory system: heart function, heart rhythm and vasculature. For example, cocaine is associated with heart attack and stroke through mechanisms such as vasoconstriction, high blood pressure, thrombosis and increased heart wall thickness.(140) Such effects are similar for amphetamines and hallucinogens. Canadian statistics show that over 50% of males report using any drugs in their lifetime, indicating the need to examine drug use a determinant for CVH in Canadians.(141)

Globally, a metanalysis of 8 prospective studies in North America and Europe, consisting of over 250,000 men and women, showed a strong inverse association between alcohol use and coronary artery disease although, the quantification of alcohol use varied widely across the studies.(142) Nevertheless, there remains strong evidence that excessive
alcohol use or binge drinking (5 drinks for men and 4 drinks for women on one occasion) is associated with increased blood pressure and vascular changes.(143) Given the growing crisis of drug and alcohol addiction, research shows that other social determinants such as social support, parental education and income in adulthood may significantly modify the association between drugs, alcohol and CVH.(144)

2.5.2.6 Psychological Stress

There is extensive literature on the strong link between both acute and chronic psychological stress and poor CVH.(145) Current studies are attempting to untangle the mechanisms through which stress impact CVH including physiology, socioeconomic status, race, and the physical and social environment.(146) In this thesis, the focus will be on chronic stress from the home and work environment, as opposed to acute stress caused by natural disasters or unexpected sudden events. Results from the INTERHEART study, a large, international case-control study, showed that those with higher levels of general stress from work, home or both were 1.45 times more likely to experience a cardiovascular event.(147) The results were consistent across race, sex and region of residence. Additionally, results were reproduced a few years later in the INTERHEART-China study.(148) A 2017 systematic review and meta-analysis examined the impact of psychological interventions on cardiac outcome in over 10,000 individuals.(149) Findings showed that while interventions did not decrease the risk of cardiovascular event, they did decrease the risk of cardiac mortality.(149)

2.5.2.7 Social Inclusion

Early work on social support was conducted by researchers of the University of Montreal, proposing social inclusion as one of five dimensions of social support and cohesion.(150) Her dimensional framework has since been embraced by the Social Cohesion Network, a professional and governmental assembly in Canada that aims to incorporate social support into policy.(150) Social inclusion is a psychosocial or interpersonal factor that represents the social interconnectedness between individuals. The term ‘social inclusion’ falls under the umbrella term ‘social support’, and implies a sense of belonging to, or connection with, surrounding social structures such as neighborhoods or
One of the earliest studies in social support and cardiovascular health was published in 1996 using data from the Framingham Heart Study. The analysis of 32,624 males revealed that, over a 4-year follow up, those in the lowest stratum of social support had a relative risk of 1.90 for cardiovascular mortality and 2.21 for incident stroke compared with those in the highest stratum. Ross et al used CCHS 2000-2001 data to demonstrate the link between sense of community belonging and health in Canadians. Results showed that those reporting a strong sense of community belonging was twice as likely to also rate their health as very good/excellent. Results are similar worldwide; a recent systematic review and meta-analysis of 23 studies conducted worldwide showed a 29% increase in the risk of coronary heart disease for those with poor social relationships (characterized by loneliness and social isolation). Further studies are needed to examine how other individual determinants, such as sex, and neighborhood determinants, such as crime, impact the relationship between social inclusion and health.

### 2.5.3 Population-Level Determinants

Population-level determinants are those factors that relate to groups of individuals or their environment and are measured at the group-level. The thesis focuses on those population-level factors that are characteristics of a group of individuals residing in the same geographic area. Studies have provided substantial evidence for the role of geographic areas in the CVH of individuals. Ross et al examined the effect of neighborhood characteristics on body mass index (BMI) in urban Canada. A lower BMI was observed in residents of neighborhoods with a higher proportion of education residents and a lower proportion of immigrants. The population density of a neighborhood was not significantly associated with BMI. In another study, Villanueva et al investigated the effect of neighborhood SES on rehospitalization and death 1 year after a major CVD event in New York residents. Neighborhood SES was defined as the proportion of residents living below the federal poverty line and divided into quintiles. In this study, no significant associations were found for neighborhood SES and rehospitalization or death 1 year after a major CVD event. However, living in neighborhoods with high levels of...
poverty was associated with higher odds of diabetes, hypertension, peripheral vascular disease and renal disease which are known CVD risk factors.(156)

Results have also been consistent in studies in Europe where low neighborhood SES has been linked to poor health outcomes for CVD. Chaix et al aimed to determine the effect of neighborhood socioeconomic status on ischemic heart disease mortality rates in the Swedish population.(157) The study used multilevel Weibull survival models with a neighborhood random intercept and observed that even after adjusting for individual factors, heart disease mortality rates increased with increasing neighborhood deprivation over the time period.(157) Sundquist et al investigated whether neighborhood socioeconomic conditions predict incident coronary heart disease in prospective sample of the Swedish population.(158) Neighborhood socioeconomic conditions were neighborhood education and income based on the proportion of individuals with less than 10 years of education and in the lowest income quartile respectively. Both lower neighborhood education and income predict coronary heart disease (HR=1.38, 95 percent confidence interval (CI): 1.13, 1.69) and (HR=1.36, 95 percent CI: 1.11, 1.66).(158) After adjustment for individual and neighborhood characteristics, there remained significant between-neighborhood variance.

2.5.3.1 Population Density

There have been exponential increases in the size of populations worldwide in the past decade, with 75% of the world population now living in cities. This has giving rise to a growing body of research that links urbanization to poorer health outcomes.(159) A study conducted in China showed that growing cities have led to increased migration rates and better living standards however, this growth has been accompanied by an increase in CVD risk factors.(160) Another key study conducted in an Australian sample showed that annual increases in population density was associated with increased weight, cholesterol levels and blood pressure levels in residents over a 12-year period.(161) Research concludes than urbanization, which may be characterized by an increase in population density, is a major determinant of health.(161) This conclusion has been supported by organizations such as the World Health Organization and even the Canadian Institute of Health Research which has launched the Healthy Cities Research Initiative
with the “overarching goal of improving health by maximizing the health-promoting potential of cities and urbanized areas in Canada and internationally”.(162) Future research on CVH should include population density as a potential determinant of health in the Canadian population.

2.5.3.2 Housing

Fundamentally, lack of adequate shelter, ventilation, water, and basic sanitation will negatively impact health and allow for the transmission of other illnesses. Housing stability, quality and affordability can all impact the physical and mental well-being of individuals.(163) Homelessness and housing insecurity are major risk factors for chronic illness and disease and can be catalysts in the cycle of poverty and poor health. For instance, individuals who are homeless or housing insecure are more likely to experience psychological distress, substance abuse, domestic violence, and symptoms of trauma which are all predisposing factors for poor health.(163) In an 11-year follow up study conducted in Canada, authors showed that the risk of mortality from ischemic heart disease was 63% to 80% higher for those who lived in shelters as compared to those who lived a stable home.(164) At the population-level, a study by Chamber et al examined the association between housing assistance and CVD outcomes in Latin American adults.(165) Results showed that while residents with public assistance had the highest risk for CVD compared to residents paying rent without assistance, health behaviors such as diet and physical activity accounted for a large proportion of the observed differences in CVD risk.(165)

2.5.3.3 Health Services

Health care is a publicly funded system which provides all Canadians residents, at no extra costs to them, with “reasonable access to medically necessary hospital and physician services.”(166) However, this system has been met with challenges that has greatly impacted the health of the population. A recent study on the effect of wait times in Canada showed that an increase in waiting times between 1993 and 2009 was associated with higher mortality rates.(167) Results revealed that the increase in waiting times was responsible for up to 44,273 additional deaths in Canada during the 16-year
Therefore, it is reasonable to hypothesize that greater cardiovascular health may be dependent on an improvement in health care and health care services. An Ontario-based study by Alter et al was one of the key studies in examining the relationship between physician supply and use of cardiac health services. Results show that in Ontario, there is an inverse relationship between physician supply for cardiologists and CVD burden. There was no association between the use of cardiac health services and CVD burden in the region. A more recent study by Tu et al, also conducted in Ontario Canada, showed that regions with lower rates of CVD events received more physician services and better control for cholesterol and blood pressure, as compared to regions with higher rates of CVD events.

2.5.3.4 Marginalization and Deprivation

In a seminal study by Hall et al, marginalization is defined as “the process through which persons are peripheralized based on their identities, associations, experiences, and environment.” Therefore, marginalization stems from inequities in determinants of health. In 2012, Canada developed the Canadian Marginalization Index (CAN-Marg) to aid researchers in understanding inequalities in health among population subgroups and geographic areas. The CAN-Marg combines four dimensions of marginalization in Canada and measures the effects of those dimensions on health: residential instability, material deprivation, ethnic concentration and dependency. Developers of the CAN-Marg conducted a study assessing the association between marginalization of neighborhoods in Canada and health outcomes. Results showed that living in areas with high residential instability was associated with poor health outcomes including binge drinking, smoking, disability, chronic diseases, low physical activity, and poor self-rated physical/mental health. Additionally, living in areas with higher material deprivation was significantly associated with being overweight, being physically inactive, smoking, binge drinking, disability, and a lower likelihood of having had a flu shot in the previous year. Findings indicate the utility of the CAN-Marg Index and more importantly, the key role of area-level marginalization in determining health.
2.5.4 Individual- and Population-Level Determinants

Some determinants can be measured and defined at both the individual- and population-levels i.e. determinants can be attributes of either individuals or populations. Cross-level bias occurs when a population-level determinant is defined only as an aggregate of an individual-level determinant and inferences are made erroneously at the individual level.(172) Therefore, when individual- and population-level variables are studied together, it is important to clearly define determinants at each level of measurement. Below is a list of determinants that may be measured at either the individual- or population-levels and, studies that have examined the influence of determinants at both levels on health.

2.5.4.1 Income

Income can be measured at the individual or population levels and is highly impactful on living conditions and health-related behaviors. Low individual income can directly affect CVH through the inability to afford adequate food and housing, poorer access to social and recreational activities and, the lack of knowledge on healthy living.(173, 174) The association between income and health in average working adults is largely positive.(174) However, the relationship between income and health is not always linear and tends to plateau, even becoming negative, at high income levels.(174) A nationally based study on Canadian trends has shown that, over the time period 1994-2005, the prevalence of heart disease, diabetes, hypertension and obesity was highest in those with average income as compared to those with low and high income.(175) In the past decade, there have been a greater number of studies examining income at the population level and the impact of population-level income on health. Results from the PURE (Prospective Urban Rural Epidemiologic) study were published in 2019, examining the risk of CVD events in 20 low-income, middle-income, and high-income countries.(176) In high income countries, the risk of CVD (based on CVD event incidence) was 1.23 (95% CI 0.96–1.58) for those with low level vs high level education.(176) However, in low income countries, the risk of CVD was 2.23 (95% CI 1.79–2.77) for those with low level vs high level education.(176)
2.5.4.2 Education

Education can have direct influence, or it may be a mechanism through which other health determinants such as income and employment, impact health. Individuals with higher education have a greater knowledge of maintaining a healthy lifestyle and actively engage in opportunities to enhance their health. Studies have shown that individuals with higher levels of education have lower risks of cardiovascular disease and better cardiovascular health. In a Denmark sample, Olsen et al noted that a decrease in cardiovascular disease from 1978 to 2006 was accompanied by a concurrent increase in education level in women. The INTERHEART study conducted in China showed that the risk of acute myocardial infarction increased by almost 50% in those with lower level education as compared to those with higher level education. Education measured at the population level is also a significant predictor of health. A survey study by Lee et al found that US youth living in neighborhoods characterized by lower educational attainment were more likely to report poorer dietary habits than youth living in neighborhoods characterized by higher educational attainment. In this study, education at the neighborhood level was defined as the proportion of persons 25 years and older with less than a high school education and was a measure of neighborhood socioeconomic status.

2.5.4.3 Employment

Employment can represent the major source of income for most individuals and the security of a career for some individuals. According to Burgard et al, work and working conditions can have positive health benefits through direct mechanisms such as improved access to health, improved psychosocial well-being and decreased harmful stress. However, they have also argued the potential for negative health benefits through longer and more stressful work hours, high levels of job dissatisfaction and significant job strain. Similarly, living in a community where there are less job opportunities or less high-paying jobs can foster job insecurity and create unhealthy work environments not meeting the needs of workers. A systematic review was conducted by Kim et al on the impact of both unemployment and job insecurity on health. Results revealed strong relationships between unemployment and mortality, and also between job insecurity and
poor physical health, with no differences noted in men and women.(182) In another study examining the effect of employment on acute myocardial infarction, Dupre et al found a higher risk of acute myocardial infarction in the unemployed as compared to the employed (HR 1.35 [95% CI, 1.10-1.66]). (183) Additionally, a dose-response relationship was noted where the risk of acute myocardial infarction increased from 1 job loss (HR 1.22 [95% CI, 1.04-1.42]) to 4 or more cumulative job losses (HR 1.63 [95% CI, 1.29-2.07]) compared with no job loss. (183)

2.5.5 The Multilevel Influence of Determinants on Cardiovascular Health

The previous sections focused on individual-level and population-level studies that have investigated the impact of determinants on CVH. However, single-level models do not reflect the real-world scenario where individuals are nested within environments, and the two often interact. (184) In analyzing CVH, a multilevel approach suggests that the CVH of individuals may be influenced by characteristics of individuals and independently, by characteristics of populations. Individual-level determinants are simply defined as those characteristics of the individual that can impact their health. On the other hand, when defining population-level determinants, the question often arises: what is the population? A population is a group of individuals that may be defined by any characteristic that the individuals in that population share. (184) For example, an assembly consists of individuals with common spiritual beliefs; a community consists of individuals with common cultural identities; a neighborhood consists of individuals residing in the same geographic region. Therefore, an important step in operationalizing the multilevel approach is defining the population – the group unit of observation and measurement. (184)

The health of individuals may be impacted directly though the social, physical, and political environments in which they live. (185) Thus, the living environment is a key component to health and characterizes the population-level effect on health. Due to their environmental contexts, neighborhoods are of particular significance in studying health. (186) A neighborhood is an area where a group of individuals reside. Individuals residing in the same area tend to have similar ethnicity, income, housing preference and
societal perspectives. Thus, neighborhood units are often divided based on race, socioeconomic status, or local policies. (186) Neighborhoods may also be defined based on geographical areas; however, the boundaries of geographic areas can vary widely even within countries. Additionally, individuals may, in essence, belong to many neighborhoods and consider their ‘job neighborhood’, where they work, different from their ‘social neighborhood’, where they socialize. (186) Therefore, when selecting the neighborhood to define populations it is important to ensure that the neighborhood is accurately classified, that is, neighborhood-level determinants accurately represent the effect of the neighborhood on health. (186) The selection of the neighborhood unit in this study is addressed in further detail in the methods chapter.

The majority of studies utilizing the multilevel approach in their analyses, tend to focus on either the individual or the neighborhood effects, controlling for one or the other as a nuisance factor. (187) However, individual-level studies tend to neglect the context of health and health behaviors. Additionally, area-level studies are unable to determine whether differences in health are due to the differences across areas themselves or to differences across people living in those areas. (187) Arguably, a more efficient use of the multilevel approach is to examine both individual and neighborhood effects and how they may interact to influence health. This concept was exemplified in a recent study by Rachele et al., which examined the associations between neighborhood disadvantage, individual-level socioeconomic position (education, occupation, and household income) and BMI (via self-reported height and weight) in Australian neighborhoods. (188) Additionally, the study examined whether the relationship between neighborhood disadvantage and BMI differed by level of individual socioeconomic position. Results show that those living in disadvantaged neighborhoods and those with little to no education had significantly higher BMI. (188) Results were not significant for the cross-interaction models. Nevertheless, the study provides evidence for the independent roles of both individual and neighborhood socioeconomic factors in determining CVH. A similar study by Shin et al examined the cross-level interaction between individual and regional socioeconomic status on the survival after onset of ischemic stroke in the Korean population. (189) In this study, cross-level interaction was significant, with individuals of low incomes living in high socioeconomic status regions having higher rates of mortality.
due to ischemic stroke than those individuals of low incomes living in low socioeconomic status regions. (189) In comparison to the Australian study, results of this study provide evidence for a joint effect of individual and regional socioeconomic factors on CVH. The mechanisms for joint vs independent effects of individual- and area-level determinants on health remain largely unexplored and further research is warranted.

As established earlier, variations in the CVH of individuals may be attributed to differences in the characteristics of individuals and/or differences in the characteristics of populations. Differences among individuals, or compositional effects, are often the focus of health research studies and over time, have become the mainstay of health practices. However, it is not implausible that our health differs, not only based on our own characteristics, but also based upon the characteristics of the areas in which we live. (190) The multilevel approach highlights the contextual influence on health by determining the share of the variation in health outcomes attributable to differences between populations. (191) Given the multifactorial nature of CVH, the contextual influence has traditionally been small but still significant. (94) Taken together with the moderate to large effects of the population characteristics on health outcomes, the substantial role of contextual effects on health are key to informing health policies and interventions aimed at CVH promotion. (94)

This thesis will adopt a multilevel analytic approach to investigating the influence of health determinants on CVH, which allows for the simultaneous examination of individual- and population-level determinants, and potential interactions, on the CVH of individuals. The use of multilevel analysis has increased greatly over the past decade alone, especially as software has and statistical methods have improved. (184, 191) The multilevel approach to examining CVH allows for more in-depth research into defining populations into groups such as neighborhoods, identifying key population-level determinants that influence CVH and highlight how interactions between individuals and populations can influence health. (192) While thesis findings will not explain the mechanisms behind the patterns observed, they will bring us one step closer in formulating causal testing that can radically change our outlook on health promotion.
The thesis is not the first attempt to examine the multilevel influence of determinants on CVH. Multilevel studies have identified strong associations between the neighborhood area environment and CVD. Fewer studies exist that examine the association between the neighborhood area environment and CVH. Unger et al in 2014 was one of the first of such studies using multinomial logistic regression to investigate the relationship between CVH and area resources in a cohort of US adults, adjusting for individual determinants.(193) Boylan et al in 2017 used hierarchical linear regression models to examine the interaction between individual- and area-level socioeconomic status on CVH in a cohort of US adults.(194) Foraker et al in 2019 used generalized estimated equations to conduct a similar study cohort of African-American US adults.(195) All studies noted that individual- and area-level determinants were associated with the CVH of individuals in the US. In the Canadian setting, CVH was not examined in multilevel models, however, Prince et al in 2011 used multilevel analysis to examine the influence of area built and social environments on physical activity and obesity.(196) A similar study was conducted in 2009 by Harrington et al.(197) Results of those studies confirm the findings of the US studies. Both Canadian studies were conducted on adults residing only in Ontario, Canada and though results confirmed the association between area-level determinants and CVH, they were not applicable outside of that province. However, review of these studies reveals considerable gaps in the existing literature which are summarized in the subsequent section.

2.6 Identifying Research Gaps in the Literature

Following a review of existing CVH and multilevel studies, considerable gaps in the literature were identified:

1. **Multilevel Methodology**: While studies have employed multilevel analysis in examining the influence of various determinants on health, most of these studies simply use the multilevel method to adjust for the hierarchical structure of the data. Existing analyses tend not to produce information beyond the strength of association between determinants and health, which can differ based on the study sample and area-level unit. Estimates on variation in health can provide complementary information of the influence of the area level on health, including the importance of the area level effect on health and explaining how area level factors can account for differences in the health of individuals.(198)
2. **Determinants of health**: Most studies examining area-level determinants focus on socioeconomic determinants of health and the built environment, such as income or availability of health food stores. Other area-level determinants such as demography or healthcare availability are less explored in the literature. Similar findings are noted for individual determinants, with lifestyle factors being less explored in relation to social determinants. Additionally, many studies omit the influence of the interpersonal realm (social connections) on health. Thus, the influence of individual, interpersonal, and area determinants on CVH are rarely addressed simultaneously, and often their independent effects are the focus of findings.

3. **Cardiovascular Health**: Studies seldom investigate CVH as a positive construct of health, not solely represented by reductions in morbidity and mortality, and even fewer of these studies originate from Canada. The literature review noted few studies that produce estimates of the influence of individual- and area-level determinants on health, using comprehensive, positive measures of health. Further, few studies examined this influence across the entire of Canada.

4. **Sex**: Finally, studies on differences in health based on biological sex have increased in the past few years. Studies that assess sex as a modifier in the relationship between determinants and health, often employ a stratified approach in analyses. While stratification is a valid approach to investigating differences by sex, estimates often cannot be compared between the sexes as they are obtained in separate models. (Note: Sex as a modifier of the relationship between determinants and health can be assessed via two methods: stratification fits separate models for the influence of determinants on health stratified by sex, whereas interaction uses a product term between determinants and sex in the same model.)

### 2.7 Chapter Summary

The literature review demonstrates that individual- and area-level factors are known to affect CVH, however there are considerable gaps in the existing literature as described above.\(^{184, 192, 199}\) Additionally, the review shows that to fully understand the distribution of population health, it is important to systematically evaluate differences in health at both the individual and population (area) levels.\(^{191}\) Ample literature exists on the impact of individual- and area-level determinants *independently* on health, fewer studies focus on the influence of individual- and area-level determinants *simultaneously*
on health. Based on the above review, it is unlikely that individual- and area-level determinants act independently, and without interplay, to influence health.

The proposed study will extend current knowledge by evaluating the simultaneous influence of individual-level and area-level determinants on the CVH in Canada. Thesis research will make a significant contribution to the scientific literature in the following ways: a) assess the status of CVH in Canadian adults, b) identify individual- and area-level determinants that influence CVH in a sample of Canadian adults, c) examine variations in CVH due to individual and area-level determinants, and d) examine sex differences in the explored relationships between health determinants and CVH. As mentioned earlier, CVH is highly amenable to health policy and intervention at both the individual and population levels. It is anticipated that the results from this study will provide a better understanding of CVH and its determinants, that will encourage government and health officials to make more informed decisions about the policies and interventions targeted at improving CVH in the Canadian population.
Chapter 3

3 Research Objectives

The thesis proposes two main objectives to systematically assess cardiovascular health (CVH) in the Canadian context. The first main objective is to assess the status of CVH in Canadian adults using a validated CVH tool. In this first step, we will produce national estimates of the prevalence of CVH in the Canadian adult population using recent data. Additionally, we will deconstruct variation in CVH among individuals by examining how much of this variation may be attributed to differences between groups of individuals residing the same geographic area. The second main objective is to examine the influence of individual- and area-level determinants on CVH and further, their influence on variation in CVH among members of a sample of Canadian adults. Area-level determinants will be defined as characteristics of the geographic regions in which members of the sample reside.

3.1 Objective 1

3.1.1 Cardiovascular Health in the Canadian population

The first objective, to assess the status of CVH in Canadian adults, has been further divided into two sub objectives. The first sub objective uses a validated CVH tool to determine the prevalence of CVH in the Canadian adult population. The second sub objective focuses on estimating how much of the variation in CVH among individuals may be attributed to the geographic areas in which these individuals reside.

a. Estimate the prevalence of CVH in the Canadian adult population.

b. Examine variation in CVH among individuals in the Canadian adult population.

i. Estimate the proportion of total variation in CVH that can be attributed to the geographic areas in which individuals reside.
3.2 Objective 2

3.2.1 Individual-Level and Area-Level Determinants of Cardiovascular Health in a Canadian Sample

The second objective examines the influence of individual- and area-level determinants on CVH and, how these determinants account for variation in CVH among individuals; that is, (a) how individual- and area-level determinants affect CVH simultaneously, and (b) how individual- and area-level determinants interact with each other to influence CVH. To accomplish this, the second objective is organized as a series of methodologic steps as follows:

a. Examine the influence of individual-level determinants on the CVH of individuals.
   i. Assess the relationship between individual-level determinants and CVH.
   ii. Determine whether individual-level determinants of CVH can account for the variation in CVH among individuals that is attributed to the geographic areas in which these individuals reside.

b. Examine the influence of area-level determinants on the CVH of individuals.
   i. Assess the relationship between area-level determinants and CVH, accounting for the influence of individual-level determinants.
   ii. Determine whether area-level determinants of CVH can account for the variation in CVH among individuals that is attributed to the geographic areas in which these individuals reside.

c. Examine the intersectional influence of individual-level and area-level determinants on the CVH of individuals.
   i. Explore whether area-level determinants, specifically those that can be altered by health policy (such as socioeconomic conditions), modify the relationship between individual-level determinants, specifically those that cannot be altered by health policy (such as age, race, and sex), and CVH.
d. Compare, between the sexes, the influence of individual- and area-level determinants on CVH.

i. Assess how the relationship between individual- and area-level determinants and CVH, differs for females as compared to males.

3.3 Chapter Summary

This chapter has outlined the two main research objectives employed in this thesis and the subobjectives that stem from each main objective. The subsequent chapters will describe the study and statistical methodology employed to address these objectives.
Chapter 4

4 Study Methodology and Operationalization of the Theoretical Framework

The purpose of this chapter is to give a brief overview of the study design and to provide a rationale for the methodological decisions that underlie the statistical methodology discussed in Chapter 5.

4.1 Brief Overview of Study Design

The study design is cross-sectional and uses secondary data from multiple national survey and administrative data sources to examine the relationships between CVH and determinants of CVH in Canadian adults, through model building and regression analyses. Multilevel Regression Modelling is employed to examine the influence of the independent variables – individual- and population-level determinants of health, on the dependent variable – CVH of individuals.

The dependent variable is the cardiovascular health of individuals, as measured by the American Heart Association Cardiovascular Health Index (CVHI). The study will use a validated self-reported version of the CVHI proposed by researchers at the American Heart Association and the US Centers for Disease Control and Prevention.(200) Data for the dependent variable are derived from the Canadian Community Health Survey 2015-2016.

The independent variables are the determinants of health hypothesized to influence CVH in the literature review. Determinants are derived from the individual and neighborhood levels of influence. Individual-level determinants are derived from the Canadian Community Health Survey 2015-2016. Neighborhood-level determinants are derived from the 2016 Canadian Census Data, 2015-2016 Canadian Institute for Health Information Administrative Datasets and the 2016 Canadian Urban Environment Datasets.
For the purposes of this study, the neighborhood-level is represented as groups of individuals residing in the same geographic areas. The concept of the ‘neighborhood’ in this study is fully described in the previous section. The study adopts the neighborhood as the unit of analysis for the population because, neighborhoods represent clusters of individuals sharing the same living, working and/or social environment that can influence health.(186)

### 4.2 Operationalization of the Theoretical Framework

The theoretical model by Dahlgren and Whitehead, which provides the framework for investigating the multilevel influence of determinants on CVH, is used as a guide for the methodological approach to thesis objectives.

**Figure 4.1 Main Determinants of Health Model (Dahlgren and Whitehead, 1991)**


The study will assess the influence of layers of determinants on the main study outcome – CVH of individuals. The Main Determinants of Health model describes the layers of determinants and does not include the CVH study outcome. Individual determinants are
encompassed in the core and the layer surrounding the core of the model. Thus, individual determinants for the study include those constitutional or intrinsic factors such as age, sex, and race. Additionally, as in the model, the study includes individual determinants that are individual lifestyle factors such as socioeconomic status, alcohol, and stress. Key lifestyle factors such as physical activity and diet are components of the CVH measure and therefore, are not included as study determinants. Interpersonal determinants are represented in the model as the second layer labelled ‘social and community networks’ which are included in the study as the social connections and relationships between individuals. Neighborhood determinants are represented by the third layer from the core labelled ‘living and working conditions’ and are included in the study as education, unemployment and healthcare services measured at the neighborhood level. The outermost layer represents the cultural and governing influence which could not be assessed in this study. Such determinants may include provincial policies that relate to CVH which were considered for study inclusion, however, the small sample size of this layer (10 provinces in Canada) was not conducive to an adequately powered multilevel study. The determinants from the core and the two inner layers (individual and interpersonal determinants) are analyzed at the level of the individual, while those from the outer layer (neighborhood determinants) are analyzed at the level of the neighborhood. Therefore, this study will employ a two-level multilevel model examining the influence of determinants from 1) the individual level—individual and interpersonal determinants, and 2) the neighborhood level—neighborhood determinants, on the CVH of individuals.

4.3 Selection of the Outcome Measure

4.3.1 Introducing the American Heart Association’s Concept of Ideal Cardiovascular Health

The World Health Organization defines health as ‘a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.’ (4) While this definition of health is broad, it emphasizes a key point – that health cannot solely be defined by the absence of disease. In other words, disease is neither a sufficient nor a necessary cause of health. Building on this definition, the term ‘cardiovascular health’
(CVH) can be described as a state of well-being based on health factors known to support heart health.

In 2010, the American Heart Association (AHA) released the 2020 Impact Strategic Goal to guide the work of the CVD clinical and research community: By 2020, to improve the cardiovascular health of all Americans by 20% while reducing deaths from cardiovascular diseases and stroke by 20%.(201) The main aim of this goal was to promote, not simply the reduction of disease and death rates, but independently the improvement of overall health - that is, a state of physical and mental wellbeing that can delay or prevent the onset of disease and untimely death. In further examining the implication of their Strategic Goal, the AHA recognized that while ‘reducing deaths’ may be unambiguous, there was little consensus over the concept of ‘improving the cardiovascular health’. (201) Thus, a key first step was to re-define the concept of ‘cardiovascular health’; the second step was to operationalize this concept by describing a measurement tool for CVH.(201)

In the literature, CVH has been used as an umbrella term to encompass any heart healthy activity. As mentioned previously, it is commonly described using measures of mortality, prevalence, quality of life or years of life lost associated with CVD. While these approaches are widely accepted, they do not focus on the positive attributes of health that can be used as disease prevention tools; for CVD, these include healthy lifestyles and behaviors.(202) This is especially important given the key findings from the INTERHEART study demonstrating that lifestyle and behavioral factors, such as smoking, physical activity, diet, psychosocial factors, hypertension and diabetes, account for 90% of the risk of coronary artery disease.(203) To this end, the AHA re-defined CVH by introducing the concept of ‘ideal cardiovascular health’ – the ‘simultaneous presence of four health behaviors (normal body mass index, adequate physical activity, healthy diet and no smoking) and three health factors (optimal levels of fasting glucose, blood pressure and total cholesterol)’ and the absence of CVD.(201)

Ideal CVH is a collective concept of seven major health components, labelled The Simple 7, with each component defined according to optimal levels that constitute maximum
health, based on scientific evidence and medical guidelines – these criteria are outlined in Table 1 below.(201) For example, optimal blood pressure was defined according to the national guideline that dictates the healthiest range for systolic and diastolic blood pressures.(201) Optimal diet was defined according to evidence on food groups known to produce the greatest risk reduction for CVD.(201)

In constructing the concept of ideal CVH, an array of factors known to prolong life and prevent the onset of CVD were considered including: tobacco exposure, hypertension, hyperlipidemia, overweight and obesity, diabetes, physical activity, family history, nutrition, stress, mental health, metabolic syndrome, quality of life and sleep. However, the AHA definition of CVH is based on those seven factors proven by the literature to be the greatest threats for diminishing CVH throughout the entire population.(201)

Table 4.1 American Heart Association’s Definition of Ideal Cardiovascular Health

<table>
<thead>
<tr>
<th>Component</th>
<th>Ideal Cardiovascular Health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking</td>
<td>Never or quit over a year ago</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>&lt;25 kg/m2</td>
</tr>
<tr>
<td>Physical activity</td>
<td>≥150 min/wk. moderate intensity or ≥75 min/wk. of vigorous intensity or combination</td>
</tr>
<tr>
<td>Diet</td>
<td>Fruits and vegetables (≥4.5 cups daily), fish (≥7 oz weekly), whole grains (≥3 oz daily), sodium (&lt;1500 mg daily), and sugar sweetened beverage (≤36 oz weekly)</td>
</tr>
<tr>
<td>Total cholesterol</td>
<td>&lt;200 mg/dL untreated</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>&lt;120/&lt;80 mmHg untreated</td>
</tr>
<tr>
<td>Fasting plasma glucose</td>
<td>&lt;100 mg/dL untreated</td>
</tr>
</tbody>
</table>


4.3.2 Measuring the American Heart Association’s Concept of Ideal Cardiovascular Health

To accurately measure the state-of-health of a population, the measure of health should be applicable to the entire population and should capture the full extent of the illness-wellness continuum.(37) Historically, health has been measured by mortality-based indicators including all-cause, disease-specific or infant mortality.(37) While such indicators are still prominent in health literature today, they provide little to no
information on the disability or injury present in those living with chronic disease.\(^{(37)}\)

This gap in health measurement has given rise to summary measures of population health or HALYs (Health-Adjusted Life Years).\(^{(38)}\) HALYs capture the morbidity and quality of life components of health in those still living with disease.

HALYs are commonly used in health literature today and provide valuable information on the life expectancy impact of CVD in the population. However, there are still a few drawbacks associated with the use of HALYs in measuring health; 1) the calculation is based on an estimation of premature death which still does not accurately quantify the burden of disease in those living with chronic disease, 2) the measure is biased against the older population and those with severe morbidity who have only a small number of ‘life years’ to be gained and 3) discriminates against those in positions of social disadvantage where the quality of life is disproportionately affected beyond disease.\(^{(52)}\)

Arguably, HALYs may not be optimal for quantifying CVH, as defined by the AHA, which emphasizes disease prevention and reduction in clinical and behavioral risk factors across all ages and socioeconomic strata.

In choosing a measure of health, one must consider the concepts of validity, reliability and utility which are central to measuring CVH and applying this measure to populations. Validity is the extent to which a score measures what it was created and intended to measure.\(^{(204)}\) The major types of validity are content, criterion and construct validity. Content or face validity assesses whether the score appears to include relevant content.\(^{(204)}\) Criterion validity infers how comparative the score is to an existing criterion measure.\(^{(204)}\) Construct validity indicates the correlation between the score and the construct is intended to measure.\(^{(204)}\) Reliability is the stability or internal consistency of score i.e. the ability to achieve the same results on separate uses of the score. In the simple context, utility indicates the usefulness of a measure.\(^{(204)}\)

According to the AHA, a measure of CVH should:

“*Encompass more than the absence of CVD*”,

\[^{(204)}\]
“Have face validity (i.e., there would be consensus that the components of the definition each represent important facets of achieving and maintaining cardiovascular health)”,

“Be consistent with current clinical practice and public health guidelines”,

“Be readily measured with existing and future data from nationally representative samples, to allow for current assessment and monitoring of changes over time”,

“Allow for all subsets of the population to make progress toward achieving or maintaining cardiovascular health.”(201)

The ideal measure of CVH should incorporate all three properties – validity, reliability, and utility – into one comprehensive CVH measure, which is the focus of the subsequent discussion.

4.3.3 Introducing the American Heart Association’s Cardiovascular Health Index

In further exploring the concept of ideal CVH, the AHA recognized that, while it is an important benchmark, ideal CVH may not be readily attained by the entire population. Therefore, progress towards the goal of ideal CVH should be measured on a moving scale, where individuals and populations can gauge their proximity to attaining ideal CVH.(201) The Cardiovascular Health Index (CVHI), released by the AHA in 2010, is a summary score consisting of the four health factors (total cholesterol, blood pressure, body mass index and, fasting plasma glucose) and three health behaviors (smoking, physical activity and, diet) used to define ideal CVH.(201) The CVHI may be assessed in either individuals or populations. The CVHI was originally defined using objective or measured data in 2010, then in 2012, in a collaboration between the AHA and US Centre for Disease Prevention and Control (CDC), it was adapted for use in self-reported data.(200) The adaptation of the CVHI to both objective and self-reported data greatly increases its applicability in research. Both versions of the CVHI have been extensively reported in the literature, as described in subsequent sections of this review.

The CVHI was originally defined in measured data and was based on the scientific evidence surrounding each of the seven components. The CVHI assigns two points for
attaining ideal health in each of the seven components according to the criteria outlined in Table 4.2 below.(201) In applying the CVHI to the entire population, the AHA sought to maximize its utility in the presence of CVD. For this reason, less than ideal health was further subdivided into ‘intermediate’ or ‘poor’ health by expanding the criteria from table 4.2. The CVHI assigns one point for attaining intermediate health and zero points for attaining poor health in each of the seven components.(201) An overall CVHI score is achieved by summing the points attained from each component for a total score ranging from 0 (worst health) to 14 (best health).

Table 4.2 American Heart Association's Cardiovascular Health Index

<table>
<thead>
<tr>
<th>Component</th>
<th>Ideal Cardiovascular Health (2 points)</th>
<th>Intermediate Cardiovascular Health (1 point)</th>
<th>Poor Cardiovascular Health (0 point)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current smoking</td>
<td>Never or quit over a year ago</td>
<td>Former ≤ 12 months</td>
<td>Current smoker</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>&lt;25 kg/m²</td>
<td>25–29.9 kg/m²</td>
<td>≥30 kg/m²</td>
</tr>
<tr>
<td>Physical activity</td>
<td>≥150 min/week moderate intensity or</td>
<td>1–149 min/week moderate intensity or</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>≥75 min/week of vigorous intensity or</td>
<td>1–74 min/week vigorous intensity or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>combination</td>
<td>1–149 min/week moderate/ vigorous</td>
<td></td>
</tr>
<tr>
<td>Diet</td>
<td>4-5 components: Fruits and vegetables</td>
<td>2-3 components: Fruits and vegetables</td>
<td>0-1 component: Fruits and vegetables</td>
</tr>
<tr>
<td></td>
<td>(≥ 4.5 cups daily), fish (≥ 7 oz weekly),</td>
<td>(≥ 4.5 cups daily), fish (≥ 7 oz weekly),</td>
<td>(≥ 4.5 cups daily), fish (≥ 7 oz weekly),</td>
</tr>
<tr>
<td></td>
<td>whole grains (≥ 3 oz daily), sodium (&lt;1500 mg daily) and sugar sweetened beverage (≤36 oz weekly)</td>
<td>whole grains (≥ 3 oz daily), sodium (&lt;1500 mg daily) and sugar sweetened beverage (≤36 oz weekly)</td>
<td>whole grains (≥ 3 oz daily), sodium (&lt;1500 mg daily) and sugar sweetened beverage (≤36 oz weekly)</td>
</tr>
<tr>
<td>Total cholesterol</td>
<td>&lt;200 mg/dL untreated</td>
<td>200–239 mg/dL or treated to goal</td>
<td>≥240 mg/dL</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>&lt;120/&lt;80 mmHg untreated</td>
<td>120–139 or 80–89 mm Hg or treated to goal</td>
<td>≥140 or ≥90 mm Hg</td>
</tr>
<tr>
<td>Fasting plasma glucose</td>
<td>&lt;100 mg/dL untreated</td>
<td>100–125 mg/dL or treated to goal</td>
<td>≥ 126 mg/dL</td>
</tr>
</tbody>
</table>

4.3.4Critiques of the Cardiovascular Health Index

The CVHI is based on seven factors known to be most influential on CVH. However, there are many other important factors that influence CVH and these have been recognized as secondary metrics of the CVHI. (201) A key secondary metric is health-related quality of life (HRQOL) which provides an overall estimate of perceived mental and physical health status measured in a variety of ways. For example, the Centers for Disease Control and Prevention in the US, incorporates Healthy Days Measures in national surveys, which include the number of physically unhealthy days, mentally unhealthy days, and days when poor physical or mental health kept one from doing his or her usual activities during the prior 30 days. (201) Other factors considered for inclusion into the CVHI include alcohol intake, psychosocial stress, sleep and air pollution. As for alcohol consumption, the AHA believed alcohol should not be included in a measure of health given the propensity to alcohol abuse. (201) Stress is another key predictor of both health and disease however, this metric is poorly and inconsistently measured across national datasets. (201) The challenges of including determinants such as alcohol, stress, sleep and air pollution into the CVHI are that there is no consensus on the thresholds and quantitative links of these determinants with CVH. For example, we know that stress is linked to poor CVH, however, the associations differ for psychological stress and biological stress or acute stress and chronic stress. The issue of which measure should be included in CVHI is debatable.

Another critique was the fact that all seven components of the CVHI are equally weighted. This was found to be appropriate for two main reasons. Firstly, unlike the Framingham Risk Score, the CVHI was not created as a predictive score or measure of risk. Therefore, it was not developed using a mathematical algorithm requiring weighting to accurately quantify the likelihood of an outcome. (201) Secondly, the evidence to weigh any individual CVH component greater than the other is lacking. (201) The CVHI is meant to combine clinical factors and health behaviors and demonstrate the significance of both in determining CVH. (202)

Further support for the validity, reliability, and usefulness of the CVHI, can only be garnered from the existing literature. Since 2010, the CVHI has been successfully
adapted to various datasets and populations indicating its versatility as a measure of CVH. The following discussion reviews the use of CVHI in current literature including the link to CVD, use in national datasets and extension to global populations.

4.3.5 Validation of the Cardiovascular Health Index in the Literature

The most recent systematic review found 88 studies in the literature reporting on CVH, using the CVHI, from the year 2010 to 2018.(114) The validity of CVHI will be described by assessing the interpretation and use of the CVHI in the existing literature, as guided by the framework of argument-based approach to validity. The argument-based approach is a well-known method that establishes the validity of scores based on inferences and supporting evidence.(205) This discussion is not intended to validate the CVHI, but to examine the basis for that validity in the following ways: (i) examine the relationship between CVHI and mortality – a gold standard measure in health and disease, (ii) identify plausible trends in CVHI distribution over time and, (iii) highlight consistencies in use of the CVHI across various populations.

4.3.5.1 Cardiovascular Health and Mortality

The discussion begins by demonstrating its correlation with existing validated measures, preferably the gold standard. However, the current gold standard for measuring population health is mortality. Since its introduction in 2010, there has been extensive review on the topic of CVH and its inverse association with disease and death. In a series of validation studies, better CVH has been linked to decreased cardiovascular and all-cause mortality.

Artero et al conducted a longitudinal analysis to examine the relationship between cardiovascular health and mortality from all causes, CVD, and cancer in middle-aged men and women residing in Texas, US.(206) Results indicated that ideal CVH at middle-age can reduce risk of death decades later. As compared to those with 0-2 ideal CVH components, middle-aged adults with 3-4 ideal components had a 55% lower risk of death due to CVD and, those with 5-7 ideal components had a 63% lower risk of death in the later decades of life.(206) Another study by Ford et al investigated the association
between ideal cardiovascular and all-cause mortality in US adults aged 20 years and older. (207) Findings indicated that smoking, low physical activity, poor diet and high blood pressure were associated with all-cause mortality. Those individuals with 5 or more ideal cardiovascular health components, compared to those with no ideal components, had decreased all-cause mortality (HR 0.22, 95% CI 0.10-0.50) and mortality from diseases of the circulatory system (HR 0.12, 95% CI 0.03-0.57). (207)

Summary analyses have shown consistency among studies linking cardiovascular health and mortality. A recent meta-analysis by Aneni at al showed a dose-response relationship between cardiovascular health and mortality. (208) Analyses of six longitudinal studies, four in the US and two in Asia, revealed a 19% decrease in CVD mortality and an 11% decrease in all-cause mortality for each additional ideal CVH component attained. (208) Another similar meta-analysis, conducted by Fang et al, confirmed the relationship between ideal health, CVD events and CVD mortality. (209) Results showed an 80% lower risk of CVD, 69% lower risk of stroke and 75% lower risk of death due to CVD in participants with ideal cardiovascular health as compared to those with poor cardiovascular health. Additionally, there was a gradient response where a 13% lower risk of CVD was noted for every unit increase in CVH score. (209)

4.3.5.2 Time Trends in Cardiovascular Health

The prevalence rates of obesity and CVD have varied considerably over the past decade, emphasizing the need for better lifestyle choices. Given that cardiovascular health is a comprehensive score that includes both behavioral and clinical components, similar trends are anticipated. Trends in CVH were first addressed in two main studies in the US by Yang and Huffman. (210, 211)

Yang et al examined age-standardized CVH prevalence in the US population from 1988 through 2010. (211) Results showed that there was a significant increase in the frequency of persons with 0 to 1 ideal CVH metrics, but no significant change in the prevalence of those with 6 or more ideal CVH metrics. (211) Both studies reported decreases in the prevalence of smoking and increases in BMI and blood glucose, but Huffman et al reported decreases in cholesterol and blood pressure (210) where Yang et al reported no
changes in these components. Further, Huffman et al reported no changes in the prevalence of ideal physical activity or diet, while the Yang et al study reported decreases in healthy diet prevalence. Both studies propose that progress made by improving smoking and physical activity status was essentially reversed by reduction in the prevalence of ideal BMI, blood glucose level, and scores for healthy diet, resulting in relatively stable rates of overall ideal cardiovascular health over time. However, given advances in drug treatment and lifestyle therapy, overall CVH is projected to increase by up to 6% by 2020.

Mostly recently, in 2018, Enserro et al investigated 20-year trends in ideal cardiovascular health in an offspring sample of the Framingham Heart Study. Findings showed a downward trend in CVH scores, indicating a worsening of cardiovascular health over the study period (1991-2008). The trends in overall CVH was attributed to the downward trend noted in ideal health status for body mass index, blood pressure, blood glucose, cholesterol levels over the same time period. Therefore, the results of trend studies for CVH are consistent in demonstrating a decrease in ideal cardiovascular health and health components over the past decades.

4.3.5.3 Adoption of the Cardiovascular Health Index in the US

Examining CVH from the population perspective, Fang et al. was one of the first studies to demonstrate geographic variations on CVH across US states using nationwide survey data. The study by Fang et al revealed that approximately 3 percent of the population had ideal health in all of the seven CVH components and 9 percent had ideal health in up to two of the components. Statewide, the proportion of the population with ideal health in all seven components was highest for District of Colombia (6.9%) and lowest for Oklahoma (1.2%). The aggregation of CVH to the state and county levels allows for the identification of regional disparities in CVH. Information from such studies can be used to inform policies and assess the effectiveness of programs aimed at improving health at the population level.

The CVHI in survey data required adaptation to self-reported data. This adaptation was conducted by the AHA and the CDC in collaboration. The CVHI in survey data assigns
one point for attaining optimal health in each seven components according to the criteria outlined in Table 4.3 below. Otherwise, if these criteria is not met then zero points are assigned for that component. Less than optimal health cannot be further subdivided into intermediate health due to limitations in the range of responses in self-reported data. Therefore, this version of the CVHI cannot be utilized in the presence of CVD. An overall CVHI score is achieved by summing the points attained from each component for a total score ranging from 0 (worst health) to 7 (best health). The major limitation of using the self-reported data version of the CVHI measure is that it overestimates the ‘true’ prevalence of health as compared to the objective data version, due to reporting bias. However, past studies comparing self-reported to objective data for CVHI components show similar estimates indicating that the bias may be minimal.

Regardless of the data utilized, the concept of CVH is maintained; the more points gathered from attaining ideal health on each of the components, the higher the overall CVHI score and the better the status of CVH.

**Table 4.3 American Heart Association/Center for Disease Control and Prevention**

**Cardiovascular Health Index Criteria in Survey Data**

<table>
<thead>
<tr>
<th>Component</th>
<th>Survey Question</th>
<th>Ideal Cardiovascular Health (1 point)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current smoking</td>
<td>Have you smoked at least 100 cigarettes in your entire life? Do you now smoke cigarettes every day, some days, or not at all? During the past 12 months, have you stopped smoking for 1 day or longer because you were trying to quit smoking? How long has it been since you last smoked cigarettes regularly?</td>
<td>Had not smoked at least 100 cigarettes in their lifetime; or reported smoking 100 cigarettes in their lifetime but not currently smoking.</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>About how much do you weigh without shoes? About how tall are you without shoes?</td>
<td>Calculated BMI (kg/m²) = 18.5 to 24.9</td>
</tr>
<tr>
<td>Physical activity</td>
<td>How many days/weeks do you do these moderate/vigorous activities for at least 10 minutes at a time? On days when you do moderate/vigorous activities for at least 10 minutes at a time, how much</td>
<td>Did enough moderate or vigorous physical activity to meet the recommendation of ≥150 minutes a week of moderate/intensity</td>
</tr>
<tr>
<td>Activity</td>
<td>Question</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>total time per day do you spend doing these activities?</td>
<td>activity, ≥75 minutes of vigorous intensity activity, or an equivalent combination of aerobic physical activity.</td>
<td></td>
</tr>
<tr>
<td>Diet</td>
<td>Not counting juice, how often do you eat fruit? How often do you eat green salad? How often do you eat potatoes, not including French fries, fried potatoes, or potato chips? How often do you eat carrots? Not counting carrots, potatoes, or salad, how many servings of vegetables do you usually eat?</td>
<td>Consumed 5 or more servings of fruits and vegetables per day</td>
</tr>
<tr>
<td>Total cholesterol</td>
<td>Have you ever been told by a doctor, nurse, or other health professional that your blood cholesterol is high?</td>
<td>Answered “no”</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>Have you ever been told by a doctor, nurse, or other health professional that you have high blood pressure?</td>
<td>Answered “no”</td>
</tr>
<tr>
<td>Fasting plasma glucose</td>
<td>Have you ever been told by a doctor that you have diabetes?</td>
<td>Answered “no”</td>
</tr>
</tbody>
</table>


4.3.5.4 Adoption of the Cardiovascular Health Index Worldwide

Although proposed by an American organization, the CVH measure has shown high replicability (similar results in different settings) in both US and non-US populations. Data from the 2010 AHA publication introducing the CVH measure, indicated a low prevalence of overall CVH in the US population, with the lowest performance observed in the diet metric.(201) Subsequent published studies have revealed similar results. A study Shay et al in 2012 found that <1% of the US population attained ideal status in all seven metrics of the CVH measure.(213) Poor CVH was most prevalent in females, those of greater age and the non-White population. Therefore, there exists the consensus that the CVH of the US population should be targeted for major improvements across all seven of the CVH metrics. Other studies have adopted the CVHI measure with similar intent, to examine the state of CVH other global populations and identify areas for improvement.(213)
United Kingdom. The versatility of scoring CVH may be attributed to its applicability in various global populations. Crichton et al. compared CVH between individuals living in New York, US and individuals living in Luxembourg, UK. (214) There was a greater proportion of individuals with more ideal components of health in the UK as compared to the US. Additionally, those in the UK had more ideal health behaviors including BMI, physical activity, and diet while those in the US had more ideal factors such as blood pressure and total cholesterol. The differences in CVH between the two sites could not be accounted for by demographic and socioeconomic factors. The study indicated the need for different approaches to improving CVH in the two regions: drug therapy in the US and lifestyle therapy in the UK. (214)

Australia. Authors in Australia examined the relationship between CVH components and CVD in Australian adults. (215) Results show an association between all components of CVH, except for diet, and the prevalence of CVD. For each additional ideal component of CVH, the risk of CVD decreases by 21%. After adjusting for demographic factors, compared to those with inadequate health overall, those with optimal health had a 33% reduced risk of CVD. (215) In another study using the same Australian population, optimal overall CVH was found in approximately 19% of individuals, with a higher proportion of ideal health in women (22%) as compared to men (15%). (216)

France. Another study conducted in a French population demonstrated sex disparities in cardiovascular health. (217) Results show that, after adjustment for individual factors such as age, education and depression, women were four times more likely than men to experience ideal overall cardiovascular health and twice as likely to experience intermediate health. Women were more often found to have ideal health in all components of CVH, except for total cholesterol. Notably, the sex differences were greater for behavioral rather than biological factors. (217)

China. A 2015 paper by Bi et al. examined the CVH of a Chinese population which showed than less than 1% of the population attained ideal CVH in all seven metrics, with only 1.6% achieving an ideal diet score. (116) The majority of the Chinese population (75%) attained poor CVH i.e. ideal status in only 0-2 CVH metrics. (116) However, a
more recent study by Zhou et al using a different sample of Chinese adults, found that while ideal diet was still the lowest metric, the over half of the population attained ideal overall CVH. Furthermore, results indicated that the risk of CVD event and CVD mortality decreased as the number of ideal metrics increased.

**Latin America.** Results from a large prospective sample study completed in Peruvian adults (n=3058) showed that no one had ideal health in all 7 metrics and, only 1% of the sample had ideal health in 6 of the 7 metrics. The best performing metrics were ideal glucose (~75%) and non-smoking (~90%). Poor cardiovascular health (having 0-2 ideal health metrics) was noted in 31.8% of the population. Stratified analyses revealed that older males with high socioeconomic status had the highest percentage of poor CVH. Many of the participants found to have high blood pressure or high blood glucose levels were aware of their poor health and using medications however, many were not treated to goal. This finding was attributed to lower chronic disease awareness and poor primary healthcare in Peru.

**Finland.** The Kuopio Ischemic Heart Disease sample study examined the association between CVH and risk of acute myocardial infarction in a group of Finnish men aged 40-62 years. There was an inverse association between the number of ideal CVH metrics and the risk of acute myocardial infarction. Men with ideal health in 6-7 metrics, compared to men with ideal health in only 0-2 metrics, had a 72% reduced risk of acute myocardial infarction. The association remained consistent after adjustment for age, alcohol, socioeconomic status, CVD history and diabetes history, confirming that ideal CVH reduces the risk of CVD in middle-aged men.

**Korea.** Over 14,000 middle-aged men from the Seoul Male Sample Study (1993-2011) were examined for all 7 metrics of the CVHI. Results showed that non-smoking, normal blood pressure and normal blood glucose were associated with reduced risks of all cause and CVD mortality. Furthermore, up to 52.8% of the risk of CVD mortality could be attributed to these 3 factors alone. A higher number of ideal CVH metrics was associated with lower risk of all-cause and CVD mortality in Korean men. Ideal
health in at least 6-7 metrics were reported for up to 12% of the Korean sample. The proportion of the population achieving ideal health in at least 0-2 metrics was <1%. (221)

Middle East. An analysis of male and female residents in Iran. The Tehran Lipid and Glucose Study was conducted to monitor the prevalence of ideal CVH in a Middle Eastern Sample. (222) Findings revealed that 0.5% of the population had ideal CVH (ideal health in 6-7 metrics) with 74% having poor health (ideal health in 0-2 metrics). (222) Sex-based analyses showed that 19.7% of women and 10.7% of men have ideal health in 5 or more metrics. (222) The best performing metric was non-smoking, and the worst performing metric was diet.

Summary. Globally, in both US and non-US studies, the prevalence of ideal overall CVH (ideal status in at least 6 metrics) remains low. A brief comparison across countries reveal a range of prevalence rates for ideal health in all seven metrics ranging from 0.5% in Iran, 7.2% in US to 12.0% in Korea. Further investigation into factors, such as lifestyle and socioeconomic conditions, are necessary for understanding global variations in CVH and the contributions of these factors to the persistently low prevalence of ideal CVH globally.

It is important to note that CVH was assessed in both objective and self-reported data in worldwide studies. Review studies acknowledge challenges in comparing CVH between countries due to differences in the following study elements: study sample composition (based on age, sex and other demographics), time periods, measures of CVH, and study design (cross sectional vs longitudinal). (223) Therefore, cross country comparisons of CVH are interpreted with caution in this study.

4.3.6 Adoption of the Cardiovascular Health Index in Canada

The first attempt at measuring CVH in the Canadian population was conducted in 2013 by researchers from the Heart and Stroke Foundation Canada. (224) The study aimed to validate the CVHI in Canadians by examining the association between ideal CVH and the risk of hospitalization/death due to CVD in a sample of Ontarians, drawn from the Canadian Community Health Survey linked to the Ontario Registrar General Death
Database and the Canadian Institute for Health Information Discharge Abstract Database. Based on the availability of variables in the self-reported data, the CVHI in this study consisted of only 6 of the 7 metrics originally proposed by AHA. Results showed that 9.7% of individuals had ideal health in all 6 metrics. Additionally, having ideal health in all 6 metrics, as opposed to 0 metrics, was associated with an 89% reduction in the risk of CVD death and 84% reduction in the risk of CVD hospitalization.

In 2014, the Heart and Stroke Foundation Canada collaborated with researchers at the Cardiovascular Health in Ambulatory Care Research Team (CANHEART) to further develop the CVHI for use in all Canadians, to gain a greater understanding of CVH locally. The CANHEART group adapted the AHA CVHI in self-reported data from the Canadian Community Health Survey 2001-2011 and published their findings in the Canadian Medical Association Journal. Once again, due to the availability of variables in the data, the CVHI in this study consisted of only 6 of the 7 metrics originally proposed by AHA. Nevertheless, the CVHI was adapted and termed the CANHEART Health Index with criteria redefined according to the 2010 Canadian health guidelines and self-reported Canadian data. A side-by-side comparison of ideal CVH in adults, as measured by the CANHEART Health Index vs the AHA CVHI, is shown below in Table 4.4.

Results from that nationwide analysis showed that the prevalence of high BMI, hypertension, diabetes, poor diet, and low physical activity increased over time in the Canadian adult population. Approximately, 33% of adults and 50% of youth in Canada were found to have poor CVH (ideal health in 0 to 3 metrics). Ideal CVH (ideal health in all 6 metrics) was noted in 9.4% of adults. Better CVH (greater number of ideal CVH metrics) was noted in women at younger ages and in men at older ages. Regional variations examined higher prevalence of ideal CVH in Western as compared to Eastern provinces. However, the main limitation of the study was that only 6 of the 7 individual components were included in the CANHEART Index. CVH, as defined by the AHA CVHI, could not be fully assessed in the Canadian population, which also limits generalizability to other studies that utilize the full extent of the CVHI.
Following the introduction of the CANHEART index in 2014, CANHEART investigators published a brief review of the literature on ideal CVH, examining the CVH of other countries and the association with subclinical markers of CVD in 2015. Results confirmed the low prevalence of ideal CVH in other studies worldwide. However, there are no subsequent publications on the CANHEART index after 2015. Interestingly, the 2014 Maclagan publication characterized ideal health as self-reported hypertension and diabetes, which is the opposite to the intended definition of ideal health. It is uncertain whether this was simply an error in the publication or whether this error was translated into the incorrect characterization of ideal CVH in analyses. The CANHEART investigators published the correct characterization of ideal health as the absence of self-reported diabetes and hypertension in the subsequent 2015 review. However, no reference was made to the error stated in the 2014 publication or whether it affected the estimates produced in that study.

**Table 4.4 Comparison between the American Heart Association's Cardiovascular Health Index and the Canadian CANHEART Index**

<table>
<thead>
<tr>
<th>Component</th>
<th>American Heart Association Ideal Cardiovascular Health</th>
<th>CANHEART Ideal Cardiovascular Health</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current smoking</strong></td>
<td>Had not smoked at least 100 cigarettes in their lifetime; or reported smoking 100 cigarettes in their lifetime but not currently smoking.</td>
<td>Non-smoker or former daily or occasional smoker who quit more than 12 months ago</td>
</tr>
<tr>
<td><strong>Body Mass Index</strong></td>
<td>Calculated BMI (kg/m²) =18.5 to 24.9</td>
<td>BMI &lt; 25 kg/m²</td>
</tr>
<tr>
<td><strong>Physical activity</strong></td>
<td>Did enough moderate or vigorous physical activity to meet the recommendation of ≥150 minutes a week of moderate/intensity activity, ≥75 minutes of vigorous intensity activity, or an equivalent combination of aerobic physical activity</td>
<td>≥ 1.5kcal/kg/day (equivalent to ≥30 minutes of walking per day)</td>
</tr>
<tr>
<td><strong>Diet</strong></td>
<td>Consumed 5 or more servings of fruits and vegetables per day</td>
<td>Fruit and vegetables consumed ≥5 times per day</td>
</tr>
<tr>
<td>Total cholesterol</td>
<td>Reported no diagnosis of high cholesterol</td>
<td>Not included</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>Reported no diagnosis of hypertension</td>
<td>No self-reported diagnosis of hypertension</td>
</tr>
<tr>
<td>Fasting plasma glucose</td>
<td>Reported no diagnosis of diabetes</td>
<td>No self-reported diagnosis of diabetes</td>
</tr>
</tbody>
</table>


Shortly after the introduction of the CVHI, the AHA created an interactive online tool to engage patients and partners with the CVHI. This tool, known as the My Life Check | Life’s Simple 7®, allows patients to enter personal information into an online assessment tool that tracks and monitors their calculated CVHI score. In 2019, researchers from the Université Laval in Quebec published a study examining the CVH of French-speaking adults in Quebec using the Life’s Simple 7 measure, i.e. the CVHI. (200, 227) This study makes no mention of the CANHEART index. Instead, the study collected clinical data and assessed health behaviors using previously validated questionnaires. For example, physical activity was assessed using the International Physical Activity Questionnaire (IPAQ) and diet was assessed using web-based 24-hour recall (R24W). The study’s definition of the Life’s Simple 7 is compared to the AHA CVHI and is shown in Table 4.5.(200, 227) Criteria for individual components were similar between the two measures, with the exception of total cholesterol and fasting plasma glucose which were converted to the equivalent standard Canadian units. The total CVHI score was calculated on a scale of 0 to 7, 1 point for each ideal component and 0 points otherwise. Results of the Quebec study showed that 0.5% of the sample had ideal CVH (ideal health in all 7 metrics), with the worst performing component being diet (4.8% having ideal diet) and the best performing component being smoking (88.1% having ideal smoking).(227) Across the sample, better CVH was noted in women than in men and, in younger adults than older adults. While the study could only be generalized to French-speaking adults in Quebec, findings are important and represent the only application of the full CVHI score to Canadians.
Table 4.5 Comparison of the American Heart Association's Cardiovascular Health Index and the LS7 in the Quebec Study in objective data

<table>
<thead>
<tr>
<th>Component</th>
<th>American Heart Association Ideal Cardiovascular Health</th>
<th>LS7 Quebec Study Ideal Cardiovascular Health</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current smoking</strong></td>
<td>Never or quit &gt;12 months ago</td>
<td>Never or quit &gt;12 months ago</td>
</tr>
<tr>
<td><strong>Body Mass Index</strong></td>
<td>&lt;25 kg/m²</td>
<td>&lt;25 kg/m²</td>
</tr>
<tr>
<td><strong>Physical activity</strong></td>
<td>≥150 min/week moderate intensity or ≥75 min/week vigorous intensity or combination</td>
<td>150 min per week of physical activity (walking or moderate to vigorous exercise)</td>
</tr>
<tr>
<td><strong>Diet</strong></td>
<td>4-5 components of healthy diet score:</td>
<td>4-5 components of healthy diet score:</td>
</tr>
<tr>
<td></td>
<td>≥4.5 cups of fruits and vegetables per day</td>
<td>≥4.5 servings/day fruits, vegetables, and legumes (total)</td>
</tr>
<tr>
<td></td>
<td>≥2 3.5-oz servings of fish per week</td>
<td>≥0.4 servings/day fish</td>
</tr>
<tr>
<td></td>
<td>Fiber-rich whole grains:</td>
<td>≥3 servings/day whole grains</td>
</tr>
<tr>
<td></td>
<td>≥1.1 g of fiber per 10 g of carbohydrate:</td>
<td>≤1.3 servings/day sugar-sweetened beverages</td>
</tr>
<tr>
<td></td>
<td>≥3 1-oz-equivalent servings per day</td>
<td>&lt;1500 mg/day sodium intake</td>
</tr>
<tr>
<td></td>
<td>≤1500 mg of sodium per day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤450 kcal (36 oz) of sugar-sweetened beverages per week</td>
<td></td>
</tr>
<tr>
<td><strong>Total cholesterol</strong></td>
<td>&lt;200 mg/dl untreated</td>
<td>&lt;5.2 mmol/L untreated</td>
</tr>
<tr>
<td><strong>Blood pressure</strong></td>
<td>&lt;120/80 mmHg untreated</td>
<td>&lt;120/80 mmHg untreated</td>
</tr>
<tr>
<td><strong>Fasting plasma glucose</strong></td>
<td>&lt;100 mg/dl untreated</td>
<td>&lt;5.6 mmol/L untreated</td>
</tr>
</tbody>
</table>

Adapted from Source: Harrison, S., Couillard, C., Robitaille, J., Vohl, M. C., Bélanger, M., Desroches, S., ... & Houle, J. (2019). Assessment of the American Heart Association's “Life’s simple 7” score in French-speaking adults from Quebec. Nutrition, Metabolism and Cardiovascular Diseases, 29(7), 684-691.

Thus, the thesis is the third attempt to adapt the CVHI and quantify CVH in the Canadian population. The thesis analyses are not intended to replicate the work of CANHEART Index but instead, to build upon it and update current statistics surrounding the measurement of CVH in the Canadian population. The thesis will utilize all seven components of the AHA CVHI and, ideal CVH will be defined according to the latest Canadian standards and national guidelines. The aim of the thesis is to apply the full AHA CVHI to the survey data in the Canadian Community Health Survey (CCHS), to attain updated estimates on the status of CVH in Canadians and to examine the determinants that influence CVH in a sample of Canadian adults.
4.4 Selection of Determinants of Health Measures

The study aims to examine the influence of both individual- and area-level determinants on CVH in a sample of Canadian adults. The selection of determinants was based on those factors proposed by the well-established theoretical model (Main Determinants of Health Model, Dahlgren and Whitehead) and the literature review. (59) Study models included, 1) determinants known to influence CVH, although their relationship with CVH is not well quantified in the Canadian context, and 2) determinants that have not been frequently examined in the CVH literature. Additionally, the study retains variables that allowed for the maximum sample size to be included in the models.

4.4.1 Individual-Level Determinants

Individual-level determinants are factors intrinsic to the individual that are measured at the level of the individual. (59). Lifestyle and biological determinants were not included as individual-level determinants because they already comprise the study outcome, CVH. Individual-level determinants utilized in this study are self-reported and include: age, sex, gender, race, immigrant status, education, annual household income, life stress, work stress, alcohol use, and illicit drug use.

The study also examines the influence of interpersonal determinants on CVH, which is not frequently examined in multilevel models. Interpersonal determinants are those factors that relate to the relationships between individuals and are often operationalized in the literature as social support. (228) Social support was measured in CCHS by incorporating the belonging and inclusion dimensions into survey questions. For this study, interpersonal determinants were represented by two variables from the CCHS, 1) feelings of social inclusion (respondents rate feelings of belongingness to their neighborhood of residence) and, 2) family structure (respondents describe their current family structure – couple/single, living with others/living alone). CCHS also included a Social Provisions module to assess current relationships with friends, family members, co-workers, community members. However, this module was optional, and responses were not recorded for all individuals in the sample (specifically Ontarian residents).
Missingness for this variable would be ‘not at random’ and introduce bias into the study, therefore the social provisions variables were excluded from this study.

The study acknowledges that social support may be assessed at the individual and/or area levels however, there are very few studies examining social support at the area level in Canada. This may be due to lack of national data sources. One study, conducted by researchers at Western University, proposed using advanced statistical techniques (such as factor analysis) to generate an index of social cohesion for census metropolitan areas in Canada using data from the National Survey on Giving, Volunteering and Participating.(229) However, given its novelty, this method was not deemed reproducible for the purpose of the thesis.

The main limitation to using self-reported survey data to represent individual-level determinants is reporting bias. Although, it should be noted that CCHS data has been used extensively in the Canadian research landscape, with reliable results.(230) Correlations between individual-level determinants were assessed using the Spearman’s correlation measure and variables with moderate to high correlation (≥0.4) were reassessed for inclusion into the study.

4.4.2 Neighborhood-Level Determinants

Neighborhood-level determinants may be measured at the level of the neighborhood or measured at the level of the individual and aggregated to represent neighborhood characteristics. The study aims to avoid ecological fallacy, where inferences about individuals are made errantly from neighborhood data, and cross level bias, where individual determinants and their aggregates are used interchangeably.(231) Neighborhood determinants are not intended to replace individual determinants in the study but will be defined as unique characteristics of the neighborhood. The neighborhood determinants in this study include ‘living and working conditions’ suggested in the theoretical framework, in addition to demographic and socioeconomic conditions hypothesized to influence CVH in the literature review.
This study utilizes many different neighborhood determinants and to facilitate meaningful interpretation of study results, determinants are grouped into 4 main ‘blocks’ based on their descriptions: 1) demographic, 2) socioeconomic, 3) environmental, and 4) healthcare characteristics. Each block consists of a set of variables hypothesized to influence CVH but may also be correlated with other variables used to measure distinctly different constructs. For example, the deprivation index, which is a comprehensive measure of socioeconomic disadvantage in a neighborhood, is calculated using demographic characteristics such as income and unemployment. Entering deprivation index, income and unemployment into the same statistical model can lead to unstable coefficients with inflated variance estimates. To avoid issues with multicollinearity between blocks, the blocks are not entered into the model simultaneously. Rather, each block is entered separately so that their independent association with CVH may be examined and, to assess the variation in CVH accounted for by each block of determinants. To avoid issues with multicollinearity within blocks, variables with moderate to high correlation (≥0.4 Spearman’s correlation) are not included in the same block. For this study, the correlations between neighborhood determinants did not exceed 0.4 therefore no determinants were removed from analyses. Stepwise regression was not considered appropriate to select determinants for study inclusion because the analyses are theoretically-, not statistically-driven; that is, determinants were included in the model based on hypothesized influences on CVH, as suggested by the literature review, as opposed to statistical significance. Data for all neighborhood determinants were not available for every neighborhood unit examined in the study. The definition of each determinant and the neighborhood unit for which data was available is summarized in Table 2 of the Measures section in the subsequent chapter.

The following is a description of each block in further detail and the methodological considerations for including each block into the study models.

Block 1. Demographic characteristics consists of the following variables: population density, number of private dwellings, age of residents, household size, median income, prevalence of low income, unemployment. Variables are sourced from 2016 Canadian Census data, which collects demographic information from the Canadian population via
phone and online surveys. Neighborhood determinants are not simply aggregated proxies of individual variables. Statistics Canada has defined and calculated national estimates for neighborhood determinants based on census definitions. Given the high response rate of Canadian Census data (>95% long-form), aggregating responses should reveal neighborhood characteristics that are similar to the true neighborhood exposure nationally. The limitation is that after exclusion of ineligible participants from the study sample, it is unclear whether the neighborhood exposure is truly representative of that of the remaining study participants in the multilevel analyses.

**Block 2.** Socioeconomic characteristics consists of the following variables: marginalization, deprivation (social and material), community well-being. Each of these variables are indices; compound measures that use multiple indicators to summarize concepts. The indices are created and validated within the Canadian context, and include the Canadian Marginalization Index, the National Material and Social Deprivation Indices, and the Community Well Being Index. Each index is described in the Data Sources and Measure section of the subsequent chapter. Indices were included in the study to address the high correlation that is often observed between socioeconomic measures such as income and education. An index is also easy to interpret and a practical approach to assessing the influence of neighborhood socioeconomic status on CVH.(232) The limitations to using these indices are that they may mask some of the variation in the components that compose the score and, they have low external validity outside of Canadian studies.(232)

**Block 3.** Environmental characteristics consists of the following variables: environmental index. The study uses the Canadian Active Living Environment Index, which is a geographic-based measure that represents the walkability of the neighborhood based on intersection density, dwelling density, points of interest, and transit stops.(233) An index is assigned to each dissemination area neighborhood unit because these units were smaller and more homogenous for the components of the index.(233) Studies have indicated that geographic-based measures at the neighborhood level provide more precise, less biased estimates of effect than self-reported survey measures.(234) A
limitation to the geographic based measures is its decreased reliability in rural areas, where geographic data (such as roadways and points of interest) is less available.(234)

**Block 4.** Healthcare characteristics consists of the following variables: physician supply, hospital bed availability. Data was available for the FSA (larger unit) neighborhood unit because it is unlikely that there would be a physician or a hospital in every DA (smaller unit). Data was reported by physicians and health organizations across Canada, therefore, there is likely to be some reporting bias. Specifically, this would affect estimates in rural areas where physicians are often temporarily deployed and may not report employment. An important limitation is that the use of these healthcare variables does not account for the fact that individuals may not be receiving healthcare in their neighborhood of residence, which does not necessarily imply that there are unhealthy. Additionally, these variables may or may not include unmeasured confounders including the quality of healthcare, which can greatly influence health in Canada.(235)

### 4.5 Selection of the Area-Level Measure

#### 4.5.1 Defining the Area-Level Unit as the Neighborhood

The neighborhood, a group of individuals residing in the same geographic region, is an essential unit of study in health research. This section will focus on how neighborhoods were operationalized in this study.

As demonstrated in the early studies in CVD epidemiology, such as the Seven Countries Study, geography is a key factor in understanding the distribution of CVH.(79) Recent research has provided substantial evidence for geographical variation of CVH in Canada. In a 2017 study, investigators from The Cardiovascular Health in Ambulatory Care Research Team (CANHEART) in Ontario demonstrated geographic variations in CVD and CVH in Ontario regions, which were defined as 14 provincial health service regions, known as Local Health Integration Networks (LHINs).(169) Results show an almost twofold variation in rates of CVD events between regions of lowest and highest incidence: from 2.1 events per 1000 person-years for women in low-risk regions to 7.7 per 1000 person-years for men in high-risk regions.(169) Additionally, individuals residing in the areas with high CVD rates had poorer blood pressure control, less
compliance with statin medication, fewer cholesterol screenings and fewer visits to their family physicians. Another study in 2019, found that poor CVH including being overweight, poor diet, low physical activity or smoking accounted for up to 90% of the geographic variation in premature mortality in Ontarians. (236)

Generally, neighborhoods are understood as the immediate environment in which a person resides. A challenge in this thesis was to define a neighborhood that was also relevant to an individual’s health and determinants of health. For example, numerous studies have shown that an individual’s health may be determined by the whether their neighborhood has parks for physical exercise or food stores with healthy diet options. (237, 238) However, it is also important to consider indirect influences on health that lie outside of the built environment; for example, socioeconomic characteristics of the neighborhood may influence key health behaviors such as smoking, drug use or alcohol consumption. (64) Furthermore, these varying contexts may all intersect, either physically or socially, influencing each other and the health outcome of residents. (64) Examining CVH in the context of more than one geographical area, that is, the use of various neighborhood units, may be an ideal approach to strengthen inferences pertaining to the area-level influence on health. (187, 234)

In Canada, there is no consensus on the definition of the geographic neighborhood unit. (239, 240) The thesis utilizes national survey data which adopts pre-set geographic boundary definitions. Provinces have defined regions differently based on administrative boundaries, governmental and census boundaries. (241) For example, in Ontario, there are 35 public health units which are used to administer resources, such as vaccines and screening services, as needed throughout the provinces. However, the delineations utilized in governance differ. In Ontario, there are 444 municipalities, which represent local governance on issues such as transit, social services, sewer and water systems, and land use planning. Furthermore, each geographic unit differs in size, with the largest municipality being the City of Toronto (2,731,571 residents) and the smallest being Cockburn Island (200-300 residents in the summer, 15 residents all year round). (241) Thus, in addition to selecting a neighborhood unit that is relevant to CVH, the thesis
aimed to utilize units that were standard across provinces with the same functional boundaries across Canada.

Importantly, not all information on the neighborhood environment can be obtained from national survey data. For example, health care resource data in Canada is still largely contained within administrative data sets managed by the provinces. Additionally, environmental data on the built environment can be difficult to collect and often requires expert tools beyond survey instruments. Therefore, the thesis uses data from both survey and administrative data sets to provide a wider range of area-level determinants. Though the selection of the area-level unit was not data driven, it was important to utilize a unit for which data was available in multiple other data sets. Given that Statistics Canada data was the main source of data for this study, the thesis adopts the geographical boundaries of the neighborhood based on the census boundaries proposed by Statistics Canada. These boundaries are standardized across all Statistics Canada data sources, including census data, and is the basis of data collection and analysis for national survey data in Canada.

Statistics Canada defines different types of units that may be characterized as neighborhoods; devised to be homogenous units of individuals based on demographic and economic features. Most multilevel studies use census tracts (CTs) as the neighborhood unit however, research suggests that smaller area units may be more representative of what individuals consider as their neighborhood. In Canada, CTs contain on average 4,000 individuals and are known to be homogenous in socioeconomic characteristics. However, CTs are located in census metropolitan areas and in census agglomerations that have a core population of 50,000 or more in the previous census. Therefore, CTs do not cover the entire Canadian geography and were not deemed suitable as a neighborhood unit in this study.

4.5.2 Defining the Neighborhood in the Study

For the purposes of the thesis, three regions may be considered as neighborhoods, according to the Standard Geographical Classification (SGC) 2016 (Statistics Canada's official classification for all geographic areas in Canada): 2 administrative units and
1 statistical unit. These three units were included in the study because they encompass the entire geography Canada (10 provinces and 3 territories), they are policy-relevant boundaries, and data on these units were readily available across all survey and administrative data sources used in the study. In 2016, the province and territory were the largest units of geography across Canada. Those units are then sub-divided into various smaller administrative units. The census subdivision (CSD) is an administrative unit defined as municipalities based on provincial/territorial legislation. There was a total of 5,162 CSDs in 2016. The CSD is further broken down into smaller areas known as dissemination areas (DA). The DA is a statistical unit defined for the purpose of census statistics as a small area comprising of 400 to 700 persons. There was a total of 56,590 DAs across Canada in 2016. Another administrative unit derived from provinces and territories is the forward sortation area (FSA). The FSA is sub-provincial; defined as the first 3 characters of the postal code. There was a total of 1,620 FSAs across Canada in 2016. The thesis will use the DA as the primary neighborhood unit and the FSA and CSD as secondary neighborhood units. DAs were chosen as the primary neighborhood unit because they are the smallest divisible unit according to the SGC, they respect larger boundaries such as census subdivisions and census tracts and they are stable over time.(241)

4.5.3 Limitations in Defining the Neighborhood

It is important to note the limitations in the selected neighborhood unit for this study. Firstly, as mentioned above, the thesis defines neighborhood based on census boundaries. Everyone in the neighborhood is assumed to have the same exposure, which may be too broad or too narrow, regardless of the neighborhood unit employed. Additionally, the selected units may not be representative of the entire environment that influences CVH. Secondly, the data is cross-sectional and represent exposures at the neighborhood-level at one point in time. However, it is well-known that individuals change neighborhoods over the course of their lives, therefore, the influence of the neighborhood on health may change over time.(234) The health experienced by an individual living in a given neighborhood at a later stage in life, may be due to the healthcare available or behaviors maintained by that individual, living in a different neighborhood in the early stages in
life. Thus, the cumulative exposure of the neighborhood may provide a more precise depiction of the influence of neighborhoods on health. However, data on the length of time a person resided in a neighborhood or whether individuals moved neighborhoods, were not available in any of the data sources accessed for this study.

In conclusion, the thesis acknowledges that neighborhoods are not the only contexts that influence health. Many other population groupings that cannot be defined by geography including families, peer groups and various congregations, undoubtedly influence CVH. Additionally, a neighborhood cannot be restricted to just a physical space at one point in time. A neighborhood may represent a dynamic place that included physical coordinates, as well as the individuals occupying the space and their social environments. Several contexts beyond the individual, including those not yet explored, interact daily to influence health and overall, this is a major challenge to studying health. Nevertheless, the thesis examines the neighborhood within a multilevel structure as a theoretical approach to providing a greater understanding of how new strategies and policies can expand their impact on improving health – from the individual to the population levels, with greater attention to the interaction between them.

## 4.6 Chapter Summary

This chapter addressed the operationalization of the theoretical framework as a study guide for structuring the levels of influence on CVH. The theoretical framework also informed the determinants of health selected for the study. The chapter also included a full description of the outcome measure for CVH, the Cardiovascular Health Index, and the adoption of that measure worldwide. Finally, the chapter ends with the selection of the neighborhood unit and the limitations encountered during that selection process. This chapter has laid the foundation for the statistical methodology outlined in the subsequent chapter.
Chapter 5

5 Statistical Methodology

This chapter begins with a description of data sources and study indicators and concludes with the statistical and analytical approach to each thesis objective.

5.1 Data Sources and Measures

5.1.1 Canadian Community Health Survey (CCHS), 2015-2016

The CCHS, conducted by Statistics Canada, is a national survey that collects self-reported information on health and health-related factors among Canadian adults and children. The purpose of CCHS is surveillance and research. The CCHS released its first annual survey in 2001 and its first two-year survey in 2005. The survey methodology and questionnaire has undergone many changes over the past few years, with the most recent and major changes occurring in 2015. To facilitate the use of the most recent data with the largest available sample size, the two-year CCHS 2015-2016 file is utilized in this thesis. (The CCHS 2017-2018 file became available for public use on October 22, 2019, after the process of data sourcing and analyses for the thesis had already begun.)

The CCHS 2015-2016 respondents included children and adults aged 12 years and over, living in 10 provinces and 3 territories across Canada. The multi-stage sample design requires approximately 130,000 respondents for every two years and is sampled from two frames: an Area frame and the Canadian Child Tax Benefit (CCTB) frame. Adults aged 18 years and over are selected from the area frame, known as the Labour Force Survey, which is based on a systematic sampling of dwellings within clusters that the CCHS further stratifies based on geography and socioeconomic status. All the clusters are then listed, and a systematic sampling of dwellings are chosen. Individual members for the survey are then chosen using selection probabilities based on age and household composition. The survey does not cover the following individuals: those living in Aboriginal settlements and specific Quebec regions, the institutionalized, members of the Canadian Forces and children in foster care. Current CCHS coverage was 71% prior
to 2013, and 96% thereafter since more communities were added to the survey in 2013. (243)

The CCHS survey contains four modules: core content, theme content, optional content, and rapid response content. The core and theme content vary every two to four years based on national survey needs. The optional content varies annually and is based on provincial and territorial survey needs. The rapid response content varies every 3 months and is based on emerging issues affecting population health. All survey participants were interviewed over the phone by trained interviewers who elicit self-reported responses on topics such as demographics, health behaviors and health status. Data used in this thesis is derived from the core content because data from other modules vary over time and are specific to selected topics, organizations, and provinces. Variables necessary for this study are all contained in the core content.

The CCHS survey design is cross-sectional and is not intended for longitudinal analysis at the individual level. Once the survey questionnaires are completed, the data is linked with income tax records with the consent of the respondent. Data is then reviewed for error detection and correction and derived variables are added. Individual weights and bootstrapping weights are calculated based on model probabilities of the responses. Before CCHS data is released to the public, it is validated comparing estimates by geographical region, age, and sex. In this study, the CCHS provides data for the study outcome, CVH, and for the individual-level determinants of CVH.

5.1.2 Canadian Census Profile, 2016

Census of Population data is collected by Statistics Canada for provinces, territories and other geographic units across Canada. (244) The Census is designed to be completed by all Canadians and population estimates, which are adjusted for under-coverage and over-coverage, were used in this study. Census data include information on demographic characteristics and socioeconomic status of individuals that can be aggregated to various levels of geography, including but not limited to the province, forward sortation area (FSA), census sub-division (CSD), and dissemination area (DA).
The national census is conducted every 5 years in Canada. This study uses 2016 Census data as it is the most current census data available to date (the next census is scheduled for 2021). Data was collected using short- and long-form questionnaires in online format. In 2016, 68.3% of households respond online and 31.7% respond on paper forms. The short form collects basic demographic information and the long form contains additional information of socioeconomic characteristics. Approximately 75% of households received the short-form questionnaire and 25% received the mandatory long-form questionnaire based on systematic sampling.

The 2016 Census target population included persons living in private dwellings and excluded foreign residents, representatives of a foreign government assigned to an embassy, high commission or other diplomatic mission in Canada; members of the armed forces of another country stationed in Canada; and residents of another country who are visiting Canada temporarily. In 2016, 25% of the sample received the long-form census to achieve national representativeness. Response rates exceeded 97% for short and long form response rates in 2016.

To ensure accuracy and improve data quality, Statistics Canada worked closely with each province and territory to obtain administrative data for demographic information (age, sex, marital status, family status). Income data was received from personal income tax and benefits files. Immigration data was received from Immigration, Refugees and Citizenship Canada. To maintain data confidentiality, figures are rounded and not released for geographic areas with less than 40 persons. Population estimates were weighted to adjust for sampling and response errors. Post-census estimates by geographical units are calculated based on population estimates.

5.1.3 Scott’s Medical Database (SMDB), 2015-2016

The Canadian Institute of Health Information (CIHI) retains data from the SMDB (formerly Southam Medical Database) which contains data on the supply, distribution, demographics and migration of physicians across Canada for 1994 onwards. The sources of information were organizations and institutions such as jurisdictional registrars, the Royal College of Physicians and Surgeons of Canada (Royal College) and
the College of Family Physicians of Canada (CFPC), and from physicians who contact them directly. CIHI is responsible for checking data quality and ensuring accurate coding of data.

The SMDB records active registered physicians and excludes interns and residents, as well as physicians who are semi-retired, who are in the military, who request to be excluded from the publication (non-registered physicians only) and who are practicing abroad. CIHI uses data on population counts from Statistics Canada to calculate physician to population ratios. Ratios were calculated as the number of physicians in a jurisdiction to the number of people in the jurisdiction (per 100,000 population). Data on physician to population ratios were available for CSDs and FSAs only.

5.1.4 Canadian Management Information Systems Database (CMDB), 2015-2016

The Canadian Institute of Health Information (CIHI) manages and produces data for the CMDB which contains financial and statistical operations information on public hospitals and regional health authorities across Canada from 1995 onwards.(246) The sources of information were the hospitals and health regions which report mandatory operational information to the Ministry of Health. CIHI is responsible for checking data quality and ensuring accurate coding of data. Data from Quebec and Nunavut were not included in the data collection agreement with the Ministry of Health. The CMDB provided data on the number of hospital beds per 100,000 of the population for FSAs only in 2015-2016.

5.1.5 Canadian Urban Environmental Health Research Consortium (CANUE), 2016

Canadian Urban Environmental Health Research Consortium (CANUE) is a collaborative group of researchers and data specialists which aims to provide resources for researchers and analysts focused on the built environment and health.(247) CANUE houses multiple datasets, 3 of which were included in this study: Can-ALE, Can MARG and MSDI.

Canadian Active Living Environment (Can-ALE) is a database created by CANUE containing a geographic-based set of measures that represent the active living friendliness of Canadian communities.(247) Measures were decided based on literature review and
suitability to the Canadian environment. The single measure of active living environment, known as the ALE index, was calculated per neighborhood as the summed z-score for the following components: intersection density, dwelling density, and points of interest measures. According to the developers of the Can-ALE data, the intersection density measure captured the directness and connectedness of streets and/or paths through a community. The dwelling density measure captured the average dwelling density of the neighborhoods in the buffer area. The points of interest measure captured the number of points of interest (POIs) in a one-kilometer buffer around the DA centroids. An ALE score of 0 indicated that the neighborhood is similar to the national average for the quality of the active living environment. A negative score indicates below national average and a positive score indicates above national average for the quality of the active living environment.

Other measures included in the dataset were the ALE/Transit Index which includes a fourth component in the ALE Index: transit stops. The transit measure captured the presence of public transit stops in the community. An ALE/Transit score of 0 indicated that the neighborhood is similar to the national average for quality of the active living environment. Both the ALE and ALE/Transit Indices were also categorized as 1 (very low) to 5 (very high) which characterized the favorability of the active living environment.

The Canadian Marginalization Index (Can MARG) database allows researchers to access information on dimensions of marginalization in urban and rural communities in Canada. The Can MARG index was developed in 2006 by a research group including St. Michaels Hospital in Toronto, University of Toronto and the Institute of Clinical Evaluative Services. Can MARG consists of four dimensions: residential instability, material deprivation, ethnic concentration and dependency. The index is created using a marginalization framework previously established in Canada and principal component factor analysis. The most recently calculated Can MARG scores were available for 2006 in neighborhoods.
The Material and Social Deprivation Indices (MSDI) were developed in 1990 by researchers at the Institut National de Sante Publique du Quebec (INSPQ) to monitor and address the lack of information on social inequalities in Quebec and Canada. The MSDI consists of six indicators: education (population without high school diploma), employment (employment to population ratio), income (average population income) and social isolation (population living alone, married and in single parent families). Two components were derived from the creation of the MSDI: material deprivation component or social deprivation component. The indicators were combined using principal component factor analysis. MSDI measures were available for 2011 in neighborhoods.

All of the above-mentioned measures were available for 2016 at the levels of the DA only.

5.1.6 The Community Well Being Index (CWB) Data, 2016

The CWB database is maintained by Statistics Canada and contains a CWB score – a score of socioeconomic well-being for 673 indigenous and 3,781 non-indigenous Canadian communities (based on the average of all residents in a given community). The CWB score is comprised of education (population with at least a high school education), income (total income per capita of community), labor (community members participating in the labor force) and housing (population with adequate housing) measures recorded in the 2016 Census data. The data are available for CSDs which represent communities or municipalities. CWB scores are available for all CSDs across Canada except those with less than 65 residents or those without accurate census data (excluded from census).

The CWB score is measured on a scale of 0 to 100. On average, the CWB score was 77.5 for non-indigenous and 58.4 for indigenous communities in Canada. The CWB score was first released in 2004 and recalculated in 2019 (and applied retrospectively) to address changes in the population labour force.
5.2 Merging Data Sources for the Study

Individual-level determinants were derived from the Statistics Canada Canadian Community Health Survey (CCHS). Neighborhood determinants were derived from Statistics Canada Census data, Canadian Institute for Health Information (CIHI), Canadian Urban Environmental Health Research Consortium (CANUE) and Statistics Canada Canadian Well Being Index (CWB). Neighborhood-level data was available for dissemination area (DAs), census subdivisions (CSDs) and forward sortation areas (FSAs) as indicated in Table 2. CCHS and Census data are made available from the Research Data Center as Western University. CWB data is publicly available online from Statistics Canada. Data from CIHI and CANUE are made available through student-user agreements with the respective institutions.

In this study, data sets were merged at neighborhood level, according to Statistics Canada guidelines for merging area-level data to census data. A geographic identifier is a unique sequence of alphanumeric characters that refer to a specific geographic area. All the data sources contained geographic identifiers which enabled the merging of neighborhood level data with individual level data. Geographic identifiers are standardized across Statistics Canada data including the CCHS, Census and CWB, and readily adopted by other data sets to facilitate merging with Statistics Canada national datasets. Geographic identifiers often change with the census year, however this study includes data for the 2015-2016 year, during which there were no changes in identifiers.

In this study, the CCHS was merged first with Census data then with the other neighborhood data. To link the individual observation to the neighborhood data, the geographic identifiers were used as the ‘by’ variable. The observation was merged with neighborhood data that has a matching identifier. CCHS respondents who did not have a corresponding matching identifier in Census data, and geographic areas not covered in the CCHS were removed from the final dataset and examined in a separate dataset labelled ‘missing.’ From the 90,000 records in the CCHS data, 85,200 were successfully merged to Census data. As data were available for varying geographic areas in the other neighborhood data, mismatched records were not removed from data sets moving
forward but remained with a missing value for neighborhood variables. The missing values were placed in a separate category for analyses, to examine whether there was statistical significance in these groups. Mismatched records were due to areas not covered in either dataset, likely due to low sample sizes. For CIHI data, mismatched records may have been due to underreporting as CIHI data relies on physician/health organization reporting. From the 85,200 records in the CCHS/Census data, 78,700 were successfully merged with CWB data, 70,100 were successfully merged with CANUE data, and 65,100 were successfully merged with CIHI data.

A strength of merging of multiple data sets was the inclusion of many types of neighborhood determinants, some of which were not examined previously in CVH studies. A limitation of merging multiple data sets was the reduction in sample size due to datasets that did not include information on all geographic areas in the CCHS data.

5.3 Study Population

The study population consists of adults aged 20 years and over from the 2015-2016 CCHS two-year file who reside in private dwellings in 10 provinces and 3 territories. The CCHS excludes individuals living on Indian Reserves and Crown lands, clientele of institutions, the full-time members of the Canadian Forces, and residents of some remote areas. Ineligible study participants included those who have already experienced cardiovascular disease or stroke (reporting ‘yes’ to the question ‘Do you have heart disease’ and ‘Do you suffer from the effects of a stroke?’). Those with existing CVD must be excluded from the study because they have already experienced at least one risk factor and are therefore have a different probability of experiencing the outcome as compared to those without CVD. Additional exclusions included those missing any information necessary to calculate the outcome measure, and females if pregnant or of unknown pregnancy status. Rather than just being classified as missing, the ‘refused to state’ category of study variables was included in analyses to identify any significant differences, between individuals who responded and those who refused to respond to survey questions, which may lead to selection bias.
5.4 Sample Size and Missing Data

Most of the literature on sample size estimation in multilevel modelling exists for two-level models where the current rule of thumb is, ‘a sufficient sample size at the level that the effect of interest is measured is most crucial in multilevel analysis’. (252) However, further research in multilevel modelling has confirmed that the number of clusters as well as the intraclass correlation (ICC) may also affect estimates. (252) Most of the existing sample size and power calculations are only applicable to single-level models.

Additionally, CCHS uses a complex multistage sampling design, where the probability of sampling units are unequal therefore conventional formulas for power and design effect calculations are not applicable to this study.

Previous simulation studies for sample size in multilevel studies have concluded that: level 2 sample size has a greater impact on statistical power than level 1 sample size, and the minimum sample size should be at least 30 individuals nested in 30 clusters i.e. the 30/30 rule. (253) Hox et al suggests a 50/20 rule, 50 individuals nested in 20 clusters, to examine interaction effects. (254) To estimate, the sample size for this study, the ICC and total variance were estimated a priori. Snijders and Bosker, leading authors in foundational books on multilevel analyses, suggests that ICC values range between 0.05 and 0.20 are most common in 2-level studies, with conservative values between 0.10 and 0.15. (255) Raudenbush and Liu suggests that a total variance of 0.05 is small and 0.15 is large where the effect size is estimated to be moderate (0.5) and power of 90%. (256) Using a program known as Optimal Design, created to estimate sample size in cluster-randomized trials but also applied to multilevel studies, a minimum sample size of 24 individuals across 30 clusters or 13 individuals across 50 clusters was sufficient for this study (effect size 0.5, power 80%). (256, 257)

The CCHS 2015-2016 population available for analysis was 110,095 adults. Any geographic unit with cells of 0 during simple stratified analyses with individual and neighborhood variables were excluded from further analyses. The CCHS does not allow for the release of unweighted estimates by geographic units. After all study exclusions and linking data sources, the study sample for the thesis was approximately 85,200 individuals, nested in 5436 DAs, 1200 CSDs and 800 FSAs. As mentioned in the
merging data sources section, excluded individuals were moved to a separate dataset labelled as ‘missing’. Analyses were completed to compare the final study sample to the ‘missing’ sample by age, sex, and the outcome CVH. There were no significant differences between these two comparable groups for the variables examined (age p-value=0.10, sex p-value=0.21, and CVH p-value=0.13). With sufficient sample size and power, and no significant differences between the missing and non-missing groups (for age, sex and CVH), methods to handle missing data such as multiple imputation were not employed in this study.

5.5 Study Variables

5.5.1 Dependent Variable

5.5.1.1 Cardiovascular Health

The study outcome or dependent variable is CVH, measured by the American Heart Association’s Cardiovascular Health Index (CVHI). This study adopts the self-reported version of the CVHI as proposed by the AHA and CDC.(200) CVHI is a summary score consisting of four health factors (total cholesterol, blood pressure, body mass index and, fasting plasma glucose) and three health behaviors (smoking, physical activity and, diet).(201)

Calculating the CVHI. For each of the 7 components of the CVHI, a component is classified as ‘ideal’ and 1 point is assigned if evidence-based criteria (set by AHA/CDC) are met as described in Table 5.1.(200) Where the criteria of ideal health is not met for a component, the component is classified as ‘poor’ and 0 points are assigned for that component. An overall CVHI score is achieved by summing the points attained from each component for a total score ranging from 0 (worst health) to 7 (best health). The more points gathered from attaining ideal health on each of the components, the higher the overall CVHI score and the better the status of CVH.

Analyzing the CVHI. The CVHI score may be treated as a count outcome measured on a scale of 0 to 7 thus, utilizing the entire range of the score in analyses. However, most of the current literature using CVHI treats the score as a categorized variable for the purpose
of clinical relevance. To facilitate comparison of this study with existing studies, the outcome, CVHI score, will be categorized as follows: ‘ideal’ (6-7 points), ‘intermediate’ (3-5 points) and ‘poor’ (0-2 points), as in existing literature. CVH is calculated for all individuals in the study and is analyzed at the individual level.

Data source. The CCHS contains all variables necessary to calculate the CVHI i.e. data on all seven components of the score. The CCHS consists of self-reported data therefore, data for calculating the CVHI score is gathered based on responses to key component questions. See table 1 for a full description of the questions used to calculate the CVHI in CCHS 2015-2016 data.

Table 5.1 Adaptation of the American Heart Association Cardiovascular Health Index in the Canadian Community Health Survey data (2015-2016)

<table>
<thead>
<tr>
<th>Component</th>
<th>Criteria for Ideal Cardiovascular Health (1 point)</th>
<th>2015-2016 CCHS Questions used to determine Ideal health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cholesterol</td>
<td>Previously screened and never been told had high cholesterol</td>
<td>Have you been told by a health professional that you have high blood cholesterol or lipids?</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>Never been told had high blood pressure</td>
<td>Have you been told by a health professional that you have high blood pressure?</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>Calculated between 18.5 and 24.9, based on reported weight and height</td>
<td>About how much do you weigh without shoes?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>About how tall you without shoes are?</td>
</tr>
<tr>
<td>Smoking</td>
<td>Had not smoked at least 100 cigarettes in their lifetime or reported smoking 100 cigarettes in their lifetime but not currently smoking</td>
<td>Have you smoked at least 100 cigarettes in your entire life? Do you now smoke cigarettes every day, some days, or not at all? About how long has it been since you last smoked cigarettes regularly, that is, daily?</td>
</tr>
<tr>
<td>Glucose</td>
<td>Never been told had diabetes</td>
<td>Have you been told by a health professional that you have diabetes?</td>
</tr>
<tr>
<td><strong>Diet</strong></td>
<td>Consumed 7-8 servings of fruits and vegetables per day (based on 2007 Eating Well with Canada’s Food Guide recommendations)(259)</td>
<td>In the last month, how many times per day, per week or per month did you drink 100% PURE fruit juices, such as pure orange juice, apple juice or pure juice blends? Do not include fruit-flavored drinks with added sugar or fruit punch. In the last month, how many times did you eat dark green vegetables such as broccoli, green beans, peas and green peppers or dark leafy greens including romaine or spinach? Please remember to include (frozen or canned vegetables and) vegetables that were cooked in soups or mixed in salad. In the last month, how many times per day, per week or per month did you eat potatoes that are not deep fried? Excluding the green and orange vegetables as well as the potatoes you have already reported, in the last month, how many times did you eat OTHER vegetables? Examples include cucumber, celery, corn, cabbage, and vegetable juice.</td>
</tr>
<tr>
<td><strong>Physical Activity</strong></td>
<td>≥ 150 min/wk. moderate to vigorous intensity for at least 10 minutes at a time (based on 2010 Canada Physical Activity Guidelines for Adults)(260)</td>
<td>How much time in total, in the last 7 days, did you spend doing physical activities such as walking or cycling? Please only include activities that lasted a minimum of 10 continuous minutes. Estimated time in moderate intensity activity per week</td>
</tr>
</tbody>
</table>
5.5.2 Independent Variables

5.5.2.1 Individual Determinants

This study examines the influence of individual characteristics on CVH using the following variables measured at the level of the individual: age, race/ethnicity, sex, gender, immigration, life stress, work stress, education, income, occupation and substance use.

*Data Source and Definitions.* Determinant data is derived from the CCHS and all variables are based on self-reported data. Participant age is categorized based on the standard population cut-offs: 20-40 years, 40-60 years, 60-80 years, 80 years and over. Race/ethnicity is divided into 10 categories (White Non-Hispanic, South Asian, Chinese, Korean and Japanese, Black, Filipino and South Asian, Hispanic Latin and South American, Aran and West Asian, Other and Mixed races). Sex is based on a question asking participants to identify with either the male, female, or neither. Gender is based on a question asking participants to identify their sexuality as homosexual, heterosexual or neither. Immigration is based on whether the participant identified as ever being a landed immigrant to Canada. Total personal income is reported as annual income after taxes and divided into 15 categories of $10,000 increments beginning with $5,000 and ending with $100,000 & over. Stress is based on whether the participant reports the frequency of experiencing life and work stress. Education is categorized as less than high school, high school only or university educated. Employment is defined as whether the participant reports having a job in the past 12 months. Substance use is based on the frequency of alcohol use and illicit drug use in the past 12 months. Each variable has a category labelled ‘refused to state’ which represented those individuals who refused to provide information for that question.
5.5.2.2 Interpersonal Determinants

This study examines the influence of interpersonal characteristics on CVH using the following variables measured at the level of the individual: social inclusion and household composition.

*Data source and Definitions.* CCHS measures social inclusion as a self-reported variable in response to the question. “How would you describe your sense of belonging to your local community? Would you say it is: very strong? somewhat strong? somewhat weak? very weak?” Household composition is assessed by whether the respondent reported living alone, in a couple, with kids or with others.

5.5.2.3 Neighborhood Determinants

*Neighborhood unit.* For the purposes of this study, a neighborhood will be represented by the dissemination area (DA), forward sortation area (FSA) and census sub-division (CSD).

*Neighborhood determinants.* Neighborhood determinants, characteristics of the neighborhood measured at the level of the neighborhood, were grouped into ‘blocks’ or groups of variables with common descriptive properties. The blocks were not grouped based on psychometric latent variable concepts or using factor analysis methods. There were four distinct blocks consisting of variables that measured: demographic characteristics, socioeconomic characteristics, built environment and healthcare availability. Correlations between variables in each block were checked using Spearman correlation methods to ensure there were no highly correlated variables exceeding 0.4 included in the same block. Blocks were entered into regression models separately to reduce multicollinearity between blocks and to isolate the effects of each block on CVH. The blocks were not used for blockwise elimination, which is a statistical method to obtain a reduced set of variables from a larger set of predictor variables. Multiple data sources were used to provide variables for each block. Table 5.2 below lists the blocks, variables comprising each block, variable definitions, data sources and the neighborhood unit at which the data was measured and made available for this study. For ease of
interpretation and applicability, all variables representing neighborhood determinants were categorized into terciles – high, medium, and low.

Data Source. The sources for neighborhood determinants were described in the data sources section above and are summarized in the table below. The data sources utilized data at the individual level to define, aggregate and calculate measures that were descriptive of the neighborhood unit. Data was made available for each variable listed below by the corresponding geographic unit.

Table 5.2 Description of Neighborhood Variables utilized in the study

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Neighborhood unit</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographic Block</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>Number of persons per square kilometer</td>
<td>DA</td>
<td>Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td></td>
</tr>
<tr>
<td>Average number of dwellings</td>
<td>Average number of dwellings per neighborhood</td>
<td>DA</td>
<td>Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td></td>
</tr>
<tr>
<td>Average household size</td>
<td>Average number of persons per household</td>
<td>DA</td>
<td>Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FSA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td></td>
</tr>
<tr>
<td>Average age</td>
<td>Average age of residents</td>
<td>DA</td>
<td>Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FSA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td></td>
</tr>
<tr>
<td>Prevalence of low income</td>
<td>The proportion or percentage of units whose income falls below a specified low-income line</td>
<td>DA</td>
<td>Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FSA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td></td>
</tr>
<tr>
<td>Unemployment rate</td>
<td>The proportion or percentage of persons aged 15 years and older not in the labour force</td>
<td>DA</td>
<td>Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FSA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td></td>
</tr>
<tr>
<td>Median household total income</td>
<td>Median based on the sum of after-tax income in households</td>
<td>DA</td>
<td>Census</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FSA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSD</td>
<td></td>
</tr>
<tr>
<td><strong>Socioeconomic block</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canadian Marginalization Index (Can MARG)</td>
<td>An index assessing social inequality among geographic units, based on socioeconomic census data</td>
<td>DA</td>
<td>CANUE</td>
</tr>
<tr>
<td>Deprivation Indices (NMDI)</td>
<td>Measures of material and social deprivation that assess social inequality among</td>
<td>DA</td>
<td>CANUE</td>
</tr>
</tbody>
</table>
geographic units, based on socioeconomic census data

<table>
<thead>
<tr>
<th>Community Well Being Score (CWB)</th>
<th>A score assessing socioeconomic well-being of geographic units (CSDs)</th>
<th>CSD</th>
<th>CWB</th>
</tr>
</thead>
</table>

**Built environment block**

<table>
<thead>
<tr>
<th>Canadian Active Living Index (Can-ALE)</th>
<th>A geographic-based index that assesses walkability of geographic units (DAs)</th>
<th>DA</th>
<th>CANUE</th>
</tr>
</thead>
</table>

**Healthcare block**

<table>
<thead>
<tr>
<th>Hospital availability</th>
<th>Total hospital beds per 100,000 individuals in a geographic unit</th>
<th>FSA</th>
<th>CMDB</th>
</tr>
</thead>
</table>

| Physician availability | Total doctors per 100,000 individuals in a geographic unit | FSA | CSD | SMDB |

DA- dissemination area, FSA- forward sortation area, CSD- census subdivision, CWB- Canadian Well Being Index data, CANUE- Canadian Urban Environmental Consortium, SMDB- Scotts Medical Database

5.6 Data Analysis

5.6.1 Statistical Modelling

*Regression modelling*. Approaches to analyzing health determinants at the neighborhood-level only, tend to ignore differences among individuals within these neighborhoods.(261) Yet, approaches to analyzing determinants at the individual-level only, ignore the clustering of individuals into neighborhoods.(261) Individuals clustered within a neighborhood tend to be more alike when compared to individuals from other neighborhoods, thus violating the principle of independence governing one-level regression models.(261) Therefore, a multilevel analytic approach is necessary for examining both intra- and inter- neighborhood differences in health within the same model. Multilevel mixed effects regression modeling is appropriate for this study because it allows for the examination of both individual- and neighborhood-level determinants simultaneously on the outcome, while accurately distinguishing differences in the outcome attributed to each level. Multilevel models allow for the partitioning of the total variation in CVH among individuals into cluster-level variation and individual-level variation. A strength of multilevel modelling is that it provides information beyond the strength of associations, and on the extent of the cluster-level variation.(262)
Levels of analysis are units of observation from which data are derived or measured. The determinants characterized in the individual and interpersonal layers are analyzed at the level of the individual. The determinants characterized in the neighborhood layer are analyzed at the level of the neighborhood. Therefore, this study employs a multilevel model examining individual CVH and how it may be influenced by determinants from 1) the individual level—personal characteristics and lifestyle factors, social and community networks and 2) the neighborhood level—neighborhood factors. Therefore, models consist of two levels of analysis – individuals and neighborhoods – that have a hierarchical structure: individuals are nested within neighborhoods. This study utilizes two-level multilevel ordinal logistic mixed effects regression models. Model 1, the null model, includes no covariates and provides a baseline for the influence of determinants on CVH. Models 2-4 progressively include individual, interpersonal and neighborhood determinants. Models assess the following: (i) the magnitude and direction of the associations between individual, interpersonal and neighborhood determinants and CVH, and (ii) the contribution of these determinants to variations in CVH among individuals.

*Software.* All analyses were conducted in Stata (StataCorp. 2019. Stata Statistical Software: Release 16. College Station, TX: StataCorp LLC).

*Testing assumptions of the models.* Ordinal models assume the proportional odds rule where the effect of determinants is constant for all levels of the outcome. To test this assumption, a method proposed by Hedeker and Mermelstein (1998) is adopted; the non-proportional odds model (where the proportional odds assumption is relaxed) is compared to the proportional odds model using the likelihood ratio test. Results revealed a non-significant result (p=0.12), thus accepting the proportional odds assumption and rejecting the non-proportional odds model.

**5.7 Model Building for Multilevel Analyses**

To address the second study aim, the thesis utilizes model building in 3 simplified steps:

- Preliminary step: Data preparation (define the outcome, categorize variables, merge datasets)
- Step 1: Construct an empty model to assess between-area variation
Step 2: Add individual- and neighborhood-level variables to the model to assess the influence of determinants on both health and between-area variations in health

Step 3: Construct final models to examine hypothesized interactions

Multilevel ordinal mixed-effects regression models, based on the logit function, were used to examine the influence of determinants on CVH, accounting for within-neighborhood and between-neighborhood correlations. Model parameters were estimated using a maximum marginal likelihood solution, with a Gauss-Hermite quadrature. The models assumed that there were \( i \) individual-level units, nested within \( j \) neighborhood-level units and the ordinal outcome \( y \) had three categories – poor, intermediate, and ideal CVH. According to the multilevel structure, initially proposed by Goldstein (263) and Bryk and Raudenbush (264, 265), the study model may be partitioned into the following:

**Within-neighborhood model:**
\[
y_{ji} = x'_{(1)ji}b_i + w'_{(1)ji}\alpha_{(1)} + \varepsilon_{ji}
\]

**Between-neighborhood model:**
\[
b_i = \mu + w'_{(2)i}\alpha_{(2)} + \delta_i
\]

In the first equation, \( w'_{(1)ji}\alpha_{(1)} \) represents the fixed individual-level covariates and their effects, \( w'_{(2)i}\alpha_{(2)} \) represent neighborhood-level covariates and their effects, \( x'_{(1)ji} \) represent the random effects that are allowed to vary at neighborhood-level, \( b_i \) represent neighborhood-level effects (differences between neighborhoods) that are influenced by an overall mean \( \mu \) and neighborhood-level covariates and effects \( w'_{(2)i}\alpha_{(2)} \), and \( \delta_i \) represents the random component which is the unexplained random neighborhood-level variation.

Combining the two equations yields the following:
\[
y_{ji} = x'_{(1)ji}(\mu + w'_{(2)i}\alpha_{(2)} + \delta_i) + w'_{(1)ji}\alpha_{(1)} + \varepsilon_{ji}
\]

In this study, \( y_{ji} \) is a logit function represented by \( \log[p_{jic}/(1-p_{jic})] \) where \( p_{jic} \) is the probability of a response \( \Pr(Y_{ji}=1) \), where \( c \) is the number of ordered response categories.
5.7.1 Statistical Measures

Measures of association and variance used in this study have been proposed, quantified and validated in multiple statistical research studies led by key researchers that have laid the foundation for multilevel analyses – Austin, Hedeker and Merlo et al.(266-268) These measures are briefly described below, and the use of these measures in study objectives are outlined in the subsequent section.

5.7.1.1 Measures of Association

The proportional odds ratio is not very intuitive in explaining the effects of determinants on the outcome in ordinal regression models.(269) Therefore, the study uses various measures of association to describe the relationship between determinants and CVH as indicated below.

Odds ratio. The models produce proportional odds ratios, which are interpreted as follows: for every one unit change in the predictor variable, the change in odds of the highest category of the outcome vs the combined middle and low categories of the outcome, given the other variables in the model are held constant. This interpretation applies regardless of how the categories of responses are ordered; that is, for an ordinal outcome of 3 categories (as in this study), the odds ratio contrasting category 0 vs. 1 and 2 holds the same interpretation as contrasting category 0 and 1 vs 2. In the multilevel model, the odds ratios are adjusted for other covariates and for the neighborhood.

Conditional probabilities. The odds produced from ordinal models may be represented as odds ratios, proportions, or probabilities. The conditional probability is the likelihood of the outcome, given that other conditions have been met. In this study, conditional probabilities will be used to express the likelihoods of ideal, intermediate, and poor CVH across categories of individual determinants, given other determinants and the neighborhood are held constant in the model.

Population-average odds ratio. The neighborhood specific odds ratios are difficult to interpret when neighborhood-level covariates are added to the models therefore an alternative measure may be used – the population-average odds ratio. This odds ratio is
the average odds ratio obtained from comparing different individuals in different neighborhoods, holding all other variables constant.\(^{(266)}\) The population-average odds ratio can be obtained from the neighborhood specific odds ratio by dividing the neighborhood specific odds ratio by a shrinkage factor (proposed and applied in previous multilevel research and outlined by Austin \textit{et al.}\(^{(266)}\)).

\textit{Interval odds ratio.} The interval odds ratio was also proposed and applied in previous multilevel research to examine the effect of cluster neighborhood variables on the outcome.\(^{(266)}\) The interval odds ratio represents the middle 80\% of the distribution of odds ratios comparing individuals who differ by one unit of the neighborhood variable, that is, the variation around the population-average odds ratio. Thus, the interval odds ratio is a range with an upper and lower limit, which if containing the value 1 is considered to be high cluster variability.

5.7.1.2 Measures of Variance and Heterogeneity

In addition to the relationships between determinants and CVH, this study aims to examine variation in CVH. Measures of variance and heterogeneity allow for more in-depth analysis of variation in the outcome and the contribution of the neighborhood level to this variation.

\textit{Variance partition coefficient.} The variance partition coefficient may be interpreted as an intraclass correlation coefficient, which is a statistical measure that quantifies correlations between groups (or classes). In the ordinal model, the neighborhood level variation, specifically, the between-cluster variation, can be estimated using the variance partition coefficient, however, the between-individual variation remains fixed as \(\pi^2/3\). In this study, the variation partition coefficient is interpreted as the proportion of the total variation in CVH among individuals, that may be attributed to the variation between neighborhoods, and indicates the role of the neighborhood level in analyses.

\textit{Median Odds Ratio.} The median odds ratio displays the cluster variation as an odds ratio that may be interpreted on the same scale as other odds ratios in the analysis. In this study, the median odds ratio compares an individual in a neighborhood with higher risk
of CVH to an identical individual in a neighborhood with lower risk of CVH. The MOR is a measure of heterogeneity or the range of neighborhood variation. The magnitude of the median odds ratio should be interpreted in context with the magnitude of the variance partition coefficient, that is, if the variance partition coefficient is low then a moderate median odds ratio may also be considered as low.

*Proportional change in cluster variance.* The proportional change in variance is a simple measure used to quantify the changes in neighborhood variance from the null model to the model with determinants. The interpretation is challenging in the ordinal model but may still indicate changes in the neighborhood variance that can be accounted for by determinants. It cannot be used to indicate the increase or deceasing relevance of the neighborhood in models.

5.7.2 Statistical Analyses

5.7.2.1 Objective 1 – Cardiovascular Health in the Canadian Population

*Estimate the prevalence of CVH in the Canadian adult population.*

To describe CVH, prevalence is calculated for all study determinants and the outcome, as the number of subjects with the determinant or outcome, divided by the total number of eligible subjects. Prevalence values are weighted by applying sampling weights and is reported as a percentage. Thus, the prevalence of CVH is nationally representative of the Canadian population.

*Estimate the proportion of total variation in CVH that can be attributed to the geographic areas in which individuals reside.*

Random intercept models are used throughout the study to allow the outcome to vary across neighborhoods. In this first objective a null (empty) model with no covariates is analyzed to identify potential sources of variation in CVH between individuals in the Canadian population. The variance partition coefficient (VPC) and the median odds ratio (MOR) are calculated to estimate the proportion of total variation in cardiovascular health between individuals that can be attributed to the neighborhood levels. The VPC (also
termed intra class coefficient in linear models) is estimated using the latent response approach where the individual variance is fixed at $\pi^2/3$.\(^{(266)}\) An increase in VPC indicates a higher contribution of the level to the variation in CVH among individuals. The MOR is estimated as an odds ratio and represents the increase in odds of improved CVH if an individual lived in a different neighborhood where individuals were known to have better CVH.\(^{(266)}\) To facilitate comparison of the null model with models in the subsequent objectives, weights are not applied.

5.7.2.2 Objective 2 – Individual-Level and Area-Level Determinants of Cardiovascular Health in a Canadian Sample

Assess the relationship between individual-level determinants and CVH.

Determinants measured at the individual-level (level 1) – individual and interpersonal determinants – were added to the null model. Individual-level determinants are entered into the multilevel model as fixed effects to determine their association with CVH. While odds ratios are essential for understanding the magnitude of the associations investigated, they do not provide an intuitive understanding of associations when interpreting results for ordinal regression models. Therefore, conditional probabilities were also used to provide a more extensive description of the associations investigated. Conditional probabilities display the probability of having poor, intermediate or ideal CVH, given that other determinants and random effects in the model are held constant. That is, the change in probability of the outcome across categories of a determinant when all other determinants are held constant and individuals are in a group with the same random effect. Conditional probabilities have a within-cluster interpretation thus, as an exploratory analysis, individual-level determinants will also be entered into the multilevel model as independent random effects to determine whether their association with CVH changes across neighborhoods.

Determine whether individual-level determinants of CVH can account for the variation in CVH among individuals that is attributed to the geographic areas in which these individuals reside.
The between-neighborhood variation in CVH, quantified in objective 1, may be due to differences among individuals (characterized by individual-level determinants) or to differences among neighborhoods (characterized by neighborhood-level determinants). This subobjective examines the proportion of between-neighborhood variation that is accounted for by differences between individuals. The VPC and MOR are again calculated for to estimate the between-neighborhood variation in CVH between individuals that can be explained by individual-level determinants. The proportional change in cluster variance (PCV) will also be used to compare the neighborhood variance in the null model to the that of models with determinants, although it will be interpreted with caution because a change in neighborhood variance may not necessarily indicate an increased relevance of the neighborhood in logistic models.

Assess the relationship between area-level determinants and CVH, accounting for the influence of individual-level determinants.

Determinants measured at the neighborhood level (level 2) – neighborhood determinants – are added to the model with individual-level determinants. Neighborhood determinants are entered into the multilevel model (already containing individual and interpersonal determinants) as fixed effects to determine their association with CVH. Neighborhood determinants are entered into models as ‘blocks’ – grouped as census variables that measure demographic characteristics, composite index variables that measure socioeconomic characteristics, environmental variables that measure the built environment and healthcare variables that measure healthcare availability. To avoid issues of multicollinearity, blocks are entered into models independently rather than simultaneously. Odds ratios (ORs) are calculated to measure the associations between neighborhood determinants and CVH. The IOR-80 was calculated to examine heterogeneity around the ORs and represents the middle 80% range of ORs observed for a unit change in the covariate, adjusted for the neighborhood. IOR-80 values were calculated only for ORs with significant values (where 95% CI did not contain 1). The ORs produced by multilevel models represent conditional i.e. neighborhood specific effects which provides a challenge for the interpretation of the associations of the outcome and neighborhood-level variables. Therefore, population-average odds ratios,
which are not neighborhood specific, are also calculated. Population-average odds ratio is the average odds ratio of comparing two subjects, each residing in different neighborhoods, who are similar in respect to all other determinants in the model.

*Determine whether area-level determinants of CVH can account for the variation in CVH among individuals that is attributed to the geographic areas in which these individuals reside.*

The between-neighborhood variation in CVH, quantified in objective 1, may be due to differences among individuals (characterized by individual-level determinants) or to differences among neighborhoods (characterized by neighborhood-level determinants). This subobjective examines the proportion of between-neighborhood variation that is accounted for by differences between neighborhoods. The VPC and MOR are again calculated for to estimate the between-neighborhood variation in CVH between individuals that can be explained by neighborhood-level determinants i.e. the remaining variation not already explained by individual-level determinants.

*Explore whether area-level determinants modify the relationship between individual-level determinants and CVH.*

Cross-level interactions between determinants measured at both the individual level (level 1) and neighborhood level (level 2) are examined in this subobjective. To examine the cross-level interaction, product interaction terms are entered into the model for selected combinations of the individual and neighborhood determinants. Selection of determinants for inclusion into interaction models were based firstly on theory informed by the literature review. Also, secondarily on whether they significantly influenced CVH (p≤0.05) in prior objectives. Based on the literature review, it may be hypothesized that neighborhood-level determinants that can be altered by health policy (such as socioeconomic conditions) modify the relationship between individual-level determinants that cannot be altered by health policy (such as age, sex and race/ethnicity) and CVH. Neighborhood-level determinants are conceptualized as the modifiers in this subobjective, as the thesis focuses on neighborhoods as context within which individual effects are observed. Interaction effects will examine the modified association of
individual determinants with CVH, for comparable categories of neighborhood
determinants. Both individual and neighborhood determinants are categorical therefore,
the interpretation of the interaction effect refers to differences in relationships between 2
or more groups.

In the logit model, odds ratios (ORs) of the interaction term produced by the statistical
software do not have a direct interpretation and the ORs that represent the cross-level
interaction of this study aim need to be recalculated. Therefore, to derive the desired odds
ratios for the interaction terms from the values produced by the statistical software, the
following concept was employed in calculations:

Simple fitted model: \( \text{logit}(P_{\text{CVH}}) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \text{error terms} \),

Where \( X_1 \) represents the individual-level variable, \( X_2 \) represents the neighborhood-level
variable, and \( X_3 \) represents the cross-level interaction of \( X_1 \) and \( X_2 \).

For those with \( X_2 = 1 \), the odds ratio for those with \( X_1 = 1 \) vs those with \( X_1 = 0 \) is calculated
as: \( \exp (\beta_1 + \beta_3) \)

These calculations were conducted and presented only for significant interaction terms
(where \( \beta_3 \ p \leq 0.05 \)).

Assess how the relationship between individual- and area-level determinants and CVH,
differs for females as compared to males.

This subobjective focuses on sex differences in the relationship between determinants
and CVH. Interaction terms for sex and individual and neighborhood determinants will
be entered into the models as in prior objectives. Analyses are not stratified but examined
as interactions. This method maintains the entire sample size and allows for males and
females to be directly compared in the same model, as opposed to stratification, where
the sample size is reduced in separate models and sex-specific estimates are not
comparable. Tabulated results indicate the odds ratio for the relationship between
determinants and CVH in females, with males as the reference category. Based on past
studies, the CVH for females has been shown to be higher than that of males, thus males
were used as the reference category in all analyses for ease of interpretation of odds ratios. The same concept of calculating odds ratios for interactions as mentioned in the above aim was applied to this aim, where $X_2$ represented the sex variable with 0= males and 1=females.

Variation in CVH was not examined in this objective because there is little evidence to support a hypothesis of sex differences in variations in CVH in the multilevel literature. Additionally, sex-specific differences would have to be examined in sex stratified models, as variation values are not odds ratios that can be compared in interactions. As an exploratory approach, analyses will be conducted attempting to stratify null models, to determine whether there are notable differences in the variation of CVH that can be attributed to neighborhoods in males vs females. These sex-specific values may not be directly comparable but may be hypothesis generating for differences in variation of CVH between the sexes. However, this exploratory stratification will not be replicated in subsequent models where sample sizes are decreased even further among subgroups of determinants.

### Table 5.3 Summary of Methodological Elements for Study Objectives

<table>
<thead>
<tr>
<th></th>
<th>Objective 1</th>
<th>Objective 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study group</strong></td>
<td>Population of adults aged 20 years and older residing in Canada</td>
<td>Sample of adults aged 20 years and over residing in Canada</td>
</tr>
<tr>
<td><strong>Approximate sample size</strong></td>
<td>23,200,000 individuals</td>
<td>85,200 individuals</td>
</tr>
<tr>
<td><strong>Study design</strong></td>
<td>Descriptive analysis-prevalence estimates</td>
<td>Regression analysis-multilevel models</td>
</tr>
<tr>
<td><strong>Levels of analysis</strong></td>
<td>Individual</td>
<td>Individual and neighborhood</td>
</tr>
<tr>
<td><strong>Data sources</strong></td>
<td>CCHS</td>
<td>CCHS, Census, CIHI, CWB data, CANUE</td>
</tr>
</tbody>
</table>
5.8 Addressing the Issue of Weighting in the Study

The thesis utilizes sample weights in the descriptive section of first study objective, however, weights were not applied for the multilevel analysis in the second objective. Numerous studies have addressed the issue of weighting in multilevel models, and these issues have been considered in-depth for application to the thesis.

When considering the inclusion of sample weights in multilevel analysis, a common recommendation is to scale individual-level weights. Scaling normalizes the raw weights for study application by summing the values of these raw weights to some population total of interest in the data. While this may not have a huge impact in linear models, scaling of weights is known to strongly impact regression estimates in dichotomous and ordinal models because these estimates are closely related to the random intercept variance. Many procedures for scaling individual-level weights allows for examination of individual-level estimates however, neighborhood-level is considered a nuisance that is adjusted for in analyses. Additionally, researchers suggest that scaling the weights at individual-level can bias the variance components of multilevel models, specifically overestimating the between-cluster variance.

To overcome this issue with scaling methods, two main methods have been proposed: 1) using a scaling factor that allows the apparent cluster size to equal the effective sample size, 2) using a scaling factor that allows the apparent cluster size to equal the actual sample size. Research comparing these methods are often contradictory and the methods are often criticized for their narrow application to particular models and sampling methods. A key study comparing weighted and unweighted estimates found contradictory results based on software and the overall approach to weights, with no consensus on which method is best. They only concluded that if weights were to be included in studies, they should be rescaled in multilevel models to avoid bias in parameter estimates.

Additional approaches include Rabe-Hesketh and Skrondal who suggests for two-level logistic regression models, the pseudolikelihood approach, the use of scaling methods for individual-level weights and marginal regression coefficients in Monte Carlo
experiments, produces less biased results. Another suggested method is a pseudo-
maximum likelihood approach in structural equation modelling using both individual and
neighborhood-level weights, although neighborhood-level weights did not have to be
scaled. Neither method was proven superior to the other in simulation studies.

There are challenges with using these approaches in Statistics Canada data. The CCHS
data provides a sampling weight only for individual-level units, based on the multistage
sampling design of the survey, that were seemingly intended for single-level and not
multilevel analyses. Thus, to use weighting with the CCHS data in a multilevel study, a
multilevel weighting scheme with various simulation models to compare weighting
methods and derive multilevel weights, would appear to be the ideal approach to
minimizing bias. However, given the extensive computing time for running even simple
multilevel models, it is likely that this method would be complex and fairly time
consuming for the thesis.

Another important consideration was the neighborhood-level data used in the study; in
addition to CCHS data, data is derived from Census, CWB data, CANUE and CIHI, and
are merged at neighborhood level. Statistics Canada suggests the use of a scaling factor
when combining different cycles of CCHS but provide no instructions on applying
weights when combining CCHS with external data. Additionally, the CANUE
and CIHI datasets do not include any weights. Researchers have suggested that the use of
individual-level weights should be maintained, ignoring any neighborhood-level weights
however, little research has been done to show whether this approach produces accurate
estimates. Stata software allows for the use of different weights in one study dataset
however, this needs to be correctly set up at the beginning of the analyses and can be
complex when more than two datasets are involved, as in this study. Another study from
Dong et al, attempting to combine two national surveys, suggested using an imputation
model to combine the datasets then treating the combined population as a simple random
sample. This method has been applied more extensively in US than Canadian data.

Examining other recent studies in the multilevel literature within the past 5 years,
revealed high variability in the approaches to the use of weights in multilevel analyses. A
study by Sissoko et al examining the impact of determinants on vaccinating children in India, used the sampling weights included in the national data and a Markov Chain Monte Carlo simulation algorithm to reduce the bias of estimates, with no mention of rescaling weights. (277) A 2018 study conducted in Brazil examining the impact of policy on oral health, revealed that the use of weights was not compatible in the study software (STATA) and so weighting was not applied. (278) However, a 2019 Finnish study using national survey data to examine neighborhood disadvantage and health, reported incorporating the survey weights into their analyses using STATA software, although there was again no mention of rescaling these weights. (188) A number of other published studies claimed to use multilevel analysis in nationally representative data with a weighted design, and completely neglected any reporting on how they incorporated weights into their multilevel analyses or reported using weights on part of the analyses only. One such multilevel study mentioned that the use of weights was “unnecessarily complex” and did not use it at all in analyses. (279) Many of the cardiovascular studies referenced throughout the thesis conducted multilevel analysis in sample data, rather than national survey data, and none used combined survey and administrative data.

According to recommendations by Carle et al “If one cannot scale the weights and include them properly in the estimation, analyzing the data without weights provides the next best option.” (270) There are no other studies in the literature examining ideal CVH in multilevel models using a Canadian sample. Thus, the multilevel analyses in the thesis are exploratory and were not intended to produce national estimates at this time. Multilevel analyses on a Canadian sample are adequate for addressing thesis objectives. For practical purposes, such as data structure (merged data), interpretability and accuracy of results, and efficient use of available software, the thesis utilizes the merged 2015-2016 sample of adults as a simple random sample, with no weights applied in multilevel analyses. Weights will be applied to descriptive analyses only, to obtain prevalence estimates of CVH in Canadians (objective 1). The advantage of this approach is that the study will maintain the internal validity and reliability of estimates; however, the disadvantage is that the external validity of multilevel model results will decrease considerably. (270)
Nevertheless, the study will provide valuable and accurate information on the pattern of multilevel influence of health determinants on cardiovascular health in the Canadian context. A similar approach was successfully adopted by another US study conducted by Diez-Roux, a leading expert in multilevel methodology in health research, examining CVD in multilevel analysis using nationally representative data. That study reports no differences between weighted and unweighted estimates in sensitivity analyses. The thesis did not aim to compare weighted and unweighted estimates as this would not contribute any additional information to the inferences derived. However, with the increased uptake of multilevel methodology in the literature, and the fast-paced updates made to statistical software, it is anticipated that thesis results can be replicated and even expanded using weighted data in future studies.
Chapter 6

6 Results

In this section, results of statistical analyses will be described as conducted for each of the study objectives. Firstly, the characteristics of the study sample, both individual and neighborhood, are described using unweighted prevalence and means values respectively. Secondly, the status of CVH is described using weighted prevalence values to provide nationally representative estimates. Lastly, regression models are conducted on the study sample to quantify the influence of individual and neighborhood determinants on CVH, providing unweighted estimates.

6.1 Characteristics of the Study Sample

6.1.1 Individual-Level Determinants

After exclusions, the eligible unweighted study population was approximately 85,200 individuals. Table 6.1 shows the unweighted prevalence of individual and interpersonal characteristics for unweighted eligible study population. The majority of the population was aged 20-39 years (38.23%) and 40-59 years (38.53%). Approximately half of the population were females (50.41%) and more than half were White Non-Hispanic (72.99%), non-immigrant (74.41%) and completed post-secondary education (66.61%). When reporting sexual orientation, 1.43% of individuals identify as homosexual. As for lifestyle factors, 41.93% and 31.87% of individuals reported feeling a bit stressed in life and at work respectively; and most individuals reported occasionally consuming alcohol (67.19%) and not using illicit drugs (88.65%) in the past 12 months. As for interpersonal characteristics, almost half of individuals reported somewhat strong feelings of social inclusion (48.86%) and living in a nuclear family structure (a couple with kids aged less than 25 years) (31.66%).
Table 6.1 Characteristics of the study sample based on individual-level determinants, Canadian Community Health Survey (2015-2016)

<table>
<thead>
<tr>
<th>Individual-level determinants</th>
<th>Category</th>
<th>Unweighted Prevalence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>20-39 years</td>
<td>38.23</td>
</tr>
<tr>
<td></td>
<td>40-59 years</td>
<td>38.53</td>
</tr>
<tr>
<td></td>
<td>60-79 years</td>
<td>21.11</td>
</tr>
<tr>
<td></td>
<td>80 years and over</td>
<td>2.13</td>
</tr>
<tr>
<td>Sex</td>
<td>Male</td>
<td>49.59</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>50.41</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td>White Non-Hispanic</td>
<td>72.99</td>
</tr>
<tr>
<td></td>
<td>South Asian</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>Chinese</td>
<td>4.15</td>
</tr>
<tr>
<td></td>
<td>Korean and Japanese</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>2.85</td>
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<tr>
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<td>Filipino and South Asian</td>
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<tr>
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<td>Hispanic Latin and South American</td>
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<tr>
<td></td>
<td>Arab and West Asian</td>
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<tr>
<td></td>
<td>Other</td>
<td>1.42</td>
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<td></td>
<td>Mixed or many races</td>
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<td>Gender (sexual orientation)</td>
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<td></td>
<td>Bisexual</td>
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<td></td>
<td>Refused to state</td>
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<td>Education</td>
<td>Did not complete Secondary Education</td>
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</tr>
<tr>
<td></td>
<td>Completed Secondary Education</td>
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<td>Completed Post-secondary Education</td>
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<td></td>
<td>Refused to state</td>
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<tr>
<td>Annual household income</td>
<td>No income</td>
<td>2.20</td>
</tr>
<tr>
<td></td>
<td>&lt;$5,000</td>
<td>3.58</td>
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<td>$5,000-$10,000</td>
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<td>$20,000-$29,999</td>
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<tr>
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<td>$30,000-$39,999</td>
<td>11.79</td>
</tr>
<tr>
<td></td>
<td>$40,000-$49,999</td>
<td>10.22</td>
</tr>
<tr>
<td></td>
<td>$50,000-$59,999</td>
<td>7.85</td>
</tr>
<tr>
<td></td>
<td>$60,000-$69,999</td>
<td>6.24</td>
</tr>
<tr>
<td></td>
<td>$70,000-$79,999</td>
<td>4.95</td>
</tr>
<tr>
<td></td>
<td>$80,000-$89,999</td>
<td>4.05</td>
</tr>
<tr>
<td></td>
<td>$90,000-$99,999</td>
<td>2.73</td>
</tr>
<tr>
<td></td>
<td>&gt;$100,000</td>
<td>9.60</td>
</tr>
<tr>
<td></td>
<td>Refused to state</td>
<td>Rate stress in life in the past 12 months</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>------------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not at all stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not very stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A bit stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quite a bit stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extremely stressful</td>
</tr>
<tr>
<td>Rate stress at work in the past 12 months</td>
<td></td>
<td>Not at all stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not very stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A bit stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quite a bit stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extremely stressful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Refused to state</td>
</tr>
</tbody>
</table>
| Alcohol use in the past 12 months |                  | Occasional (consumed any alcohol less than once a month) | 67.19
|                                   |                  | Regular (consumed any alcohol more than once a month) | 15.37
|                                   |                  | Not in 12 months                           | 17.15
|                                   |                  | Refused to state                          | 0.29
| Illicit Drug use in the past 12 months |                  | Current use                               | 10.97
|                                   |                  | No current use                            | 88.65
|                                   |                  | Refused to state                          | 0.38
| Rate feelings of social Inclusion |                  | Very strong                               | 17.79
|                                   |                  | Somewhat strong                           | 48.86
|                                   |                  | Somewhat weak                             | 24.96
|                                   |                  | Very weak                                 | 7.36
|                                   |                  | Refused to state                          | 1.03
| Household composition             |                  | Single, lives alone                       | 15.50
|                                   |                  | Single, lives with others                 | 4.37
|                                   |                  | Couple, lives together                     | 29.10
|                                   |                  | Couple, lives together with kids ≤ 25 years | 31.66
|                                   |                  | Couple with kids ≤ 25 years, lives with others | 4.18
|                                   |                  | Couple with kids > 25 years living together or with others | 5.78
|                                   |                  | Single female, living with kids ≤ 25 years | 4.83
|                                   |                  | Single female, living with kids > 25 years | 1.98
|                                   |                  | Single male, living with kids ≤ 25 years   | 1.27
|                                   |                  | Single male, living with kids > 25 years   | 0.47
|                                   |                  | Refused to state                          | 0.86
6.1.2 Neighborhood-Level Determinants

Table 6.2 describes the unweighted means of neighborhood characteristics for the three neighborhood units from which the eligible study population was sampled. Included in this study were 5436 DAs, 1200 CSDs and 800 FSAs; the sample size (85,200 individuals) is maintained across units as described in the previous section on missing data. Neighborhood characteristics are first described using means as an indication of the range of these variables. To facilitate ease of interpretation in further analyses, neighborhood characteristics are categorized into terciles to indicate neighborhoods with high, medium, and low categories of characteristics. The DAs consist of demographic, built environment and socioeconomic blocks. The CSDs consist of demographic, socioeconomic and healthcare blocks. The FSAs consist of demographic and healthcare blocks. For DAs, the smallest unit of geography, the average density is highest (4129.89 per square km), and values of marginalization and active living are mid-range (average Canadian marginalization index 3.03, and average active living environment index score 0.60 respectively). For CSDs, the average density is lower (1419.41.89 per square km), and the average community well-being index is high at 81.59. For FSAs, the largest unit of geography, and physician supply is on average 258 physicians per 100,000 individuals and hospital bed supply is 225 per unit.
### Table 6.2 Characteristics of the study sample based on neighborhood-level determinants, multiple data sources*

<table>
<thead>
<tr>
<th>Neighborhood-level determinants</th>
<th>Means (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dissemination Area</strong></td>
<td></td>
</tr>
<tr>
<td>Average Density (per square kilometer)</td>
<td>4129.89 (1915.30)</td>
</tr>
<tr>
<td>Average Age of residents (years)</td>
<td>41.36 (50.78)</td>
</tr>
<tr>
<td>Average Household Size (persons)</td>
<td>2.51 (9.18)</td>
</tr>
<tr>
<td>Median Income ($)</td>
<td>36531.55 (12342.33)</td>
</tr>
<tr>
<td>Average Prevalence of Low income (%)</td>
<td>9.85 (6.89)</td>
</tr>
<tr>
<td>Average Unemployment Rate (%)</td>
<td>7.76 (8.81)</td>
</tr>
<tr>
<td>Average Canadian Marginalization Index (scaled 0 to 5)</td>
<td>3.03 (14.11)</td>
</tr>
<tr>
<td>Average Material Deprivation Index Score (standardized score)</td>
<td>-0.002 (0.71)</td>
</tr>
<tr>
<td>Average Social Deprivation Index Score (standardized score)</td>
<td>0.006 (0.71)</td>
</tr>
<tr>
<td>Average Active Living Environment Index Score (scaled 0 to 1)</td>
<td>0.60 (61.72)</td>
</tr>
<tr>
<td>Average Active Living Environment Transit Index Score (scaled 0 to 1)</td>
<td>0.60 (72.03)</td>
</tr>
<tr>
<td><strong>Census Sub-division</strong></td>
<td></td>
</tr>
<tr>
<td>Average Density per area (per square kilometer)</td>
<td>1419.41 (2355.47)</td>
</tr>
<tr>
<td>Average Age of residents (years)</td>
<td>41.11 (54.27)</td>
</tr>
<tr>
<td>Average Household Size (persons)</td>
<td>2.47 (5.34)</td>
</tr>
<tr>
<td>Median Income ($)</td>
<td>35092.09 (10086.39)</td>
</tr>
<tr>
<td>Average Prevalence of Low income (%)</td>
<td>9.94 (8.74)</td>
</tr>
<tr>
<td>Average Unemployment Rate (%)</td>
<td>7.68 (9.56)</td>
</tr>
<tr>
<td>Average number of physicians per 100,000 individuals</td>
<td>252.12 (240.34)</td>
</tr>
<tr>
<td>Average Community Well Being Index score (scaled 0 to 100)</td>
<td>81.59 (62.59)</td>
</tr>
<tr>
<td><strong>Forward Sortation Area</strong></td>
<td></td>
</tr>
<tr>
<td>Average Age of residents (years)</td>
<td>41.11 (59.94)</td>
</tr>
<tr>
<td>Average Household Size (persons)</td>
<td>2.48 (6.86)</td>
</tr>
<tr>
<td>Median Income ($)</td>
<td>35481.85 (13295.04)</td>
</tr>
<tr>
<td>Average Prevalence of Low income (%)</td>
<td>5.68 (9.41)</td>
</tr>
<tr>
<td>Average Unemployment Rate (%)</td>
<td>7.77 (8.21)</td>
</tr>
<tr>
<td>Average number of physicians per 100,000 individuals</td>
<td>258.50 (182.00)</td>
</tr>
<tr>
<td>Average number of hospital beds available per FSA</td>
<td>224.99 (139.36)</td>
</tr>
</tbody>
</table>

6.2 Cardiovascular Health in the Canadian Population

6.2.1 Prevalence of Cardiovascular Health

Objective 1a. Estimate the prevalence of CVH in the Canadian adult population.

Table 6.3 shows the weighted prevalence of cardiovascular health (CVH) in the eligible study population, based on the score of overall CVH and its seven individual components. The weighted study population was approximately 23,200,000 individuals. The distribution of the CVH score (measured on a scale of 0 to 7) was left-skewed as shown in figure 6.1. Approximately 34% of Canadians reported ideal health in at least 5 of the 7 individual components of CVH. Based on prior use of the CVH score in existing literature, the CVH score is categorized into three categories – ideal CVH (6-7 points), intermediate CVH (3-5 points) and poor CVH (0-2 points). The majority of the population was categorized as having intermediate CVH (68.31%), followed by ideal CVH (26.62%). Poor CVH was noted in 5.02% of the population, which was equivalent to over 1 million individuals. Each of the 7 CVH components is categorized as ideal health (1 point) or poor health (0 points). For each of the clinical score components (blood pressure, cholesterol, and glucose) the prevalence of ideal health exceeded 80% in the study population. For each of the behavioral score components (smoking, body mass index, diet, physical activity) the prevalence of ideal health was variable with 81% of the population having ideal smoking habits in comparison to 19% of the population with ideal dietary habits. Of all the individual components, the highest prevalence of ideal health was noted for glucose (93.67%) and the lowest prevalence of ideal health was noted for diet (19.00%).
Table 6.3 Prevalence of Cardiovascular Health in the Canadian population, Canadian Community Health Survey (2015-2016)

<table>
<thead>
<tr>
<th>Components</th>
<th>Status</th>
<th>Weighted Prevalence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure</td>
<td>Poor</td>
<td>16.24</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>83.76</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>Poor</td>
<td>11.95</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>88.05</td>
</tr>
<tr>
<td>Glucose</td>
<td>Poor</td>
<td>6.33</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>93.67</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>Poor</td>
<td>56.46</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>43.54</td>
</tr>
<tr>
<td>Smoking</td>
<td>Poor</td>
<td>18.06</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>81.94</td>
</tr>
<tr>
<td>Physical Activity</td>
<td>Poor</td>
<td>39.50</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>60.50</td>
</tr>
<tr>
<td>Diet</td>
<td>Poor</td>
<td>81.00</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>19.00</td>
</tr>
<tr>
<td>Cardiovascular Health</td>
<td>Poor</td>
<td>5.07</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>68.31</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>26.62</td>
</tr>
</tbody>
</table>

Figure 6.1 Distribution of the Cardiovascular Health Index in the Canadian population, Canadian Community Health Survey (2015-2016)
6.2.2 Variation in Cardiovascular Health

Objective 1b: Estimate the proportion of total variation in CVH that can be attributed to the geographic areas in which individuals reside.

Table 6.4 lists results of analyses conducted using null models to examine variation in CVH in the Canadian population. The CVH of Canadians varies significantly across all three neighborhood units (level 2 variance_{DA}=0.16; 95% CI 0.13-0.18, level 2 variance_{CSD}=0.07; 95% CI 0.06-0.09, level 2 variance_{FSA}=0.10; 95% CI 0.09-0.12). As demonstrated by the variance partition coefficient (VPC), approximately 7%, 4.5% and 5% of the variation in CVH among Canadians can be attributed to the geographic areas in which individuals reside: the DA, the CSD and the FSA units, respectively. Generally, these VPC values indicate a small contextual effect for the neighborhoods. Median odds ratios (MOR) values show considerable heterogeneity across neighborhoods. In DAs, the MOR is 1.46 at the neighborhood level which indicates that when comparing two individuals from two randomly selected DAs, the odds of better CVH was 1.46 for the individual in the DA with higher average CVH as compared to the individual in the DA with lower average CVH. Overall, the highest VPC and MOR values were noted for DAs followed by FSAs then CSDs.

Table 6.4 Multilevel model to estimate the variation in cardiovascular health, Canadian study sample (2015-2016)

<table>
<thead>
<tr>
<th>Model 1 (null model)</th>
<th>Dissemination area (DA)</th>
<th>Census subdivision (CSD)</th>
<th>Forward Sortation Area (FSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random effects</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
</tr>
<tr>
<td>Variance (95% CI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighborhood</td>
<td>0.16 (0.13-0.18)</td>
<td>0.07 (0.06-0.09)</td>
<td>0.10 (0.09-0.12)</td>
</tr>
<tr>
<td>Variance partition coefficient (VPC) (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighborhood</td>
<td>6.9</td>
<td>4.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Median odds ratio (MOR)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighborhood</td>
<td>1.46</td>
<td>1.30</td>
<td>1.36</td>
</tr>
</tbody>
</table>
6.3 Individual-Level and Neighborhood-Level Determinants of Cardiovascular Health in a Canadian Sample

6.3.1 The Relationship between Individual-Level Determinants and Cardiovascular Health

Objective 2a(i): Assess the relationship between individual-level determinants and CVH.

Table 6.5 displays results of multilevel models for the associations between cardiovascular health and individual and interpersonal determinants (Model 2). Using sex as an example, the interpretation of the odds ratio estimate is as follows; the odds of ideal CVH versus the combined intermediate and poor categories of CVH are 1.81 greater for females as compared to males, given that other individual and interpersonal characteristics and the neighborhood are held constant. These are not very intuitive interpretations therefore conditional probabilities are also utilized. Conditional probabilities, expressed as percentages, are graphed in Figure 6.2, and show the probabilities of having ideal, intermediate, or poor CVH for each subgroup of determinants, given that other individual and interpersonal characteristics and the neighborhood are held constant. For the demographic characteristics, the probability of ideal health is highest for; those aged 20-39 years females, immigrants, homosexual gender, Chinese ethnicity, those earning less than $5,000 or more than $70,000 annually, and those with post-secondary education. For lifestyle characteristics, the probability of ideal health is highest for; those who are not very stressed in life or at work, occasional drinkers and those who do not use illicit drugs. For the interpersonal determinants, the probability of ideal health is highest for; those with somewhat strong social inclusion and those living in the common nuclear family structure (couple living with kids).

In exploratory analyses, random slopes models are used to determine whether the relationship between CVH and individual and interpersonal factors differs across neighborhoods (results not tabulated). For the DA, significant results (p≤0.05) were noted for sex, immigration status, education, life stress and social inclusion. For the CSD, significant results (p≤0.05) were noted for sex, work stress and social inclusion. For the FSA, significant results (p≤0.05) were noted for immigration and alcohol use. Therefore,
the magnitude of the relationships between these covariates and CVH are higher or lower in some neighborhoods as compared to others. When examining the relationship between the random intercept and random slopes using the covariance structure, the covariance was positive for sex in DAs, for work stress in CSDs and, negative for all other significant covariates. For sex, a positive covariance indicates that neighborhoods with better CVH had greater improvements in CVH for females than males; while for education, the negative covariance indicates that neighborhoods with better CVH had smaller improvements in CVH for the educated than the less educated.

6.3.2 Variation in Cardiovascular Health accounted for by Individual-Level Determinants

Objective 2a(ii): Determine whether individual-level determinants of CVH can account for the variation in CVH among individuals that is attributed to the geographic areas in which these individuals reside.

The proportional change in cluster variance (PCV), which compares the full model with all determinants to the null model with no determinants, was 43.8%, 28.6% and 40.0% in DAs, CSDs and FSAs, respectively. Results indicate that individual and interpersonal determinants account for some but not all of the variation in CVH among neighborhoods. As demonstrated by the variance partition coefficient (VPC), after adjusting for individual and interpersonal determinants, approximately 4.5%, 3.5% and 3.6% of the remaining variation in cardiovascular health among Canadians can be attributed to the DA, the CSD and the FSA neighborhoods respectively. Additionally, 2.0%, 2.1% and 1.9% of the variation in CVH can be attributed to the province when the neighborhoods are represented as DAs, CSDs and FSAs respectively, indicating that neighborhood accounted for a greater proportion of variance in CVH than provinces. In model 2, the highest MOR was 1.32 for DAs which indicates that when comparing two individuals who share the same individual and interpersonal characteristics from two randomly selected DAs, the odds of better CVH was 1.32 for the individual in the DA with higher average CVH vs the individual in the DA with lower average CVH.
Table 6.5 Multilevel model to estimate the association between individual-level determinants and cardiovascular health, Canadian study sample (2015-2016)

<table>
<thead>
<tr>
<th>Model 2 (Individual-level determinants)</th>
<th>Dissemination Area (DA)</th>
<th>Census Subdivision (CSD)</th>
<th>Forward Sortation Area (FSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed effects</strong></td>
<td>Odds ratio (95% CI)</td>
<td>Odds ratio (95% CI)</td>
<td>Odds ratio (95% CI)</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-39 years</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>40-59 years</td>
<td>0.51 (0.49-0.53)</td>
<td>0.51 (0.49-0.53)</td>
<td>0.51 (0.49-0.53)</td>
</tr>
<tr>
<td>60-79 years</td>
<td>0.34 (0.32-0.35)</td>
<td>0.34 (0.32-0.35)</td>
<td>0.34 (0.32-0.35)</td>
</tr>
<tr>
<td>80 years and over</td>
<td>0.40 (0.36-0.45)</td>
<td>0.40 (0.36-0.45)</td>
<td>0.40 (0.36-0.45)</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Female</td>
<td>1.81 (1.75-1.87)</td>
<td>1.80 (1.74-1.86)</td>
<td>1.80 (1.74-1.86)</td>
</tr>
<tr>
<td><strong>Race/ethnicity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Non-Hispanic</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>South Asian</td>
<td>0.73 (0.65-0.82)</td>
<td>0.69 (0.61-0.78)</td>
<td>0.73 (0.65-0.83)</td>
</tr>
<tr>
<td>Chinese</td>
<td>1.30 (1.14-1.49)</td>
<td>1.23 (1.11-1.37)</td>
<td>1.29 (1.16-1.43)</td>
</tr>
<tr>
<td>Korean and Japanese</td>
<td>0.75 (0.65-0.87)</td>
<td>0.71 (0.62-0.82)</td>
<td>0.75 (0.65-0.86)</td>
</tr>
<tr>
<td>Black</td>
<td>0.84 (0.73-0.95)</td>
<td>0.79 (0.70-0.91)</td>
<td>0.84 (0.74-0.96)</td>
</tr>
<tr>
<td>Filipino and East Asian</td>
<td>0.89 (0.75-1.07)</td>
<td>0.86 (0.72-1.03)</td>
<td>0.89 (0.75-1.07)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>0.73 (0.61-0.86)</td>
<td>0.68 (0.58-0.81)</td>
<td>0.71 (0.60-0.84)</td>
</tr>
<tr>
<td>Arab and West Asian</td>
<td>0.88 (0.75-1.02)</td>
<td>0.85 (0.73-0.99)</td>
<td>0.87 (0.75-1.01)</td>
</tr>
<tr>
<td>Other</td>
<td>1.07 (0.92-1.26)</td>
<td>1.03 (0.88-1.21)</td>
<td>1.07 (0.91-1.25)</td>
</tr>
<tr>
<td>Mixed or many races</td>
<td>0.77 (0.72-0.83)</td>
<td>0.78 (0.73-0.84)</td>
<td>0.78 (0.73-0.84)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heterosexual</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Homosexual</td>
<td>1.30 (1.13-1.49)</td>
<td>1.26 (1.10-1.45)</td>
<td>1.27 (1.11-1.46)</td>
</tr>
<tr>
<td>Bisexual</td>
<td>0.97 (0.85-1.11)</td>
<td>0.96 (0.84-1.09)</td>
<td>0.97 (0.85-1.11)</td>
</tr>
<tr>
<td>Refused to state</td>
<td>1.08 (0.98-1.19)</td>
<td>1.06 (0.96-1.16)</td>
<td>1.07 (0.97-1.18)</td>
</tr>
<tr>
<td><strong>Immigrant status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-immigrant</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Immigrant</td>
<td>1.10 (1.05-1.16)</td>
<td>1.07 (1.01-1.13)</td>
<td>1.08 (1.03-1.14)</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did not complete Secondary Education</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Completed Secondary Education</td>
<td>1.44 (1.36-1.52)</td>
<td>1.42 (1.34-1.50)</td>
<td>1.42 (1.34-1.50)</td>
</tr>
<tr>
<td>Completed Post-secondary Education</td>
<td>2.05 (1.95-2.16)</td>
<td>2.00 (1.91-2.11)</td>
<td>2.00 (1.91-2.11)</td>
</tr>
<tr>
<td>Refused to state</td>
<td>1.52 (1.29-1.78)</td>
<td>1.50 (1.28-1.76)</td>
<td>1.49 (1.27-1.75)</td>
</tr>
<tr>
<td>Income</td>
<td>No income</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td></td>
<td>&lt;$5,000</td>
<td>0.95 (0.82-1.11)</td>
<td>0.95 (0.82-1.11)</td>
</tr>
<tr>
<td>$5,000-$10,000</td>
<td>0.96 (0.84-1.11)</td>
<td>0.96 (0.84-1.11)</td>
<td>0.96 (0.84-1.11)</td>
</tr>
<tr>
<td>$10,000-$14,999</td>
<td>0.77 (0.67-0.88)</td>
<td>0.77 (0.67-0.88)</td>
<td>0.78 (0.68-0.89)</td>
</tr>
<tr>
<td>$15,000-$19,999</td>
<td>0.84 (0.74-0.96)</td>
<td>0.84 (0.74-0.96)</td>
<td>0.85 (0.74-0.97)</td>
</tr>
<tr>
<td>$20,000-$29,999</td>
<td>0.79 (0.70-0.90)</td>
<td>0.79 (0.70-0.90)</td>
<td>0.80 (0.71-0.91)</td>
</tr>
<tr>
<td>$30,000-$39,999</td>
<td>0.88 (0.77-1.00)</td>
<td>0.88 (0.77-1.00)</td>
<td>0.89 (0.78-1.02)</td>
</tr>
<tr>
<td>$40,000-$49,999</td>
<td>0.87 (0.76-0.99)</td>
<td>0.87 (0.76-0.99)</td>
<td>0.88 (0.77-1.00)</td>
</tr>
<tr>
<td>$50,000-$59,999</td>
<td>0.89 (0.78-1.02)</td>
<td>0.89 (0.78-1.02)</td>
<td>0.90 (0.80-1.02)</td>
</tr>
<tr>
<td>$60,000-$69,999</td>
<td>0.91 (0.79-1.03)</td>
<td>0.91 (0.79-1.03)</td>
<td>0.91 (0.80-1.05)</td>
</tr>
<tr>
<td>$70,000-$79,999</td>
<td>0.99 (0.86-1.14)</td>
<td>0.99 (0.86-1.14)</td>
<td>1.00 (0.87-1.15)</td>
</tr>
<tr>
<td>$80,000-$89,999</td>
<td>0.93 (0.80-1.07)</td>
<td>0.93 (0.80-1.07)</td>
<td>0.93 (0.81-1.08)</td>
</tr>
<tr>
<td>$90,000-$99,999</td>
<td>0.99 (0.85-1.15)</td>
<td>0.99 (0.85-1.15)</td>
<td>0.99 (0.85-1.16)</td>
</tr>
<tr>
<td>&gt;$100,000</td>
<td>0.95 (0.83-1.09)</td>
<td>0.95 (0.83-1.09)</td>
<td>0.95 (0.83-1.09)</td>
</tr>
<tr>
<td>Refused to state</td>
<td>0.88 (0.77-1.02)</td>
<td>0.88 (0.77-1.02)</td>
<td>0.89 (0.77-1.02)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Life stress</th>
<th>Not at all stressful</th>
<th>reference</th>
<th>reference</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not very stressful</td>
<td>0.98 (0.93-1.03)</td>
<td>0.98 (0.93-1.03)</td>
<td>0.98 (0.93-1.03)</td>
<td></td>
</tr>
<tr>
<td>A bit stressful</td>
<td>0.84 (0.80-0.89)</td>
<td>0.84 (0.80-0.89)</td>
<td>0.84 (0.80-0.89)</td>
<td></td>
</tr>
<tr>
<td>Quite a bit stressful</td>
<td>0.75 (0.71-0.80)</td>
<td>0.75 (0.71-0.80)</td>
<td>0.75 (0.71-0.80)</td>
<td></td>
</tr>
<tr>
<td>Extremely stressful</td>
<td>0.67 (0.60-0.75)</td>
<td>0.67 (0.60-0.75)</td>
<td>0.67 (0.60-0.75)</td>
<td></td>
</tr>
<tr>
<td>Refused to state</td>
<td>0.91 (0.68-1.21)</td>
<td>0.91 (0.68-1.21)</td>
<td>0.91 (0.68-1.21)</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Work stress</th>
<th>Not at all stressful</th>
<th>reference</th>
<th>reference</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not very stressful</td>
<td>1.05 (0.97-1.13)</td>
<td>1.05 (0.97-1.13)</td>
<td>1.04 (0.97-1.12)</td>
<td></td>
</tr>
<tr>
<td>A bit stressful</td>
<td>0.98 (0.92-1.05)</td>
<td>0.97 (0.92-1.04)</td>
<td>0.98 (0.91-1.05)</td>
<td></td>
</tr>
<tr>
<td>Quite a bit stressful</td>
<td>0.99 (0.91-1.07)</td>
<td>0.98 (0.91-1.06)</td>
<td>0.98 (0.91-1.06)</td>
<td></td>
</tr>
<tr>
<td>Extremely stressful</td>
<td>0.92 (0.82-1.04)</td>
<td>0.92 (0.82-1.04)</td>
<td>0.92 (0.82-1.04)</td>
<td></td>
</tr>
<tr>
<td>Refused to state</td>
<td>0.74 (0.69-0.79)</td>
<td>0.74 (0.69-0.79)</td>
<td>0.74 (0.69-0.79)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alcohol use</th>
<th>Occasional</th>
<th>reference</th>
<th>reference</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(consumed any alcohol less than once a month)</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
<td></td>
</tr>
<tr>
<td>Regular (consumed any alcohol more than once a month)</td>
<td>0.71 (0.67-0.73)</td>
<td>0.71 (0.67-0.73)</td>
<td>0.71 (0.67-0.73)</td>
<td></td>
</tr>
<tr>
<td>Not in 12 months</td>
<td>0.75 (0.72-0.79)</td>
<td>0.76 (0.73-0.80)</td>
<td>0.76 (0.73-0.80)</td>
<td></td>
</tr>
<tr>
<td>Refused to state</td>
<td>0.89 (0.66-1.20)</td>
<td>0.88 (0.66-1.19)</td>
<td>0.89 (0.66-1.20)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Illicit drug use</th>
<th>Current use</th>
<th>reference</th>
<th>reference</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>No current use</td>
<td>1.10 (1.04-1.16)</td>
<td>1.12 (1.06-1.18)</td>
<td>1.12 (1.06-1.18)</td>
<td></td>
</tr>
<tr>
<td>Refused to state</td>
<td>0.96 (0.73-1.26)</td>
<td>0.99 (0.75-1.29)</td>
<td>0.98 (0.75-1.28)</td>
<td></td>
</tr>
</tbody>
</table>

<p>| Social inclusion |</p>
<table>
<thead>
<tr>
<th>Reference Level</th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very strong</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Somewhat strong</td>
<td>0.90 (0.86-0.93)</td>
<td>0.90 (0.86-0.93)</td>
<td>0.90 (0.86-0.93)</td>
</tr>
<tr>
<td>Somewhat weak</td>
<td>0.79 (0.75-0.83)</td>
<td>0.78 (0.74-0.82)</td>
<td>0.79 (0.75-0.83)</td>
</tr>
<tr>
<td>Very weak</td>
<td>0.67 (0.62-0.72)</td>
<td>0.66 (0.62-0.71)</td>
<td>0.67 (0.62-0.71)</td>
</tr>
<tr>
<td>Refused to state</td>
<td>0.82 (0.70-0.97)</td>
<td>0.82 (0.70-0.97)</td>
<td>0.83 (0.71-0.97)</td>
</tr>
</tbody>
</table>

### Household composition

<table>
<thead>
<tr>
<th>Household composition</th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single, lives alone</td>
<td>1.19 (1.08-1.30)</td>
<td>1.17 (1.07-1.28)</td>
<td>1.17 (1.07-1.28)</td>
</tr>
<tr>
<td>Couple, lives together</td>
<td>1.11 (1.06-1.16)</td>
<td>1.12 (1.07-1.17)</td>
<td>1.12 (1.07-1.17)</td>
</tr>
<tr>
<td>Couple, lives together with kids ≤ 25 years</td>
<td>1.23 (1.18-1.29)</td>
<td>1.25 (1.19-1.30)</td>
<td>1.25 (1.19-1.30)</td>
</tr>
<tr>
<td>Couple with kids ≤ 25 years, lives with others</td>
<td>1.04 (0.92-1.17)</td>
<td>1.03 (0.94-1.18)</td>
<td>1.06 (0.94-1.19)</td>
</tr>
<tr>
<td>Couple with kids &gt; 25 years living together or with others</td>
<td>1.02 (0.93-1.12)</td>
<td>1.02 (0.93-1.12)</td>
<td>1.03 (0.94-1.13)</td>
</tr>
<tr>
<td>Single female, living with kids ≤ 25 years</td>
<td>1.12 (1.03-1.21)</td>
<td>1.12 (1.03-1.21)</td>
<td>1.13 (1.05-1.22)</td>
</tr>
<tr>
<td>Single female, living with kids &gt; 25 years</td>
<td>0.83 (0.73-0.95)</td>
<td>0.83 (0.73-0.95)</td>
<td>0.83 (0.73-0.95)</td>
</tr>
<tr>
<td>Single male, living with kids ≤ 25 years</td>
<td>1.17 (1.02-1.35)</td>
<td>1.18 (1.02-1.36)</td>
<td>1.18 (1.02-1.36)</td>
</tr>
<tr>
<td>Single male, living with kids &gt; 25 years</td>
<td>0.96 (0.73-1.25)</td>
<td>0.96 (0.73-1.25)</td>
<td>0.96 (0.73-1.25)</td>
</tr>
<tr>
<td>Refused to state</td>
<td>1.02 (0.82-1.28)</td>
<td>1.02 (0.82-1.28)</td>
<td>1.03 (0.83-1.29)</td>
</tr>
</tbody>
</table>

### Random effects

<table>
<thead>
<tr>
<th>Variance (95% CI)</th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neighborhood</td>
<td>0.09 (0.07-0.11)</td>
<td>0.05 (0.04-0.06)</td>
<td>0.06 (0.05-0.07)</td>
</tr>
<tr>
<td>Percent Change in Variation (PCV) (%)</td>
<td>43.8</td>
<td>28.6</td>
<td>40.0</td>
</tr>
<tr>
<td>Variance Partition Coefficient (VPC) (%)</td>
<td>4.5</td>
<td>3.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Median Odds Ratio (MOR)</td>
<td>Neighborhood</td>
<td>Neighborhood</td>
<td>Neighborhood</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------</td>
<td>---------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>1.32</td>
<td>1.23</td>
<td>1.26</td>
</tr>
</tbody>
</table>
Figure 6.2 Distribution of poor, intermediate and ideal cardiovascular health among individual-level variables, Canadian sample (2015-2016)
6.3.3 The Relationship between Neighborhood-Level Determinants and Cardiovascular Health

Objective 2b(i): Assess the relationship between area-level determinants and CVH, accounting for the influence of individual-level determinants.

The influence of neighborhood determinants on CVH, adjusted for individual determinants, is examined for each of the three neighborhood units in separate models. Results are shown in table 6.6.

Dissemination area. Examining the demographic block, average age, median income, and prevalence of low income were positively and significantly associated with CVH while unemployment rate was negatively associated with CVH, after accounting for the influence of individual and interpersonal determinants. For the socioeconomic block, both material and social deprivation were negatively and significantly associated with CVH. For the built environment block, walkability of the neighborhood was positively and significantly associated with CVH.

Census subdivision. Examining the demographic block, median income and the highest tercile of average age and prevalence of low income were positively and significantly associated with CVH while the highest tercile of unemployment rate was negatively associated with CVH, after accounting for the influence of individual and interpersonal determinants. For the socioeconomic block, the community well-being score was positively and significantly associated with CVH. Healthcare was not significantly associated with CVH.

Forward sortation area. When examining the demographic block, median income, prevalence of low income and the highest tercile of unemployment rate were positively and significantly associated with CVH while household size and the highest tercile of unemployment rate was negatively associated with CVH, after accounting for the influence of individual and interpersonal determinants. For the healthcare block, total number of hospital beds and the highest tercile of total number of doctors per 100,000 population was positively associated with CVH.
Shrinkage factors, corresponding to the population-average odds ratio, were approximately the same value (1.01) for all neighborhood determinants across all neighborhood units. Therefore, with shrinkage factors close to 1.00, the cluster-specific odds ratios for the neighborhood determinants listed in table 4 are considered equivalent to population-average odds ratios. Additionally, the 80% interval odds ratios (IOR-80) for all neighborhood determinants across all neighborhood units contained the value of 1.00 (shown in table 6.6) indicating that there is high variability in the odds ratios (influence of the neighborhood determinants on CVH) across neighborhoods. This variability in the odds ratios across neighborhoods is large in comparison to the population-average odds ratio (average magnitude of the association between neighborhood determinants and CVH).

6.3.4 Variation in Cardiovascular Health accounted for by Neighborhood-level Determinants

Objective 2b(ii): Determine whether area-level determinants of CVH can account for the variation in CVH among individuals that is attributed to the geographic areas in which these individuals reside.

*Dissemination area.* Demographic and socioeconomic determinants both accounted for the same amount of additional variance in CVH, beyond that of individual and interpersonal determinants, with the PCV increasing from 43.8% in model 2 to 62.5% in model 3. The use of the Can Marg index and the environment block accounted for some additional variance in CVH, beyond that of individual and interpersonal determinants, with the PCV increasing from 43.8% in model 2 to 50.0% in model 3. Additionally, after accounting for individual, neighborhood demographic and environment determinants, 4.2% of the variation in CVH could still be attributed to the DA neighborhood. Overall, the MOR values in model 3 were 1.27-1.29, indicating that the odds of better CVH was 1.27 to 1.29 times higher moving from a DA of lower to higher CVH.

*Census subdivision.* Demographic and socioeconomic determinants both accounted for the same amount of additional variance in CVH, beyond that of individual and interpersonal determinants, with the PCV increasing from 28.6% in model 2 to 57.1% in
model 3. Additionally, after accounting for individual, neighborhood demographic and healthcare determinants, 3.5% of the variation in CVH respectively could still be attributed to the CSD neighborhood. Overall, the MOR values in model 3 was 1.24-1.27, an increase from 1.23 in model 2, indicating that the odds of better CVH was 1.24 to 1.27 times higher moving from a CSD of lower to higher CVH.

*Forward sortation area.* Demographic determinants do not account for additional variance in CVH, beyond that of individual and interpersonal determinants, with the PCV remaining the same in models 2 and 3 (40.0%). Additionally, after accounting for individual, neighborhood demographic and healthcare determinants, 3.5% of the variation in CVH could be attributed to the FSA neighborhood. Overall, the MOR values in model 3 was 1.22-1.26, only a slight decrease from 1.26 in model 2, indicating that the odds of better CVH was 1.22 to 1.26 times higher moving from a neighborhood of lower to higher CVH.
Table 6.6 Multilevel model to estimate the association between neighborhood determinants and cardiovascular health adjusting for individual-level determinants, Canadian study sample (2015-2016)

<table>
<thead>
<tr>
<th>Model 3 (Individual- and Neighborhood-level determinants)</th>
<th>Dissemination area (DA)</th>
<th>Census subdivision (CSD)</th>
<th>Forward Sortation Area (FSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic block</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed effects</td>
<td>Odds ratio (95% CI)</td>
<td>80% Interval Odds Ratio</td>
<td>Odds ratio (95% CI)</td>
</tr>
<tr>
<td>Average density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>0.98 (0.94-1.02)</td>
<td>-</td>
<td>0.96 (0.90-1.01)</td>
</tr>
<tr>
<td>High</td>
<td>1.03 (0.98-1.08)</td>
<td>-</td>
<td>1.07 (0.98-1.16)</td>
</tr>
<tr>
<td>Average number of dwellings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>0.99 (0.95-1.03)</td>
<td>-</td>
<td>1.01 (0.95-1.07)</td>
</tr>
<tr>
<td>High</td>
<td>1.03 (0.98-1.07)</td>
<td>-</td>
<td>1.04 (0.94-1.15)</td>
</tr>
<tr>
<td>Average age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>1.06 (1.01-1.10)</td>
<td>0.65-1.72</td>
<td>1.04 (0.97-1.11)</td>
</tr>
<tr>
<td>High</td>
<td>1.11 (1.06-1.17)</td>
<td>0.69-1.81</td>
<td>1.11 (1.02-1.21)</td>
</tr>
<tr>
<td>Average household size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>1.00 (0.95-1.05)</td>
<td>-</td>
<td>1.06 (0.98-1.10)</td>
</tr>
<tr>
<td>High</td>
<td>1.02 (0.96-1.08)</td>
<td>-</td>
<td>1.10 (1.01-1.19)</td>
</tr>
<tr>
<td>Median income</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>1.13 (1.08-1.18)</td>
<td>0.70-1.84</td>
<td>1.06 (0.99-1.12)</td>
</tr>
<tr>
<td>High</td>
<td>1.41 (1.33-1.49)</td>
<td>0.87-2.28</td>
<td>1.12 (1.04-1.20)</td>
</tr>
</tbody>
</table>
### Prevalence of low income

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimate</td>
<td>reference</td>
<td>1.02 (0.98-1.06)</td>
<td>0.78-2.28</td>
</tr>
<tr>
<td>95% CI</td>
<td>reference</td>
<td>1.01 (0.95-1.06)</td>
<td>1.16 (1.06-1.28)</td>
</tr>
<tr>
<td></td>
<td>reference</td>
<td>1.07 (1.01-1.12)</td>
<td>1.21 (1.15-1.28)</td>
</tr>
<tr>
<td>Variance</td>
<td>0.73</td>
<td>1.02 (0.98-1.06)</td>
<td>1.07 (1.01-1.12)</td>
</tr>
</tbody>
</table>

### Average unemployment rate

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimate</td>
<td>reference</td>
<td>0.99 (0.94-1.02)</td>
<td>0.93 (0.89-0.98)</td>
</tr>
<tr>
<td>95% CI</td>
<td>reference</td>
<td>0.95 (0.90-1.02)</td>
<td>0.88 (0.82-0.94)</td>
</tr>
<tr>
<td></td>
<td>reference</td>
<td>0.95 (0.90-1.00)</td>
<td>0.88 (0.82-0.94)</td>
</tr>
<tr>
<td>Variance</td>
<td>0.50</td>
<td>0.57-1.51</td>
<td>0.50-1.25</td>
</tr>
</tbody>
</table>

### Random effects

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>Estimate</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Var (95% CI)</td>
<td>0.06 (0.05-0.09)</td>
<td>0.03 (0.02-0.05)</td>
<td>0.06 (0.05-0.07)</td>
</tr>
</tbody>
</table>

### Variance Partition Coefficient (VPC) (%)

|            | Neighborhood | 62.5 | 57.1 | 40.0 |

### Median Odds Ratios (MOR)

|            | Neighborhood | 1.29 | 1.27 | 1.24 |

### Socioeconomic block

#### Fixed effects

<table>
<thead>
<tr>
<th></th>
<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
</tr>
</thead>
</table>
| Material deprivation
| Medium | 0.78 (0.75-0.79) | 0.50-1.25 | - | - | - | - |
| High   | 0.67 (0.64-0.69) | 0.43-1.06 | - | - | - | - |

#### Social deprivation

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimate</td>
<td>reference</td>
<td>0.93 (0.88-0.95)</td>
<td>0.96 (0.90-1.00)</td>
</tr>
<tr>
<td>95% CI</td>
<td>reference</td>
<td>0.59-1.46</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>reference</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>
### Community Well Being Index

<table>
<thead>
<tr>
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<th>95% CI</th>
<th>95% CI</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>-</td>
<td>-</td>
<td>1.12 (1.07-1.20)</td>
<td>0.83-1.53</td>
</tr>
<tr>
<td>High</td>
<td>-</td>
<td>-</td>
<td>1.33 (1.26-1.41)</td>
<td>0.98-1.81</td>
</tr>
<tr>
<td>Random effects</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
<td>variance (95% CI)</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>0.06 (0.02-0.15)</td>
<td>-</td>
<td>0.03 (0.02-0.04)</td>
<td>-</td>
</tr>
<tr>
<td>Percent Change in Variance (PCV) (%)</td>
<td>Neighborhood</td>
<td>62.5</td>
<td>-</td>
<td>57.1</td>
</tr>
<tr>
<td>Variation Partition Coefficient (VPC) (%)</td>
<td>Neighborhood</td>
<td>6.4</td>
<td>-</td>
<td>2.7</td>
</tr>
<tr>
<td>Median Odds Ratio (MOR)</td>
<td>Neighborhood</td>
<td>1.24</td>
<td>-</td>
<td>1.17</td>
</tr>
<tr>
<td>Fixed effects</td>
<td>Odds ratio (95% CI)</td>
<td>80% Interval Odds Ratio (Lower-Upper)</td>
<td>Odds ratio (95% CI)</td>
<td>80% Interval Odds Ratio (Lower-Upper)</td>
</tr>
</tbody>
</table>
| Canadian Marginalization Index

<table>
<thead>
<tr>
<th>Level</th>
<th>estimate</th>
<th>95% CI</th>
<th>95% CI</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>0.90 (0.86-0.94)</td>
<td>0.53-1.52</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>High</td>
<td>0.87 (0.82-0.91)</td>
<td>0.51-1.46</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Random effects</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
<td>variance (95% CI)</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>0.08 (0.06-0.11)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Percent Change in Variance (PCV) (%)</td>
<td>Neighborhood</td>
<td>50.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Variation Partition Coefficient (VPC) (%)</td>
<td>Neighborhood</td>
<td>4.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Median Odds Ratio (MOR)</td>
<td>Neighborhood</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>1.27</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>---------------</td>
<td>------</td>
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</tbody>
</table>

*Environment block*

**Fixed effects**

<table>
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<tr>
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<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
</tr>
</thead>
</table>

**Active Living Environment index**

<table>
<thead>
<tr>
<th></th>
<th>reference</th>
<th>reference</th>
<th>reference</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>1.11 (1.04-1.14)</td>
<td>0.66-1.88</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>High</td>
<td>1.20 (1.09-1.33)</td>
<td>0.71-2.03</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Active Living Environment Transit index**

<table>
<thead>
<tr>
<th></th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
<th>Estimate (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>0.90 (0.84-1.00)</td>
<td>0.53-1.52</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>High</td>
<td>0.97 (0.87-1.07)</td>
<td>0.57-1.63</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Variance (95% CI)**

| Neighborhood | 0.08 (0.06-0.10) | - | - | - | - |

**Percent Change Variance (PCV) (%)**

| Neighborhood | 50.0 | - | - | - | - |

**Variance Partition Coefficient (VPC) (%)**

| Neighborhood | 4.2 | - | - | - | - |

**Median Odds Ratio (MOR)**

| Neighborhood | 1.26 | - | - | - | - |

*Healthcare block*

**Fixed effects**

<table>
<thead>
<tr>
<th></th>
<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
<th>Odds ratio (95% CI)</th>
<th>80% Interval Odds Ratio (Lower-Upper)</th>
</tr>
</thead>
</table>

**Total number of doctors per 100,000**

<table>
<thead>
<tr>
<th></th>
<th>reference</th>
<th>reference</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td>Medium</td>
<td>-</td>
<td>-</td>
<td>0.95 (0.90-1.01)</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>----------------</td>
<td>----------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Total number of hospital beds per 100,000</strong></td>
<td>reference</td>
<td>reference</td>
<td>reference</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.13 (1.03-1.25)</td>
<td>0.76-1.70</td>
</tr>
<tr>
<td><strong>Random effects</strong></td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
</tr>
<tr>
<td><strong>Variance (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Neighborhood</strong></td>
<td></td>
<td>0.03 (0.02-0.05)</td>
<td>- 0.06 (0.05-0.07)</td>
</tr>
<tr>
<td><strong>Percent change in variance (PCV) (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Neighborhood</strong></td>
<td></td>
<td>51.1</td>
<td>- 40.0</td>
</tr>
<tr>
<td><strong>Variance Partition Coefficient (VPC) (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Neighborhood</strong></td>
<td></td>
<td>3.5</td>
<td>- 3.4</td>
</tr>
<tr>
<td><strong>Median Odds Ratio (MOR)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Neighborhood</strong></td>
<td></td>
<td>1.22</td>
<td>- 1.24</td>
</tr>
</tbody>
</table>

Note: - indicates a measure that was not calculated for the corresponding neighborhood, it does not indicate missing
6.3.5 The Intersectional Influence of Individual-Level and Neighborhood-Level Determinants of Cardiovascular Health

Objective 2c: Explore whether area-level determinants, specifically those that can be altered by health policy (such as socioeconomic conditions), modify the relationship between individual-level determinants, specifically those that cannot be altered by health policy (such as age, race, and sex), and CVH.

Interactions are between area-level determinants, specifically those that can be altered by health policy (such as socioeconomic conditions), and individual-level determinants, specifically those that cannot be altered by health policy (such as age, race, and sex). Results are shown in table 6.7 for significant interaction effects.

Dissemination area. Those aged 40-59 years who live in a neighborhood with high marginalization are 55% less likely to experience better CVH than those aged 20-39 years living in a neighborhood with low marginalization. Females living in neighborhoods with middle and high marginalization were 71% and 58% more likely to experience better CVH than males living in neighborhoods with low marginalization. Persons of the Black and Hispanic races living in neighborhoods with high and middle marginalization were more likely to experience better CVH than persons of the White race living in neighborhoods with low marginalization.

Similarly, those aged 40-59 years who live in a neighborhood with high material and social deprivation are less likely to experience better CVH than those aged 20-39 years living in a neighborhood with low material and social deprivation. Females living in neighborhoods with high material and social deprivation were more likely to experience better CVH than males living in neighborhoods with low material and social deprivation. Those of the South Asian, Arab, and West Asian races living in neighborhoods with high material and social deprivation were less likely to experience better CVH than those of the White race living in areas with low material and social deprivation.

Census subdivision. In contrast to marginalization and deprivation, living in a neighborhood with higher community well-being is more desirable than living in a
neighborhood with lower community well-being. Females living in neighborhoods with middle and high community well-being scores were 86% and 90% more likely to experience better CVH than men living in neighborhoods with low community well-being scores. Persons of the South Asian, Korean, Japanese, and Black races living in neighborhoods with high and middle community well-being scores were less likely to experience better CVH than persons of the White race living in neighborhoods with low community well-being scores.

*Forward sortation area.* Females living in neighborhoods with medium and high median income were 76% and 87% more likely to experience better CVH than males living in neighborhoods with low median income. Persons of the Black, Filipino and East Asian races living in neighborhoods with high and middle income were less likely to experience better CVH than persons of the White race living in neighborhoods with low income. Additionally, persons of the Black race living in neighborhoods with medium and high median income were up to 25% less likely to experience better CVH than those of the White race living in neighborhoods with low median income.
Table 6.7 Multilevel model to estimate the interactional influence of individual- and neighborhood-level determinants on cardiovascular health, Canadian study sample (2015-2016)

<table>
<thead>
<tr>
<th>Model 4 (Interaction between individual- and neighborhood-level determinants)</th>
<th>Individual-level determinant</th>
<th>Neighborhood-level determinant</th>
<th>Calculated odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Canadian Marginalization Index (DA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-59 years</td>
<td>High</td>
<td></td>
<td>0.45</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>Medium</td>
<td></td>
<td>1.71</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td></td>
<td>1.58</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>High</td>
<td></td>
<td>1.09</td>
</tr>
<tr>
<td>Hispanic</td>
<td>Medium</td>
<td></td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Deprivation (DA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-59 years</td>
<td>High</td>
<td></td>
<td>0.45</td>
</tr>
<tr>
<td>80 years and over</td>
<td>Medium</td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td></td>
<td>0.42</td>
</tr>
<tr>
<td>Sex</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>Medium</td>
<td></td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td></td>
<td>1.52</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Asian</td>
<td>Medium</td>
<td></td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Deprivation (DA)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-59 years</td>
<td>High</td>
<td></td>
<td>0.45</td>
</tr>
<tr>
<td>60-79 years</td>
<td>High</td>
<td></td>
<td>0.31</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>High</td>
<td></td>
<td>1.67</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arab and West Asian</td>
<td>High</td>
<td></td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Community Well Being (CSD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>Medium</td>
<td></td>
<td>1.86</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td>Race/ethnicity</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>South Asian</td>
<td>Medium</td>
<td></td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td></td>
<td>0.64</td>
</tr>
<tr>
<td>Korean and Japanese</td>
<td>High</td>
<td></td>
<td>0.58</td>
</tr>
<tr>
<td>Black</td>
<td>High</td>
<td></td>
<td>0.59</td>
</tr>
<tr>
<td>Median Income (FSA)</td>
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<td></td>
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</tr>
</tbody>
</table>
6.3.6 The Relationship between Individual- and Neighborhood-Level Determinants and Cardiovascular Health for females as compared to males

Objective 2d: Assess how the relationship between individual- and area-level determinants and CVH, differs for females as compared to males.

Interactions are conducted between sex and individual and neighborhood determinants; results for significant interactions are shown in tables 6.8-6.10.

*Individual and interpersonal determinants.* Table 6.8 demonstrates results for the influence of individual and interpersonal determinants on CVH in females as compared to males. Females aged 40-59 years are more likely to experience better CVH as compared to males aged 20-39 years. Furthermore, Females aged 60-79 years are up to 35% more likely to experience better CVH as compared to males aged 20-39 years, in DAs and FSAs. Females of the Arab, West Asian and Other race were more likely to experience better CVH than males of the White race. Females who identify as being homosexual are up to 10% less likely to experience better CVH than males who identify as heterosexual.

Females earning $80k-$100k annually were over 73% more likely to experience better CVH than males with no annual earnings. Females with post graduate education were up to 42% more likely to experience better CVH than males with no high school education. Females report not having a very stressful life were over 33% more likely to experience better CVH than males reporting no stress at all. Females who consume alcohol regularly or not in the past 12 months were up to 10% less likely to experience better CVH than...
males who are occasional drinkers. Females who live with a partner or kids, experience better CVH than males living alone.

*Neighborhood determinants.* There was only one significant interaction for the influence of neighborhood determinants on CVH in females as compared to males, controlling for individual and interpersonal determinants. All other interactions tested were not statistically significant and odds ratios were not recalculated for interpretation. Females residing in neighborhoods with high material deprivation were 10% less likely to experience better health than males residing in neighborhoods with low material deprivation.

*Exploratory sex-specific null models.* Results for sex-specific null models are shown in Tables 6.9 and 6.10. The variance in females were twice as high as that of males in DAs. Differences in variances were smaller among the sexes for CSDs and FSAs. For DAs, the neighborhood accounted for 9.1% of the variation in CVH in females and 4.9% of the variation in CVH in males. For CSDs, the neighborhood accounted for 5.2% of the variation in CVH in females and 1.8% of the variation in CVH in males. For FSAs, the neighborhood accounted for 5.8% of the variation in CVH in females and 1.9% of the variation in CVH in males. The highest MOR was noted for females residing in DAs, which indicates that when comparing two females who share the same individual and interpersonal characteristics from two randomly selected DAs, the odds of better CVH was 1.55 for the female in the DA with higher average CVH vs the female in the DA with lower average CVH. MORs were similar for males and females in CSDs and FSAs.
Table 6.8 Multilevel model to estimate the association between individual-level determinants and cardiovascular health in females as compared to males, Canadian study sample (2015-2016)

<table>
<thead>
<tr>
<th>Model 5 (Individual-level determinants in females as compared to males)</th>
<th>Dissemination area (DA)</th>
<th>Census subdivision (CSD)</th>
<th>Forward sortation area (FSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed effects</strong></td>
<td>Calculated Odds ratio</td>
<td>Calculated Odds ratio</td>
<td>Calculated Odds ratio</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-59 years</td>
<td>1.73</td>
<td>1.66</td>
<td>1.73</td>
</tr>
<tr>
<td>60-79 years</td>
<td>1.36</td>
<td>NS</td>
<td>1.35</td>
</tr>
<tr>
<td><strong>Race/ethnicity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arab and West Asian</td>
<td>1.66</td>
<td>NS</td>
<td>1.67</td>
</tr>
<tr>
<td>Other</td>
<td>1.81</td>
<td>1.74</td>
<td>1.81</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homosexual</td>
<td>0.88</td>
<td>0.88</td>
<td>0.90</td>
</tr>
<tr>
<td>Refused to state</td>
<td>1.57</td>
<td>1.51</td>
<td>1.55</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completed Post-secondary Education</td>
<td>1.42</td>
<td>1.38</td>
<td>1.42</td>
</tr>
<tr>
<td><strong>Income</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$80,000-$89,999</td>
<td>1.81</td>
<td>1.73</td>
<td>1.77</td>
</tr>
<tr>
<td>$90,000-$99,999</td>
<td>1.84</td>
<td>1.74</td>
<td>1.79</td>
</tr>
<tr>
<td><strong>Life stress</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not very stressful</td>
<td>1.38</td>
<td>1.33</td>
<td>1.38</td>
</tr>
<tr>
<td><strong>Alcohol use</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular (consumed any alcohol more than once a month)</td>
<td>0.91</td>
<td>0.89</td>
<td>0.92</td>
</tr>
<tr>
<td>Not in past 12 months</td>
<td>0.90</td>
<td>0.87</td>
<td>0.91</td>
</tr>
<tr>
<td><strong>Household composition</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Couple, lives together</td>
<td>1.50</td>
<td>1.46</td>
<td>1.50</td>
</tr>
<tr>
<td>Couple, lives together with kids ≤ 25 years</td>
<td>1.56</td>
<td>1.51</td>
<td>1.56</td>
</tr>
<tr>
<td>Couple with kids &gt; 25 years living</td>
<td>1.48</td>
<td>1.43</td>
<td>1.47</td>
</tr>
<tr>
<td>together or with others</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Single female, living with kids ≤ 25 years</td>
<td>0.92</td>
<td>0.89</td>
<td>0.92</td>
</tr>
<tr>
<td>Single male, living with kids ≤ 25 years</td>
<td>2.06</td>
<td>1.92</td>
<td>1.99</td>
</tr>
</tbody>
</table>

Table 6.9 Multilevel model to estimate the variation in cardiovascular health in males, Canadian study sample (2015-2016)

<table>
<thead>
<tr>
<th>Model 1 (null model in males)</th>
<th>Dissemination area (DA)</th>
<th>Census subdivision (CSD)</th>
<th>Forward sortation area (FSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random effects</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
</tr>
<tr>
<td>Variance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighborhood</td>
<td>0.10 (0.07-0.12)</td>
<td>0.06 (0.03-0.09)</td>
<td>0.06 (0.02-0.08)</td>
</tr>
<tr>
<td>Variance Partition Coefficient (VPC) (%)</td>
<td>4.9</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>1.36</td>
<td>1.27</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Table 6.10 Multilevel model to estimate the variation in cardiovascular health in females, Canadian study sample (2015-2016)

<table>
<thead>
<tr>
<th>Model 1 (null model in females)</th>
<th>Dissemination area (DA)</th>
<th>Census subdivision (CSD)</th>
<th>Forward sortation area (FSA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random effects</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
<td>Estimate (95% CI)</td>
</tr>
<tr>
<td>Variance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighborhood</td>
<td>0.21 (0.17-0.24)</td>
<td>0.08 (0.06-0.11)</td>
<td>0.09 (0.07-0.12)</td>
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<tr>
<td>Variance Partition Coefficient (VPC) (%)</td>
<td>9.1</td>
<td>5.2</td>
<td>5.8</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>1.55</td>
<td>1.30</td>
<td>1.37</td>
</tr>
</tbody>
</table>
Chapter 7

7 Discussion

This section will summarize the overall key findings noted above. Further interpretation of these findings in the broader clinical and social context will be discussed with implications for future policy highlighted throughout.

7.1 Summary of Thesis Findings

7.1.1 Low Prevalence of Ideal Cardiovascular Health in Canada

The thesis is the first and only known study to quantify CVH at the national level in Canada, using all seven components of the AHA’s CVHI. Overall study findings demonstrated that approximately 68% of Canadians experienced intermediate CVH (ideal health in 3 to 5 of the 7 CVH components). Only about a quarter of Canadians (27%) experienced ideal CVH (ideal health in 6 to 7 of the 7 CVH components). Approximately 5% of Canadians, over one million individuals, experienced poor CVH (ideal health in 0 to 2 of the 7 CVH components). In other words, the majority of the Canadian population reported meeting 3 to 5 of the following 7 criteria: no hypertension, no diabetes, no high cholesterol, normal body mass index, no current smoking, healthy diet and physical activity. The prevalence of ideal health was higher for the clinical components and lower for the behavioral components. The least prevalent ideal component of CVH was healthy diet (19%), while the most prevalent ideal component was no diabetes (94%).

7.1.1.1 Implication of Thesis Findings

To put these findings into context, one must refer to the existing knowledge on the utility of the CVHI. A 2018 systematic review and meta-analysis showed a lower hazard for CVD incidence in those with intermediate CVH (ideal health in 3 to 4 components of CVH), as compared to those with poor CVH (ideal health in 0 to 2 ideal components of CVH) (HR=0.53; 95% CI, 0.47-0.59).(281) Importantly, the hazard for CVD was reduced by almost half in those with ideal CVH (ideal health in 5 to 7 components in CVH) (HR=0.28; 95% CI, 0.23-0.33).(281) Therefore, while most Canadians have lowered their overall likelihood of CVD by achieving intermediate CVH, as opposed to
poor CVH, that likelihood may be reduced more significantly by achieving ideal CVH. In other words, the odds of an individual avoiding a CVD event in their lifetime are greatest when that individual achieves ideal CVH. Regardless of the effectiveness of blood-pressure lowering and lipid-lowering medication, no other primary prevention strategy is known to be easily attainable by all, while also reducing the risk of CVD by half. Given that CVD remains a leading cause of death in Canadians, encouraging ideal CVH can have a substantial impact on preventing unnecessary death, reducing CVD burden, and improving CVH in Canada.

7.1.1.2 Comparison of Thesis Findings to Other Studies

Results of this study are comparable to other studies conducted in the US, Canada and internationally. Of the two studies examining CVHI in Canada, the earlier 2014 study by Maclagan et al utilized CCHS data (2003-2011) to examine trends in CVH and CVH components in Canadians.(225) Maclagan et al found that in 2009-2010, 37.3% of Canadians experienced ideal health in 0 to 3 of the 6 CVH components, 53.3% experienced ideal health in 4 to 5 of the 6 components, and 9.4% experienced ideal health in all 6 CVH components.(225) Notably, the Maclagan study utilized only 6 of the 7 components of the CVHI whereas the thesis utilized the full 7 component CVHI as proposed by the AHA. In comparison to the thesis, the Maclagan study included individuals with heart disease in the study population, which may account, in part, for the higher prevalence of poor CVH found in that study. Maclagan reported that the prevalence of heart disease ranged from 12% to 25% in those with poor CVH.

Additionally, in the thesis, physical activity and diet criteria were updated based on guidelines existing in 2016 and differ from those outlined by Maclagan et al.

The latter and more recent Canadian study was conducted in the Quebec population only, utilizing objective measures and the full 7-point CVH score(227). Despite the use of objective measures, rather than self-reported measures as in this thesis, and differences in study samples, the Quebec study findings aligned more closely with thesis findings. The Quebec study found that approximately 70% of participants were classified as intermediate health (ideal health in 3 to 5 of the 7 CVH components).(227) Additionally, the least prevalent ideal component was healthy diet (4.8%) and the most prevalent ideal
component was no smoking (88.1%). Differences in the prevalence values may, in part, be attributed to the measures utilized; for example, a validated 24-hour recall questionnaire was used in the Quebec study and a frequency diet measure was used in the thesis. The CCHS diet measure may be less accurate as it relies solely on the respondent’s recall of diet consumption frequency in a one-month period. As with the Maclagan study, the Quebec study and the thesis are not directly comparable due to the different study samples and measures of CVH components utilized. The AHA’s CVHI can be adapted to either objective or self-reported data, which contributes to its versatility as a prevention tool. However, more Canadian studies are needed to facilitate direct comparisons using either version of the CVHI in similar populations.

Fang et al found that 10% of Americans had poor overall CVH while our study found that 5% of Canadians had poor overall CVH. This difference in poor CVH may be due to the differences in the prevalence of ideal health for clinical components of the CVHI. Specifically, the US study showed that 65% of Americans report no hypertension or high cholesterol, whereas the thesis showed that 85% of Canadians report no hypertension or high cholesterol. Consistently across both studies, diet is the poorest performing metric with the least prevalence of ideal health, and in the US study, smoking is the best performing metric with the highest prevalence of ideal health. The thesis shows that in Canadians, no diabetes was the best performing metric with a prevalence of 93% whereas the prevalence for smoking was 81%. Findings align with national studies showing that the prevalence of diabetes was 7% in Canadian adults aged 12 years and older in 2016 using CCHS data. Administrative data, known as the Canadian Chronic Disease Surveillance System (a collaborative network of provincial and territorial surveillance systems) shows that 8.1% of Canadians aged 18 years and older had a diagnosis of diabetes in 2013-2014. In contrast, the US reported a prevalence of 9.4% for diabetes in adults aged 18 years and older using nationally representative self-reported data. Additionally, the prevalence of hypertension in Canada (23%) has been found to be lower than both the US and England (30%).

A recent systematic review and meta-analysis examined the prevalence of CVH in adults, including studies from 2010, when AHA’s CVHI was released, to 2018. Of the 1112
studies that examined CVH prevalence worldwide, 88 studies were included in the review and prevalence values were compared between the objective and the self-reported versions of CVHI. No Canadian studies were included in the review. Similar to the thesis, results from the review showed that the most prevalent ideal components were no diabetes and no smoking, and the least prevalent component was diet. Overall for the meta-analysis, 32.2% of subjects were found to have poor CVH (ideal health in 0 to 2 of the 7 CVH components) and 19.6% were found to have ideal CVH (ideal health in 5 to 7 of the 7 CVH components).(114) Many national studies, particularly in Asia, showed a high proportion of poor CVH in their populations, which may have resulted in the high prevalence of poor CVH noted overall. There were no significant differences in the review findings based on the version of CVHI used.

7.1.2 The Neighborhood's Role in the Cardiovascular Health of Individuals

It is well established that the immediate living environment or ‘the neighborhood’ impacts the health of individuals. However, given the multifactorial nature of health outcomes, the issue of neighborhoods accounting for a small percentage of the variation in health is not uncommon and remains a debate in the literature.(186, 199) Studies show that variation values tend to be moderate, with the neighborhood accounting for between 5% and 15% of the variation in health outcomes.(186, 199) Results of this study which show that up to 7% of the variation in CVH can be attributed to the neighborhood. These values were consistent with other similar studies examining the relationship between neighborhood determinants and obesity and physical activity in Canadian adults.(196, 285)

It is important to note that this 7% variation value only indicates the proportion of the CVH in individuals that can be accounted for by differences between neighborhoods, with the remaining variation accounted for by differences between individuals. The variation value does not provide information on the size of the variation between neighborhoods or the magnitude of the effect of neighborhoods on CVH.(266) For this reason, other measures of variance and heterogeneity were utilized in this study to quantify the influence of the neighborhood and neighborhood characteristics on CVH.
The median odds ratio (MOR) quantifies the size of the variation between neighborhoods and can be interpreted in the same manner as a fixed effect odds ratio. A MOR value of 1 indicates that there is no variation between neighborhoods. The highest MOR value in the null model was 1.46, which indicates considerable variation in CVH between neighborhoods. In other words, the likelihood of experiencing better CVH differs a fair amount based on the neighborhood of residence, which lends to the importance of the neighborhood in determining health.

The significant reduction in the proportional change in cluster variance (PCV) and variance partition coefficient (VPC), comparing the null model to the full model with individual determinants, showed that adding individual and interpersonal determinants to the model reduced the variation by almost half, but not completely. In other words, variations in the CVH of individuals across neighborhoods are not solely due to the differences between individuals based on their personal characteristics. The MOR values continue to indicate high heterogeneity in CVH among neighborhoods however, a small portion of this heterogeneity was reduced by accounting for individual and interpersonal determinants. Adding neighborhood determinants to the models with individual determinants reduced the PCV minimally with no real changes in the VPC or MOR values. Thus, variations in the CVH of individuals are only in part due to differences between neighborhood characteristics accounted for in the model. The remaining variation may be accounted for by unmeasured confounders at either level or, by a third omitted provincial or national level of the multilevel model. The thesis methodology considered the inclusion of a third provincial level in analyses however, Canada has only 10 provinces which is a very low sample size that can lead to reduced power and increased errors in estimates.

7.1.3 The Influence of Individual Determinants on Cardiovascular Health

Study findings confirm strong associations between socioeconomic and lifestyle individual determinants and CVH, which were consistent across all neighborhood units examined. Findings are consistent with other studies showing an increased likelihood of ideal CVH with decreasing age, females and those who were educated.
Other studies have begun postulating the mechanism by which these common factors impact CVH, for example, individuals with higher socioeconomic status are more likely to be able to afford healthier foods and to dedicate time to physical activity, thus enhancing their CVH. Conversely, individuals with lower socioeconomic status may not be able to adequately access healthcare or healthy food and safe areas for physical activity, thus leading to poorer CVH.

Thesis findings not consistent with the current literature include the lack of significant associations between household income and CVH. It is well known that income and education are complimentary, rather than contradictory indicators of socioeconomic status that have been shown to impact CVH. In Canada, a 2015 study by Lemstra et al, conducted in adults in Saskatchewan using CCHS data, showed a significant association between household income terciles and CVD, independent of education. The lack of this association in thesis results may be due to the high number of income categories employed in the study, leading to a misclassification bias for the income variable. The challenge in categorizing income for the thesis was that income cut-offs vary across Canada. For example, ‘low’ household income is estimated at about $41,000 for Alberta, but that value is reduced to $33,000 in Quebec. In 2018, Canada proposed, for the first time, introducing an official poverty line into legislation in their national plan “Canada’s Poverty Reduction Strategy” released by Jean-Yves Duclos, the Federal Minister of Minister of Families, Children and Social Development. It is hoped that this document can provide statistical clarity on income cut-offs for Canadians that can be employed at the national level.

This thesis is the first known study to show that higher social inclusion, reported as a greater sense of belonging to the community and living with others, independently increase the likelihood of ideal CVH in adults. Recent studies have indicated that CVH is concordant within couples and families, suggesting the need for family-based interventions for improving CVH. A 2018 study by Erqou et al showed high intracouple concordance for CVH components, with a greater odds of achieving high levels of CVH if individuals had partners also achieving high CVH. Results of the thesis expand upon this idea, demonstrating that a strong sense of community
belongingness and not living alone act as factors that independently improve CVH for all individuals, regardless of age, sex, socioeconomic status or the neighborhood of residence.

Other important findings include the influence of lifestyle factors including alcohol, illicit drug use and psychological stress on CVH. While many studies have linked alcohol and illicit drug use to CVD, few studies examine the association with CVH. (296) Thesis findings on alcohol use are consistent with two other studies, both conducted in the US, that show alcohol consumption is associated with poor CVH and adding that even persons who had not consumed alcohol in the past year were still less likely to experience better CVH. (297, 298) Additionally, thesis findings on psychological are consistent with one other study, also conducted in the US, showing that higher psychological stress is associated with a reduced likelihood of ideal CVH, regardless of income or education. (299) The thesis examined life stress and work stress as different variables and results were only significant for life stress, It is possible that life stress encompasses the same concept as work stress in the view of respondents leading to the thesis finding. No studies have shown a direct association between illicit drug use and ideal CVH, as in the thesis. It is hoped that the thesis findings can add to the existing sparse literature on the link between lifestyle factors and CVH and shed new light on current challenges including illicit drug use.

Finally, for individual level determinants, this study adds to the existing literature by examining the influence of gender on CVH, using sexual orientation as a proxy variable. Thesis findings reveal that individuals identifying as homosexual experienced better CVH than individuals identifying as heterosexual, while those identifying as bisexual did not experience better or worse CVH than individuals identifying as heterosexual. Thesis findings are not consistent with the existing literature which finds that LGB (lesbian, gay, bisexual) individuals are more likely report poor CVH than their heterosexual counterparts. (300, 301) The higher CVH for individuals identifying as homosexual noted in this study may be linked to reporting or measurement bias in this population. This hypothesis is supported by Canadian researchers, Hottes et al, who noted misclassification and under sampling in surveys to support inconsistent findings of
suicide rates in homosexual males.(302) Hottes et al also cited an unpublished Canadian study from the Community-Based Research Centre for Gay Men’s Health which revealed that up to 30% of Canadian homosexual men were unwilling to report their sexual orientation to a survey interviewer.(302)

Exploratory analyses in random slope models, which allowed determinants to vary across neighborhoods, show that the relationship between some individual determinants and CVH differed across the neighborhoods. The relationship noted in the main fixed effects models are an indication of the overall influence of individual determinants on CVH but may not hold for every neighborhood. For example, the influence of education on CVH differs across the dissemination area such that areas with better CVH had smaller improvements in CVH (than areas with poorer CVH) for increasing education. Thus, a nationwide intervention to educate the population as a means of improving health would be much less effective in some neighborhoods as compared to others, even after controlling for other differences between individuals. Findings indicate that policies and interventions to improve CVH should consider a neighborhood-specific approach.

7.1.4 The Influence of Neighborhood Determinants on Cardiovascular Health

Further analyses reveal that neighborhood determinants are strongly associated with CVH, even after adjusting for the influence of individual and interpersonal determinants. There are two important findings of the thesis to note; (1) variables from each of the four blocks (demographic, socioeconomic, environment and healthcare) were significantly associated with CVH and, (2) there was high variability in the associations between neighborhood determinants and CVH across neighborhoods.

Thesis findings reveal that demographic and socioeconomic characteristics of the neighborhood, including age, median income, unemployment, deprivation, and marginalization were associated with the CVH of individuals. Findings are consistent with a recent 2019 US study showing that neighborhood socioeconomic status, including income and education, were associated with a decrease in CVH score among individuals after accounting for individual socioeconomic status.(303) An earlier 2017 US study also
showed that a higher neighborhood socioeconomic status, represented by a summary indicator of poverty, income and education, was associated with better CVH, particularly among low income individuals. (194) The thesis adds to these studies by including the environment and healthcare variables in neighborhood models, which have not been previously explored in multilevel models with CVH. Results of the thesis show that individuals residing in neighborhoods with higher walkability scores and a greater physician and hospital bed supply were more likely to experience better CVH. Additionally, thesis analyses saw significant results with Canada-specific measures of the neighborhood including the deprivation indices, marginalization index and the community well-being index. Findings demonstrate the utility of these measures with the CVH outcome in Canada and encourages similar research beyond the typical neighborhood socioeconomic measures.

The highest reduction in the variation of CVH were seen by adding the demographic block to the model, indicating neighborhood demographic variables accounted for more of the variation between neighborhoods than variables from the socioeconomic, built environment and healthcare blocks. Neighborhood units could not be directly compared because neighborhood variables were not available for all the neighborhood units. For example, neighborhood environment data were only available for the DA. Nevertheless, examining the null model showed that the DA, which was the smallest neighborhood unit, accounted for the highest proportion of variation in CVH, followed by the FSA then the CSD. This is consistent with the current literature suggesting that, from a spatial perspective, smaller neighborhood areas may be more representative of what an individual would define as their neighborhood. (304) However, this reasoning may not always align with the social and functional definition of the neighborhood and its impact on health; this issue in the discussed further in a subsequent section. (304)

Examining interactional relationships revealed that the influence of non-modifiable individual determinants on CVH were modified by selected neighborhood determinants. Additionally, thesis findings shed some light on interactions using the approach of modifiable determinants as modifiers in the relationship between non-modifiable determinants and CVH. These findings are important because they show the strength of
combined effects that occur when individuals and neighborhood determinants act simultaneously on CVH. For example, results show the likelihood of better CVH is further reduced for the influence of age and neighborhood marginalization, than when either of these determinants act on CVH independently. The thesis did not employ methods to directly quantify the full extent of these interactional effects, such as the synergy index, however, results are indicative of a synergistic effect for the influence of individual and neighborhood determinants on CVH. Results of cross-level interaction analyses are inconsistent across studies. A study by Rachele et al showed that individual socioeconomic status did not significantly modify the relationship between neighborhood disadvantage and body mass index in a sample of Australian adults. (188) In contrast, Boylan et al and Winkleby et al both found that individual socioeconomic status modifies the relationship between neighborhood socioeconomic status and CVH. (194, 305)

7.1.5 The Influence of Determinants on Cardiovascular Health differs based on Sex

This thesis adds to the existing literature on CVH by comparing the influence of determinants on CVH in males and females. Thesis results for comparisons between females and males revealed significant differences between the sexes for the influence of individual determinants, but not for neighborhood determinants, on CVH. The only exception to this finding was for material deprivation in DAs. Notable differences were that, the association of gender with CVH was reversed, where females who identified as homosexual were less likely to experience ideal health than males who identified as heterosexual, and females of higher income groups were more likely to experience ideal health than males in lower income groups, even though income was not a statistically significant determinant in earlier analyses. Much of the research between sexual orientation and CVH is new (less than a decade old) and further research is needed to better understand the mechanisms behind these findings. Based on the current literature, differences in risky health behaviors and sexual-orientation-related discrimination between the sexes may be a possible explanation for the findings noted. (124)

In comparison to other studies that only examine differences in CVH between the sexes, controlling for other determinants, the thesis focuses on the interactions between sex and
One study by Simon et al in 2017 conducted interaction analyses as in the thesis and found significant interactions for deprivation and education of individuals, but not for education, depression, age, or race. These results were only generalizable to a study sample of 50-75-year-olds from Paris, France. Another similar study by Mathews et al in 2018, found no significant interactions between sex and psychological factors such as stress and depression. Neither study examined the influence of neighborhood determinants in their analyses.

Exploratory stratified analyses show that the neighborhood accounted for a higher proportion of the variation in CVH in females than in males. Prince et al conducted a study using multilevel modelling to examine the impact of the built and social environment on physical activity and obesity in a sample of Ottawa adults. In contrast to the thesis results, stratified null models in the Prince study showed a higher proportion of variation accounted for by the neighborhood, in males than in females. Results were consistent with a similar prior study conducted in an Ontario sample. A 2004 paper by Stafford et al confirmed very little investigation into the issue of sex differences in contextual effects, and this is still the case in research today. Nevertheless, Stafford proposes three possible explanations which support the differences noted in the sex-based analyses of thesis, 1) men and women perceive their environments differently, 2) men and women engage with several varying aspects of their environment, and 3) men and women are vulnerable to different aspects of their environment based on social roles, for example. While further research is needed to test these hypotheses, the thesis offers evidence that the influence of the neighborhood differs between the sexes, in relation to CVH. Neighborhood determinants were not significant in their interaction with sex in this study, however, this may be because the neighborhood determinants utilized were mainly objective and did not incorporate perception as a construct.

7.2 Contributions of the Thesis Findings

The thesis is the first known study to utilize the full extent of the American Heart Association’s Cardiovascular Health Index (CVHI) for producing national estimates of
CVH in the Canadian population. The most recent research using the CVHI tool in Canada was conducted in a sample of Quebec adults and thus, not generalizable to the entire Canadian population.\textsuperscript{(227)} Results of this study have shown a low prevalence of ideal CVH in Canada which may be driven by poor cardiovascular health behaviors among Canadians. Furthermore, the thesis found significant associations between less commonly identified individual, interpersonal, and neighborhood determinants on CVH, and showed how these determinants interact to influence CVH. The study also highlighted the role of the neighborhood in the variation of CVH among individuals. Finally, the differences in the influence of some of these determinants and the neighborhood on CVH based on sex provides strong evidence for sex-based interventions for improving CVH.

7.2.1 Contributions to the Literature on Determinants of Cardiovascular Health

The current study examines a wide range of individual and neighborhood determinants, including those not frequently studied in the literature. Such key determinants include household composition and social inclusion, which have been shown to improve overall health but not specifically CVH using the CVHI.\textsuperscript{(15, 308)} Thesis results show that both living alone and experiencing weak social inclusion are associated with poor CVH, adjusting for other individual and neighborhood determinants. The study provides evidence of the strong, independent associations of social support and CVH and advocates for the inclusion of interpersonal determinants in future CVH studies. Further, social support should be a more integral part of policies to improve CVH both in individuals and across populations, through investments into neighborhood resources such as community centers and gathering places (parks, arenas, etc.).

An important element of the study is the cross-level interaction between individual and neighborhood determinants, which can shed light on mechanisms through which individual and neighborhood determinants influence CVH. For many of the interaction effects, there is a greater change in the likelihood of ideal CVH when determinants are examined together, as opposed to the change observed with each determinant separately. The study fills a gap in the literature by suggesting that neighborhood determinants are
possible modifiers of the relationship between individual determinants and CVH, further confirming the importance of the neighborhood in defining the CVH of individuals. Thus, the interaction models provide key information on how individual and neighborhood determinants act simultaneously to influence CVH, which may in turn inform more integrative policies that can impact both the individual and population levels.

7.2.2 Contributions to the Literature on the Role of the Neighborhood in the Cardiovascular Health of Individuals

In addition to quantifying the association between determinants and CVH, the study examines and quantifies the contribution of the between-neighborhood variation to CVH. While the neighborhood may not account for a high proportion of the variation in CVH between individuals, there is considerable heterogeneity in CVH between the neighborhoods. Furthermore, the relationship between individual determinants and CVH may change from neighborhood to neighborhood. Study findings indicate the need for local approaches to health interventions that are tailored to the neighborhoods in which individuals reside. The one-size-fits-all approach, which usually applies to all individuals, may no longer be the single most effective approach to improving CVH. While existing literature has hinted towards this fact, this study quantifies the strong influence of the neighborhood on CVH and CVH variation, and provides evidence for new policy approaches involving multiple smaller, neighborhood-centered initiatives that utilize local resources and experts, to improve population CVH in Canada.

As part of the exploratory approach, the study examines more than one neighborhood unit. Many multilevel studies select a neighborhood unit based on the most applicable unit to the study outcome, availability of data or the most frequently used unit in similar studies.(234) In this study, neighborhood units cannot be directly compared because models contained varying neighborhood determinants however, it was important to note major differences in the estimates at the individual level. Models that included social and demographic individual level variables, show that the smallest neighborhood unit, the dissemination area, accounted for the largest neighborhood proportion in CVH variation. Results do not imply that the dissemination area is the optimal neighborhood unit, as statistical power usually increases with the number of clusters in multilevel analyses.
Further research is needed to examine whether the dissemination area best describes the neighborhood concept. Nevertheless, study findings can inform future studies in Canada, where there is no consensus on the definition of a neighborhood.

### 7.2.3 Contributions to the Literature on Multilevel Methodology

Finally, the study uses a merged dataset which includes survey and administrative data, which allowed for a wide range of determinants at the neighborhood level to be utilized in the study. The merging of survey and administrative data is not new, however, few CVH studies in Canada have employed this method in multilevel research. The merged data was ideal for this thesis research. The survey dataset provided a large sample size for level 1 units, with reliable data on social and demographic determinants, while the administrative dataset provided data on environmental and healthcare determinants that may otherwise be costly and labor-intensive to collect in a national survey. Given the multifactorial nature of CVH, a rich dataset is essential to perform detailed analysis and precise estimation of effects on the outcome. The merging of data in this study has been complex and time consuming however issues such as coverage and the use of weights have been addressed throughout the study and has strengthened the study methodology and output. It is hoped that the use of merged data in this study can motivate other Canadian studies to efficiently utilize locally available data and contribute new insights to multilevel research on CVH.

### 7.3 Strengths of the Thesis

The multiple strengths of the thesis have been detailed throughout this document and are best summarized in point format as below.

- **Promoting CVH research**: The thesis used epidemiological methods and population health tools to address a major health issue in Canada and worldwide. CVD is a leading cause of morbidity and mortality yet, in Canada, oncology has the largest share of health research funding and publications. Research providing insight into reducing CVD burden and promoting CVH, which will aid in developing stronger health policies, is urgently needed and the thesis contributes to this need.
• **Promoting CVH measurement:** The thesis is the first to quantify cardiovascular health, as represented by the Cardiovascular Health Index, in Canadian adults nationally. In doing so, thesis findings can be used to inform interventions for improving clinical and behavioral components of CVH in the Canadian population.

• **Adapting CVH measurement to Canadian context:** The thesis adapted the Cardiovascular Health Index to the Canadian context rather than simply inserting a US score into a Canadian study. This is especially important for the total cholesterol component which is prioritized as non-HDL-C in Canadian adult dyslipidemia management guidelines.

• **Utilizing a wide range of determinants:** The thesis utilized multiple data sources for addressing the multilevel influence of individual and neighborhood determinants on CVH. Findings confirm individual determinants that influence CVH in a sample of Canadian adults, while elaborating on the influence of interpersonal and neighborhood determinants that are minimally addressed in the existing literature.

• **Utilizing the full extent of multilevel methodology:** The thesis expanded on the use of multilevel methodology in examining CVH, by integrating variation and heterogeneity into analyses and results. Aside from the customary association analyses conducted with regression models, findings confirm the role of the neighborhood in the CVH of individuals and demonstrate how determinants can account for variation in CVH among individuals.

• **Examining multiple definitions of the neighborhood:** The thesis simultaneously examines more than one neighborhood unit in analyses, which allowed for more neighborhood determinants to be studied and extended upon the findings on the variation account for by the neighborhood. Additionally, findings contribute to the current literature debating the definition of the neighborhood in Canada for health research studies.
• **Examining sex-based differences:** The thesis also addressed the issue of sex-based differences for the influence of determinants on CVH. Sex-based analyses are an important mandate of the Canadian Institute for Health Research and should be incorporated into all health research. Findings showed clear differences when comparing the influence of determinants on CVH between the sexes, a phenomenon that has been underscored in previous studies.

### 7.4 Limitations and Implications of Thesis Findings

#### 7.4.1 Cardiovascular Health

In this study, cardiovascular health is measured by the self-reported version of the American Heart Association’s Cardiovascular Health Index. Self-report bias is an important limitation to note in this study. Given the multi-component index of the CVHI, it is expected that self-reporting will introduce variable bias into the study as noted in the existing literature. A report published by the Canadian Journal of Cardiology in 2016 examined the prevalence of hypertension using direct measured, self-reported and administrative data. Results showed that the prevalence estimates were similar, 24.5% in administrative data, 23.0% in direct measured data and 22.1% in self-reported data. However, results are more inconsistent for behavioral measures such as physical activity. A recent systematic review by Prince *et al* showed that self-reported measures both underestimate and overestimate direct measures of physical activity. Another review by Maukonen *et al* found similar results for body mass index, with self-reported weight and height being underestimated in comparison to direct measures. No study has compared the direct measures and self-reported version of the CVHI, given that both versions were utilized and produced reliable estimates worldwide.

As pointed out in the literature review, there are many ways of measuring health, self-reported or direct measures, and comprehensive or single measures. The CVHI is a comprehensive score consisting of seven key factors known to directly impact CVH. The INTERHEART study, which was conducted in 52 countries, found that more than 90% of the risk of heart disease of an individual can be attributed to nine factors: high cholesterol, smoking, diabetes, hypertension, abdominal obesity, psychosocial factors,
diet, physical activity and alcohol consumption. Indeed, any of these individual factors can be used to measure CVH, however, the concept of CVH is multifactorial and is well encompassed in a comprehensive measure such as the CVHI. It is important to note that the INTERHEART study attributed over 90% of the risk of heart disease to nine factors, however, that risk also consists of the mediating and moderating mechanisms that give rise to these nine factors, including the environment. Furthermore, the thesis serves to introduce the concept of the CVHI to the Canadian literature as a candidate measure for CVH at the individual and population levels, a tool already adapted in various other countries. The CVHI contributes to the local need for novel measures that can be easily and quickly adapted into CVH research, and that is readily derived from existing data.

7.4.2 The Neighborhood

As mentioned earlier in the thesis, the issue of defining the neighborhood remains unresolved in the literature. Thesis results show that the highest proportion of variation in CVH for neighborhoods was noted for dissemination areas (DAs). The DA may be a suitable neighborhood unit because its small size allows for some homogeneity in the characteristics of individuals; thus, variation within the DA is low and variation between DAs may be more observable. It should be noted that the balance of the within- and between-neighborhood variation is key in defining a neighborhood based on size. A neighborhood that is too homogenous will have insufficient variations in determinants, which precludes investigation of how these determinants influence health. A neighborhood that is too heterogenous will have high variation within the neighborhood and detecting neighborhood effects becomes more difficult.

For the purpose of this research design, the thesis assumes that the CVH of individuals is directly impacted by determinants grouped by geographic boundaries. However, this does not mimic the real-world scenario. The demographic, social, economic, environmental and healthcare determinants that influence the CVH of individuals likely do not function solely within the geographic confines of a neighborhood. An appropriate example of this is healthcare; which was not assessed in DAs because there is not a physician or hospital in every small unit neighborhood. A hospital or physician likely serves a much
broader geographic area, such as the forward sortation area (FSA), and was therefore assessed for that unit. Another important issue is that geographic boundaries are fairly arbitrary in relation to the determinants that influence health. (186, 242) Individuals residing on the border of one neighborhood may not have a drastically different exposure from the individuals residing on the border of the adjacent neighborhood, yet the thesis may attribute the neighborhood to differences in their health outcomes. (312) There is no universal method for addressing these issues in multilevel studies however, this study employs varying units of the neighborhood that strengthen the inferences made based on neighborhood exposure. (234)

Another important study limitation is residential self-selection bias, where individuals select into their neighborhood of residence based on their preferences and attitude towards health. (313) The basis of this issue was well-described by Diez Roux et al; neighborhoods are important units of study because individuals with similar socioeconomic status tend to cluster, which may lead to inequalities between neighborhoods that can influence health and health behaviors. (186) Residential self-selection can cause bias in the thesis study because it acts as confounder which leads to an underestimation or overestimation of the strength of relationships between neighborhood determinants and CVH. Given that this bias is not uncommon in neighborhood health research, a recent systematic review conducted in 2020 examined how this issue of neighborhood self-selection bias was handled in other studies. (314) As is a typical approach to the issue of confounding, most studies adjusted for neighborhood preference however, the success of this adjustment in reducing bias could not be assessed. The review suggests that temporality in relation to neighborhood preference should be considered in future studies.

One such study was conducted by James et al, a few years prior, which examined pre- and post-move health factors to assess neighborhood self-selection in a US prospective sample study. (315) Overall, individuals with higher adiposity and lower levels of physical activity tended to move to areas with lower socioeconomic status. However the associations were small and additional analyses showed that individuals with healthy pre-move behaviors tended to move to areas with lower socioeconomic status, even after
Researchers concluded that residential self-selection does not completely drive health behaviors and may not be a major source of bias in cross-sectional studies in neighborhood health research. Findings were consistent with another study showing that associations between neighborhood disadvantage and poor health over time were mainly due to between-person differences as opposed to within-person differences comparing individual health with changes in neighborhood over time. Variables on temporality, neighborhood relocation or neighborhood preference were not available in thesis data; therefore, some neighborhood self-selection bias may impact study results. However, in line with other studies, it is anticipated that this bias is minimal and not solely responsible for the associations between neighborhoods and CVH noted in thesis results.

This thesis is cross-sectional; however, neighborhoods are dynamic; constantly evolving in response to the actions of individuals and the society at large. The study uses recent data but shows the relationship between determinants and CVH at one moment in time. Studies show that length of time residing in a neighborhood is likely to influence the health of residents. Certainly, the CVH of an individual just moving into a neighborhood may not be comparable to that of another individual who has lived in that neighborhood their entire lives. Although this type of data was not available for the current study, future studies should consider using longitudinal data that can highlight the process through which neighborhoods may impact changes in CVH.

7.4.3 Determinants of Health

In the real-world scenario, it is likely that the social, demographic, economic, environment and healthcare determinants of neighborhoods act through numerous complex mediating and moderating mechanisms to impact the health of its individuals. This study investigates the interaction between modifiable neighborhood and non-modifiable individual determinants of health. Findings suggest that neighborhood determinants may act as targets for policy aimed at improving health, within the context of individual determinants, a concept that can prove useful in policymaking. Canada has already made some progress in this field; in a position paper by the Ontario Public Health Association entitled “Health In Cities: The Role for Public
Health, health authorities acknowledge the role of interacting determinants on health by recognizing targets for public health action that include: children in low-income neighborhoods, Indigenous people living in regions with high economic inequalities and new migrants forced into areas with poor physical and social infrastructure. The thesis could not explore all the possible modifications between individual and neighborhood determinants however, it is anticipated that this study can bring to the forefront new targets for public health action, including those based on sex.

Some of the determinants in this study may not fully represent its latent concept. For example, neighborhood median income, intended to measure socioeconomic status of a neighborhood may not encompass the political, economic, and social factors that link income to health. Hence, simply addressing one neighborhood determinant will not necessarily improve CVH for the residents of that neighborhood. There is, therefore, a need to examine determinants in a comprehensive manner and a reasonable start is to examine how determinants impact health in various political, economic, social and cultural contexts. The thesis has included multiple socioeconomic determinants of health, measured by both individual determinants and collective indices, to highlight how these various contexts can influence health. In the study, the challenge of multicollinearity was addressed by grouping similar determinants as blocks and separately fitting each block into models.

The thesis uses multiple data sources in an attempt to include a wide range of neighborhood determinants, which may be important contributors to CVH. Results of the thesis showed that a considerable portion of variation in CVH was still unaccounted for by these range of determinants, indicating that an even wider range of neighborhood determinants may be warranted in further studies. The thesis was able to examine the influence of at least four blocks of neighborhood determinants independently on CVH, which was not possible with the use of only the CCHS data. Most neighborhood determinants were defined and measured based on the characteristics of the larger census population rather than on aggregates of the study sample alone; thus, reducing same-source bias and ecological fallacy. Many neighborhood determinants were derived from census data and administrative data sources that collect data from across the country,
rather than solely aggregates of the study sample. However, a limitation in using the merged data was that data for all variables were not available for each neighborhood unit and although the study remained sufficiently powered, there was some loss in sample size due to data merging.

7.4.4 Study Population and Design

The multilevel analysis portion of the study was conducted on a study sample of Canadian adults. Given the eligibility criteria of the study, the study sample was not random and may not be entirely representative of the Canadian population. On the other hand, the sample size provided sufficient power to conduct the multilevel analysis with reduced error, and the study sample had a similar composition to the Canadian population from which the sample was drawn (for the determinants examined). Although, individuals were not sampled from every neighborhood unit in Canada, the CCHS adopted a multistage sampling design that selected individuals from clusters of varying socioeconomic and demographic strata across the country. The lack of use of weights in analyses reduce generalizability and introduce some bias because the clusters may underrepresent the population by chance alone.

The study design is observational and cross sectional therefore causal methods were not employed. Causal methods, such as propensity scoring and inverse probability weighting, can eliminate residual confounding and ensure exchangeability to reveal whether the neighborhood ‘causes’ individual CVH. However, causal methods for neighborhood studies involve experimental research which can be costly and problematic. Few studies have attempted using causal methods in multilevel research and the results of such studies have been less consistent than observational studies. For example, an ecological study by Vortuba and Kling examined data from the local housing relocation program in Chicago to determine whether neighborhood socioeconomic factors impact mortality rates in low-income men of the Black race. Results showed that all-cause mortality and mortality rates due to homicide were lower for men who move to neighborhoods with a higher socioeconomic status, defined by higher rates of education. In contrast, another study conducted by Hearst et al, using propensity score matching to examine the effect of racial segregation on Black infant mortality,
found no independent effect of racial segregation on mortality rates of Black infants. (320)

However, it should be noted that the thesis does not aim to totally extricate the causal effect of the neighborhood on health. The study design is appropriate because the study aims to examine the simultaneous and collective influences of neighborhood and individual determinants on health. Therefore, the conclusions of the study should inform policy that can improve health by intervening at the individual and population levels, rather than simply ‘changing the neighborhood.’

7.5 Recommendations and Conclusions

While individual factors are known to affect health, including CVH, most studies fail to consider the clustering of individuals into neighborhoods. This study emphasizes that to fully understand the distribution of population CVH, it is important to systematically evaluate differences in health both within and between neighborhoods. This study has contributed to the scientific literature by completing the following objectives: a) assessed variations in CVH and determinants that influence these variations, b) introduced the role of individual, interpersonal and neighborhood determinants in shaping CVH, c) examined the interactional influences of individual and neighborhood determinants on CVH, in a sample of Canadians. Findings from this study provide a better understanding of CVH and its determinants, that should encourage government and health officials to make more informed decisions about the policies and interventions targeted at improving CVH in Canadians.

The completion of this thesis highlights four main recommendations for future health research and policy surrounding CVH. The following recommendations are not meant to be an exhaustive list of all thesis findings, but simply to highlight those areas of immediate action for health policy planning.

**Recommendation 1:** Healthy behaviors to promote optimal CVH should be treated with urgency and relevance alongside pharmacological interventions for CVD prevention.
While the majority of Canadians experience intermediate overall CVH, their poor performance in the behavioral components of the CVH score indicate that prevention efforts should be intensified around health behaviors. The satisfactory performance in clinical components may be attributed to fair access to the public health system in Canada or advancements in pharmacological therapy for diseases such as hypertension and diabetes. Studies have shown that the greatest benefits, including major reductions in risk of morbidity and mortality, are seen in those maintaining optimal CVH i.e. achieving ideal health in all 7 components of the CVH score, which is maintained by only a quarter of Canadians. Therefore, interventions aimed at improving CVH beyond pharmacological maintenance of risk factors, are necessary to significantly reduce the burden of CVD in Canada. The grave issue of poor health behaviors in Canadians has been highlighted in a national report, which stated that four in five Canadian adults reported at least one poor behavior including tobacco smoking, physical inactivity, unhealthy eating or harmful use of alcohol in 2017. Estimates place Canada in the top third of OECD countries for poor performance in health behaviors. Authors of this report, the Public Health Agency of Canada, called for greater surveillance of health behaviors in Canadians. The thesis supports this call, adding that further awareness about the role of poor health behaviors in declining CVH be a focus of further discussions.

**Recommendation 2:** *Social cohesion should be an integral and mandatory component in community-based interventions for improving the CVH of populations.*

Interpersonal determinants such as social inclusion are important independent determinants of CVH. While this supports the growing body of evidence of the link between social networks and health, the uptake of this concept into policy and intervention remains a slow and challenging process. One way of tackling this issue is to integrate more measures of social networks and interpersonal factors into health data so that researchers can accurately quantify the effect of social connections on health. For example, the CCHS has other measures of social support in the survey however, it is optional content and data is missing for more than one of the populous provinces in Canada, thus that measure could not be included in this study. Health authorities have begun to focus on social inclusion and its role in health, even in major cities where
remoteness is not an issue. A recent report titled, “Promoting Health and Well-Being through Social Inclusion in Toronto” suggested 14 new interventions and various funding models to support greater social inclusion in the city. (321) Thesis findings show that similar policies are needed across the entire of Canada, and possibly in less dense areas where social inclusion can be more challenging.

**Recommendation 3:** *The one-size-fits-all approach to health intervention planning for individuals should be reconsidered and replaced with community-specific plans for CVH improvement that may be implemented at the neighborhood, school, or family levels.*

The impact of the neighborhood and neighborhood determinants on the CVH of individuals, even after adjusting for the influence of individual and interpersonal determinants, is substantial and should not be dismissed as inaccessible to policy makers. Arguably, issues such as deprivation and marginalization are complex and may not be addressed by one policy or even one governing power. (322) However, physician supply, community-well-being and active living may well be addressed in existing political frameworks aimed at improving neighborhood resources. A systematic review examined the effectiveness of community-based programs for CVD prevention, including 36 studies from the US, Europe and Australia, and 4 interventions in Canada. (323) Most of the Canadian interventions did not achieve a net 10-year reduction in CVD risk. The role of the neighborhood in CVH is evident, however, a review of recent literature for the thesis did not reveal any successful (or proposed) large-scale community-based interventions for improving CVH in Canada in the past 5 years.

**Recommendation 4:** *Interventions to improve CVH should not simply consider the role of sex, but actively incorporate and target sex in the execution of such interventions.*

Sex-based differences are evident in the relationship between determinants and CVH, with exploratory results suggesting that neighborhoods may be accounting for more variation in CVH in females than in males. There has been a growing interest in addressing health differently for each sex, however, interventions and policies that are sex-specific are still limited. (324) Obviously, one sex cannot always be prioritized over the other but careful attention must be paid to the sex that, in the context of individual
and neighborhood determinants, are at an increased risk for poor CVH. Evidence must be derived, not only from stratified analyses that monitor the sexes in isolation, but also from interaction studies examining combined effects and directly comparing the sexes. Canada has made significant progress in promoting sex-based analyses in health research, with the Canadian Institute for Health Research requesting that applicants for grant funding indicate how they will incorporate sex and/or gender into their research. Nevertheless, Canadian researchers agree that more work needs to be done to incorporate health differences noted in research analyses, into existing clinical trials and health policies. Thesis findings provide strong evidence to support this proposal, adding that differences in health between the sexes persist, even at the neighborhood level.

### 7.6 Chapter Summary

In conclusion, individual, interpersonal and neighborhood determinants should all be incorporated in interventions and policies to improve the CVH of Canadians. Neighborhoods are vital in determining CVH, and neighborhood determinants significantly influence an individual’s likelihood of experiencing ideal CVH. However, there exists considerable heterogeneity for the influence of neighborhood determinants on CVH, from neighborhood to neighborhood – an issue that warrants further contemplation when distributing public health resources. Furthermore, identifying determinants of health as key sources of variation in CVH is an important step towards addressing CVH inequalities. Importantly, studies that neglect to incorporate a multilevel approach into the analyses of population health serve only to provide a misinformed and biased perspective for the influence of determinants on CVH. In fact, further studies are needed, to investigate the influence of other levels of health determinants, such as provincial policy and governmental legislation, on CVH. Canada is an ideal setting for examining the role of such levels in health because expansive data is available at both the national and provincial levels. Finally, a focus on CVH as a positive construct that can be measured in all individuals, apart from death and disease, is also needed in local research. Canada has previously been at the forefront of CVD prevention, through CVH promotion, and expanding our knowledge on the multilevel influence of determinants on CVH can bring us back to that place of innovation once again.
8 References

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Appendices

Appendix A Western Research Ethics Board Policy on Research Exempt from HSREB Review

Western Research

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Approvals

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1. PURPOSE

This standard operating procedure (SOP) describes the process for determining if research should be reviewed by a sanctioned university research ethics board (REB) or if it is exempt from this review process.

2. GENERAL POLICY STATEMENT

Any research involving human participants, including secondary data, and human biological materials that is conducted by any Faculty, employee, student of Western University, or Adjunct Faculty member of any department or school, regardless of where the research is carried out, must be reviewed and approved by a university sanctioned research ethics board before the research can begin.

Undergraduate and graduate courses that require or permit the students to participate in research projects as part of their training or for the purposes of assessments must have the research project reviewed and approved before the course begins unless the work is being done strictly for pedagogical purposes.

Some studies are exempt from research ethics review as outlined below, if there is a doubt whether or not a particular research project requires ethics review, the opinion of the Director, Ethics Officer, Chair or Vice Chair(s) should be sought.

3. RESPONSIBILITY

This SOP applies to the HSREB Chair and Vice-Chair(s) and to all Office of Human Research Ethics (OHRE) staff.

The HSREB Chair, designee or OHRE staff member is responsible for determining whether or not a research project requires approval or can be exempt from the approval process.

4. DEFINITIONS

See Glossary of Terms

5. SPECIFIC POLICIES AND PROCEDURES.

5.1. Research Exempt from Research Ethics Approval

5.1.1. Research that relies exclusively on publicly available information does not require REB review when:
5.1.1.1. (a) the information is legally accessible to the public and appropriately protected by law; or
5.1.1.2. (b) the information is publicly accessible and there is no reasonable expectation of privacy.

5.1.2. Research involving the observation of people in public places where:
5.1.2.1. (a) it does not involve any intervention staged by the researcher, or direct interaction with the individuals or groups;
5.1.2.2. (b) individuals or groups targeted for observation have no reasonable expectation of privacy; and
5.1.2.3. (c) any dissemination of research results does not allow identification of specific individuals.

5.1.3. Research that relies exclusively on secondary use of anonymous information, or anonymous human biological materials, so long as the process of data linkage or recording or dissemination of results does not generate identifiable information.

5.1.4. Quality assurance and quality improvement studies, program evaluation activities, and performance reviews, or testing within normal educational requirements when used exclusively for assessment, management or improvement purposes, do not constitute research for the purposes of this Policy, and do not fall within the scope of REB review.

5.1.5. Creative practice activities, in and of themselves, do not require REB review. However, research that employs creative practice to obtain responses from participants that will be analyzed to answer a research question is subject to REB review.

5.2. Documentation
5.2.1. When required by the researcher a letter of exemption will be written from the REB to the researcher.

6. REFERENCES

7. SOP HISTORY

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Appendix B Research Data Center Contract to access CCHS 2015-2016 data

Contract number:

Microdata Research Contract

Amendment

The Microdata Research Contract or Framework Agreement Research Project or Microdata Service Contract is hereby amended as follows:

The list of data sets will be amended by adding:

CCHS 2015
CCHS 2015-2016
CCHS 2016

FOR STATISTICS CANADA:

[Signatures and print names]

Witness:

DATED at Ottawa, Province of Ontario, this 13th day of April (month), 2018 (year).

FOR THE PRINCIPAL RESEARCHER AND CO-RESEARCHER(S):

[Signatures and print names]

Witness (sign here)

DATED at London (location), this 14th day of April (month), 2018 (year).

1 Researchers being amended to a Microdata Research Contract or Framework Agreement Research Project or Microdata Service Contract are responsible for reading and complying with the terms and conditions of that contract.
Appendix C Copy of Application to Canadian Institute for Health Information
Graduate Student Data Access Program

Detailed description of data requested (150 words max)

This study requires data on the supply of healthcare for aggregate areas not publicly available from the online CIBI databases. Data from two (2) sources are required to complete this study:

1) Study variable: Supply of physicians per aggregate area

Data Source: Scott’s Medical Database (SMBD)

Data required: a) The number of primary care physicians per 10,000 or 100,000 population (Primary care physicians include family and general practitioners, general internists, and general pediatricians).

b) The number of specialist physicians per 10,000 or 100,000 population (Specialist physicians include all other physicians who are not primary care physicians).

2) Study variables: Supply of hospitals and hospital beds per aggregate area

Data Source: Canadian MIS Database (CMDB)

Data required: a) The number of hospitals (All hospitals and/or health/medical centers, including but not limited to public hospitals operated by provinces/territories or health authorities, federal hospitals and proprietary or private hospitals).

b) The number of hospital beds staffed and in operation per hospital (the beds and cots available and staffed to provide services to inpatients at the required type and level of service at the beginning of the fiscal year).

Research question or purpose of request (150 words max)

The purpose of this request is to obtain data that will be used to conduct my doctoral dissertation at Western University. The research question is: Does the supply of healthcare at the aggregate level impact cardiovascular health at the individual level? The supply of healthcare will be operationalized as two main variables: 1) supply of physicians and 2) supply of hospitals and hospital beds, per aggregate area. Three aggregate areas will be examined in this study including: forward sortation area, census sub-division and dissemination area. Data on the two main variables are required at the level of each of the three aggregate areas. The statistical method that will be used to examine the research question is Multilevel Regression Analysis.

Please note that this request is only for data pertaining to the supply of healthcare at the aggregate level. The outcome, cardiovascular health at the individual level, will be obtained from other publicly available data sets.

Plan for disseminating results (150 words max)

Preliminary results may be presented at local research conferences geared towards healthcare services and policy. The full scope of results from this study will be presented during my doctoral dissertation examination at Western University, scheduled for 2020. Following the publication of the thesis, a manuscript containing the full results will be submitted to a peer-reviewed journal for publication.

My thesis will be available in full-text on the internet for reference, study and/or copy. Except in situations where a thesis is under embargo or restriction, the electronic version will be accessible through the Western Libraries web pages, the Library’s web catalogue, and also through web search engines. I will also be granting Library and Archives Canada and ProQuest/UMI a non-exclusive license to reproduce, loan, distribute, or sell single copies of my thesis by any means and in any form or format. These rights will in no way restrict republication of the material in any other form by you or by others authorized by you.
Appendix D Data Agreement to access CANUE data for thesis

Data Sharing and Use Agreement

November 15, 2018

CANUE Data Request ID: (Note: Data Request ID will be issued by CANUE)

1. Purpose of Agreement

This agreement documents the data sharing and use conditions related to the indicated dataset(s) (Addendum 1), the intended use of the dataset(s), the Principal Data User who takes delivery of the data and accepts responsibility for ensuring these conditions are fulfilled, and the project team members who will have access to the datasets. The signature of the Principal Data User is required to fully execute this agreement. Copies of this agreement must be provided to CANUE by email (info@canue.ca). CANUE will forward copies to all original data developers as per the exposure data source contact listed in the associated metadata files.

2. Disclaimer

Data are provided “as-is”. While substantial efforts are made to ensure the accuracy of data and associated documentation, complete accuracy cannot be guaranteed. CANUE makes no guarantee, either express or implied, including but not limited to, the fitness for any purpose. The Data User holds all parties involved in the production or distribution of the data harmless for damages resulting from its use or interpretation.

3. Intended Use(s)

Use of CANUE datasets is restricted to academic, research, educational, or other not-for-profit purposes.

- Project Name: Individual and Neighborhood Characteristics influencing Cardiovascular Health in Canadians
- Associated Health Cohort or Health Database: Canadian Community Health Survey (CCHS)

Project Summary:

The study aims to examine the influence of both individual and neighborhood socioeconomic factors on the cardiovascular health of Canadians. Data on individual socioeconomic factors including education, income and employment, and cardiovascular health will be provided by the CCHS. Data for neighborhood socioeconomic factors, including deprivation and the active environment should be provided by a database that purposively assesses data at the neighborhood level (such as CANUE). The datasets will not be linked at the individual level. Findings of the study will inform future efforts to target specific subgroups and characteristics of the neighborhood that can have the highest impact on improving cardiovascular health.
Data Sharing and Use Agreement

November 15, 2018

4. Data users covered by this agreement

Principal Data User: 

Academic Affiliation: Western University

*REQUIRED: Include the name of Additional Project Team Members, Institutional Affiliation, Email Address. If team members are students include their associated degree program (e.g., BA, BSc, MA, MSc, PhD, Post Doctoral)

I am affiliated with a Canadian academic institution listed in Addendum 2. (If no, please contact info@canue.ca to identify possible study collaborators)

☐ I have read the associated metadata files for the indicated datasets/variables and agree to abide by the limits for data sharing and use conditions contained in each file.

☐ I will ensure all project team members are aware of and abide by the limits for data sharing and use conditions set out in each metadata file.

☐ I understand this agreement will be terminated immediately upon breach of, or non-compliance with, any of its terms and/or those contained in each metadata file, and that I may be held responsible for any misuse that is caused or encouraged by failure of myself or members of the project team to abide by the terms of this agreement.

☐ I agree to provide CANUE staff with information, upon request, on how the analytical results were disseminated, i.e., published journal articles, academic or professional conference abstracts, posters and presentations, invited presentations and webinars, and project reports.

Signature (Principal Data User) 

Date 

2019-05-23
Curriculum Vitae

Name: Sarah Singh

Post-secondary Education and Degrees:
- St. Georges University
  St. Georges, Grenada
  2006-2011 M.D

- West Virginia University
  Morgantown, WV, USA
  2013-2015 M.P.H Epidemiology

- Western University
  London, Ontario, Canada
  2016-present Ph.D. Epidemiology and Biostatistics

Related Work Experience (since 2016):
- Teaching Assistant
  The University of Western Ontario
  2017-2019

Awards (since 2016):
- Western Research Graduate Scholarship
  2016-2020 For completion of Doctoral Studies in Epidemiology and Biostatistics at Western University

Peer Reviewed Publications (since 2016):

