CARDIOVASCULAR RISK AND THE NEIGHBOURHOOD BUILT ENVIRONMENT IN URBAN SETTINGS

by

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ABSTRACT

Cardiovascular disease (CVD) is a leading cause of death, and the greatest contributor to health care costs in Canada. Primary prevention is an important strategy for limiting both disease and costs. Cardiovascular disease incidence and mortality are causally related to physical activity in an inverse, dose-response trend. Physically inactive lifestyles increase and hasten the incidence of CVD. Features of the built environment have been shown to moderate physical activity levels in neighbourhood residents and thus could also be contributing to CVD risk. However, investigation into the association between the built environment and modifiable CVD risk factors is rather limited. The purpose of this investigation is to compare levels of CVD risk factors affected by physical activity in neighbourhoods varying on walkability and number of leisure-time physical activity correlates. Objective measures of several cardiovascular risk factors: BMI, waist girth, systolic blood pressure and HDL-C concentration were collected on participants across British Columbia, Canada. Geographical information system software was used to score a 750m network buffer around each participant's residence on the Neighbourhood Walkability Index and number of leisure-time physical activity correlates. Participants were also grouped based on their neighbourhood-level median after-tax income. A total of 2999 individuals were included in statistical analyses. Findings revealed significantly lower BMI, waist girth and systolic blood pressure values amongst residents of high (compared to low) walkable neighbourhoods. Individuals living in environments with more leisure-time physical activity correlates also exhibited significantly lower BMI and waist girth values. Higher income groups were associated with significantly less risk for BMI and waist girth. These results contribute to a growing body of research on the effect of the urban built environment at the neighbourhood level on cardiovascular health. This investigation is unique in its analysis of several CVD risk factors which are influenced by physical activity, beyond BMI. Findings of lower waist girths among residents of high walkability neighbourhoods are novel and speak to potential cardiometabolic effects of living in areas which support active transportation and leisure-time physical activity. Furthermore, our data identify low income neighbourhoods with the least physical activity correlates as relatively high risk areas.

PREFACE

One manuscript is presented in Chapter 2 of this document and is cited as: Johnson, M.Z., Warburton, D.E.R., Blanchard, C.M., & Bredin, S.S.D. Cardiovascular Disease Risk Factors, Neighbourhood Walkability and Leisure-Time Physical Activity Correlates. This manuscript will be submitted for peer review immediately following final submission of the thesis document to graduate studies.

Identification and design of the research presented within this document was primarily the work of Ms. Mika Z. Johnson and Dr. Shannon S. D. Bredin. Significant contributions were made by Dr. Darren E. R. Warburton and Dr. Chris M. Blanchard.

Cardiovascular data collection was performed as a component of Act Now BC, a cardiovascular health initiative funded by the provincial government of British Columbia, Canada. The data collection team (i.e., Canadian Society of Exercise Physiology - Certified Exercise Physiologists®) was funded solely by the Cardiovascular Physiology and Rehabilitation Laboratory at the University of British Columbia.

Several geospatial data files, attained through the University of British Columbia in agreement with DMTI Spatial Inc. (Markham, ON), were used for analyses within the manuscript presented in Chapter 2. Results or views expressed within this document are those of the first author and not of DMTI Spatial Inc.

All data analysis was performed by Ms. Johnson with significant contributions from Mr. Anthony Smith. The manuscript presented in Chapter 2 was prepared primarily by Ms. Johnson, with major contributions by Dr. Bredin.

All research was pre-approved by the Clinical Research Ethics Board of the University of British Columbia, to be acceptable on ethical grounds for research involving human subjects (UBC CREB number H07-03187) (See Appendix A).

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LIST OF SYMBOLS

±: "Plus or minus"

∑: Summation

cm: Centimetres

ln: Natural logarithm

p<: "Probability is less than"

µ: Mean

Kg/m^2: Kilograms per metre squared

mmHg: millimetres of mercury

mmol/L: millimoles per litre

LIST OF ABBREVIATIONS

ANOVA: Analysis of variance

BMI: Body mass index

CSEP: Canadian Society for Exercise Physiology

CSEP-CEP: Canadian Society for Exercise Physiology – Certified Exercise Physiologist®

HDL-C: High-density lipoprotein cholesterol

LDL-C: Low-density lipoprotein cholesterol

LTPAC: Leisure-time physical activity correlate

MANOVA: Multivariate analysis of variance

SD: Standard deviation

SE: Standard error

TC: Total cholesterol

Tukey's HSD: Tukey's Honestly Significant Difference test

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DEDICATION

Dad, Steve, Zeb, Evelyn, Mom, Connor, Brady and Greysen (in order of descending height♥); you've always supported me in any way I've needed. You've helped me both to realize and celebrate my accomplishments. I know your thoughts were with me throughout every step of this process and there isn't anything more I could have hope for. Thank you for so much more than helping me through this degree.

♥ *Heights are approximate, and up-to-date as of submission.*

CHAPTER 1

Introduction to Thesis

1.1 Introduction

Cardiovascular disease, alternatively termed heart disease, refers to a group of conditions affecting the form and function of the heart and its vasculature. Coronary artery disease is the most common form of cardiovascular disease, the underlying cause of which is atherosclerosis, or the hardening of the arteries through the deposition of plaque (Heart and Stroke Foundation of Canada 2003; Young and Libby 2007). Cardiovascular disease is one of four non-communicable diseases, along with diabetes, cancer and chronic respiratory disease, which account for the majority of mortality worldwide (International Diabetes Federation, World Heart Federation et al. 2009). From a Canadian perspective cardiovascular disease poses a serious threat. Cardiovascular disease causes more deaths among Canadians than any other disease. It is also the leading contributor to both direct and indirect health care costs in Canada (Heart and Stroke Foundation of Canada 2003; CHHS-AP Steering Committee 2009).

Physical activity, defined as bodily movement produced by skeletal muscles which results in increased caloric expenditure above basal metabolic rate (Pate, Pratt et al. 1995), is associated with reduced risk of cardiovascular mortality (Wannamethee and Shaper 2001; Warburton, Nicol et al. 2006). This can be attributed to improvements in several cardiovascular risk factors (i.e., characteristics that are associated with an increased risk of developing future disease) that come with being physically active (Ridker and Libby 2008). These include decreased risk of both central and general obesity, decreased blood pressure, improved glucose tolerance, and improvements in one's lipid profile (Young and Libby 2007; Prasad and Das 2009). Yet, physical activity rates in Canada are low. The Heart and Stroke Foundation of Canada reported in 2009 that nearly half of all Canadians age 12 and over report being physically inactive (Heart and Stroke Foundation of Canada 2009). Physical activity rates are the second highest amongst residents of the province of British Columbia, compared to the rest of Canada (the highest rates being reported in the Yukon). Still, only 53.7% of British Columbians report being physically active (Heart and Stroke Foundation of Canada 2010). Hence, increasing the proportion of physically active British Columbians, and Canadians in general is crucial to population health.

Physical activity can be classified behaviourally into leisure-time physical activity and utilitarian physical activity. Leisure-time physical activity refers to physical activity that is purposeful exercise or participation in play or sport (or other active pursuits) simply for the enjoyment of the activity itself. Utilitarian physical activity, alternatively, refers to physical activity which serves a purpose other than leisure. For instance, activities such as washing the dishes or doing laundry are within the definition of physical activity but are performed for a function outside of enjoyment or exercise. Active transportation, most often referring to walking or cycling for purposes such as running errands or commuting to work, is a form of utilitarian physical activity. Recent research has emerged which investigates the influence of the form of communities on leisure-time physical activity and active transportation rates. It has been hypothesized, and to some degree shown, that certain features of one's environment can act as facilitators or barriers to physical activity (Frank, Schmid et al. 2005; Sallis, Bowles et al. 2009; Sallis, Saelens et al. 2009).

The built environment, a construct which refers to the physical form of communities, is comprised of urban design (i.e., the arrangement and appearance of physical elements), land use (i.e., the distribution of activities across space), transportation systems, and human activity within an environment (Handy, Boarnet et al. 2002). Several factors within the built environment of urban settings in particular (defined in Canada as areas having a population of at least 1000 people and having a population density of no less than 400 persons per square kilometre), have been correlated to active transportation and leisure-time physical activity, respectively. Specifically, neighbourhoods with increased population and/or residential density, a greater variety of land uses (i.e., mixture of residential, commercial and office land use) and more connected, grid-like streets, are said to be more "walkable", or conducive to active transportation (Saelens, Sallis et al. 2003). The degree of “walkability” of a neighbourhood has commonly been assessed using various versions of the Neighbourhood Walkability Index (Cervero and Kockelman 1997; Frank, Sallis et al. 2009).

Neighbourhoods with features such as greater access to park and recreational facilities, more thorough sidewalk and street-lighting infrastructure and more pleasing aesthetics have been described as more conducive to leisure-time physical activity (Ball, Timperio et al. 2007; Sallis, Bowles et al. 2009). Methods of assessing the degree of neighbourhood friendliness to leisure-time physical activity have often been based on intensity or proximity measures of the previously mentioned leisure-time physical activity correlates.

It should be noted, however, that a causal link between the built environment and physical activity has not been established. Research designs capable of doing so present many challenges in this real world, complex relationship. Furthermore, there are a multitude of factors, ranging from intra-personal to policy level which may moderate the relationship between the built environment and physical activity (Sallis, Owen et al. 2008). However, numerous investigations have examined the correlation between various built environment factors and physical activity rates (Frank, Schmid et al. 2005; Sallis, Bowles et al. 2009; Sallis, Saelens et al. 2009). Research has reported that individuals living in traditional, “walkable” urban neighbourhoods participate in 30 minutes more walking as active transportation per week (Saelens, Sallis et al. 2003). Several investigations have also shown that living in less walkable neighbourhoods is correlated with an increased incidence of overweight and obesity (Ewing, Schmid et al. 2003; Giles-Corti, Macintyre et al. 2003; Saelens, Sallis et al. 2003; Frank, Andresen et al. 2004; Lopez 2004; Frank, Sallis et al. 2006; Sallis, Saelens et al. 2009). However, despite the importance of increasing physical activity levels for cardiovascular disease risk reduction, and the potential capability of the built environment to influence physical activity levels, to-date there has been little investigation into the effects of living in neighbourhoods of varying levels of affordance for physical activity on cardiovascular risk markers that are modifiable with physical activity. Thus, the uniqueness of this investigation lies in its evaluation of cardiovascular risk factors which have not previously been investigated with respect to the built environment. Four indicators were chosen because of their relationships with physical activity. These include body mass index (BMI), waist girth, systolic blood pressure and serum concentration of high-density lipoprotein cholesterol (HDL-C).

Body mass index and waist girth can both be considered indicators of body fatness. Although neither are direct measures of body composition, they are commonly used in cardiovascular health literature (Bei-Fan 2002; Al-Lawati, Barakat et al. 2008; Al-Lawati and Jousilahti 2008; Canoy 2008; Cameron, Sicree et al. 2009; Brenner, Tepylo et al. 2010). Body mass index takes into account the whole body and is an indicatory of general adiposity (i.e., fatness). Waist girth, alternatively, measures abdominal adiposity only and is an indicator of visceral adiposity (i.e., fat tissue which surrounds the internal organs of the body). Total adiposity and abdominal adiposity have both been shown to be independently related to cardiovascular risk (Van Gaal, Mertens et al. 2006). Additionally, each is negatively correlated with levels of physical activity (Hills and Byrne 1998; Lakka and Bouchard 2005).

Systolic blood pressure refers to the peak arterial pressure reached during ventricular contraction of the heart (Saladin 2001). Chronic hypertension, or elevated blood pressure, increases risk of atherogenesis (Young and Libby 2007). Systolic blood pressure, specifically, is predictive of adverse cardiovascular events such as heart attacks and strokes (Young and Libby 2007). Exercise can decrease blood pressure through weight-loss and independent of weight-loss (Ross and Janiszewski 2007; Zamani, Williams et al. 2007). The first may occur because of chronic decreased peripheral vascular resistance (Fagard 2006) and thus has a chronic effect of lowering blood pressure. The latter is termed post-exercise hypotension and has an acute (i.e., temporary) effect of lowering blood pressure.

Dyslipidemia, a condition characterized by abnormal circulating blood lipid levels, is a major risk factor for cardiovascular disease because of its association with the development of atherosclerosis (Young and Libby 2007). One component of measures of dyslipidemia is HDL-C concentration, which is negatively associated with cardiovascular risk (Ridker and Libby 2008). This is because HDL-C can be protective against atherosclerotic plaque development (Young and Libby 2007). Physical activity can improve dyslipidemia in part by increasing production of HDL-C (Enger, Herbjornsen et al. 1977).

The above four cardiovascular risk factors are the focus of the current investigation because of their relationships with physical activity. Specifically, each is affected by an individual's physical activity levels, whereby increased physical activity can decrease the cardiovascular risk associated with each risk factor.

1.1.1 Overview of Thesis Investigation

The purpose of this investigation was to observe rates of several cardiovascular risk markers of adults living in urban environments which varied on level of neighbourhood walkability and access to leisure-time physical activity correlates. Cardiovascular risk was assessed via objective measures of BMI, waist girth, systolic blood pressure and non-fasting HDL-C concentration. Cardiovascular measures were collected by qualified health care professionals (e.g., Canadian Society for Exercise Physiology-Certified Exercise Physiologists® (CSEP-CEPs), registered nurses) on location at a number of communities across British Columbia, Canada. Only participants with urban residential locations within British Columbia, Canada, were used in the analyses (see Appendix B).

To evaluate the built environment we scored each of the participants' neighbourhood using the Neighbourhood Walkability Index (a combination score of three characteristics of environment which support active transportation; land use mix, street connectivity and residential density) and a count of leisure-time physical activity correlates (defined as access to parks and/or water-bodies). Neighbourhoods were defined using postal code centroids as a proxy place of residence, and 750 metre network buffers. Walkability and access to leisure-time physical activity correlates (an intensity measure) were assessed objectively using

Geographical Information System software (ESRI ArcGIS 9.3.1, Redlands, CA), CanMap® Route Logistics Version 2009.4 data from DMTI Spatial Inc. (Markham, ON) (2009) and 2006 Canadian Census data (Statistics Canada 2007). Participants were divided into groups based on their neighbourhood's walkability score percentile relative to rest of the sample (above and below the 50th percentile), and based on the number of leisure-time physical activity correlates within their neighbourhood (categorized as 0, 1-2 or 3+). In addition, participants were classified into high and low income groups based on the median after-tax income of the dissemination area in which their postal code centroid fell. Neighbourhood-level median after-tax income (in Canadian dollars) was obtained from the 2006 Canadian Census (Statistics Canada 2007).

We hypothesized that groups with high neighbourhood walkability would exhibit significantly lower cardiovascular risk (i.e., lower BMI, lower waist girth, lower systolic blood pressure and higher HDL-C concentration) than groups with low neighbourhood walkability. This was based on previous research which found that residents of high walkability neighbourhood exhibited higher rates of objectively measured physical activity than residents of low walkability neighbourhoods (Frank, Schmid et al. 2005; Sallis, Saelens et al. 2009). Previous research by Sallis and colleagues (2009) found that high and low income groups responded similarly to increased walkability. Based on these previous findings, we expected the observation of lower cardiovascular risk associated with higher neighbourhood levels of walkability to be present for both high and low income groups. However, we hypothesized that high neighbourhood income groups would exhibit significantly lower cardiovascular risk than low neighbourhood income groups with the same level of walkability, as similar observations have been made in the past (Sallis, Saelens et al. 2009).

Cardiovascular risk was also hypothesized to be lower in groups with greater numbers of neighbourhood leisure-time physical activity correlates. This hypothesis was made based on previous findings that increased access to park and recreational facilities, as well as water bodies, is associated with more physical activity (Ball, Timperio et al. 2007; Sallis, Bowles et al.

2009). Again, we expected the observation of lower risk among residents of areas with more leisure-time physical activity correlates to be present for both high and low income groups. However, higher income groups were again expected to exhibit lower cardiovascular risk than low income groups within the same number of leisure-time physical activity correlates.

1.1.2 Overview of the Document

This thesis is comprised of three chapters. The first chapter includes an introduction to the topic of the research, an overview of the thesis investigation, an overview of the thesis document, a review of the relevant literature, and an overview of the rationale for the investigation undertaken as a component of this thesis. The findings from this investigation have been compiled into a manuscript titled “Cardiovascular risk factors, neighbourhood walkability and leisure time physical activity correlates”, which is presented in Chapter 2 of this document. The purpose of this manuscript is to examine, using a cross-sectional design, the relationship between one’s neighbourhood’s built environment and several physical activity-moderated cardiovascular risk factors. The conclusion to the thesis document is presented in Chapter 3. Chapter 4 contains the list of references used in this document. Appendix A and Appendix B contain the certificate of ethical approval and a list of residential locations of participants, respectively.

1.2 Extended Review of the Literature

1.2.1 Cardiovascular Disease

The term cardiovascular disease refers to many diseases of the heart and vessels, which are alternatively categorized as heart disease. These diseases predominantly have an underlying cause of atherosclerosis (Crespo 1999). Atherosclerosis is a chronic inflammatory condition characterized by the hardening of the arteries through the deposition of plaque (Young and Libby 2007). Atherosclerosis can be initiated by injury to the arterial endothelium caused by chemical irritants or haemodynamic stress (Young and Libby 2007). Complications of atherosclerotic plaque include acute restriction of blood flow or diminished vessel wall integrity and can have varying clinical outcomes in different organ systems (e.g., myocardial infarction, stroke, peripheral vascular disease) (Young and Libby 2007).

The burden of cardiovascular disease in Canada is significant. According to the most recent 2005 summary on the causes of mortality by Statistics Canada cardiovascular diseases killed more than 71,000 individuals. This accounted for 30% of all deaths in Canadian males and 31% of all female deaths. Additionally, cardiovascular disease is still the greatest contributor to both direct and indirect health costs in Canada (Heart and Stroke Foundation of Canada 2003; CHHS-AP Steering Committee 2009; Statistics Canada 2009). In the province of British Columbia specifically, major cardiovascular diseases accounted for over 9,000 deaths in 2005. Primary prevention has been identified as an important and cost effective means of decreasing the burden of cardiovascular disease in British Columbia and Canada. Thus, investigating environmental correlates of cardiovascular risk is warranted.

There is significant evidence supporting the link between physical inactivity and most global chronic disease (Roberts and Barnard 2005; Statistics Canada 2009). Some hypothesize that this is because humans have evolved to be physically active; therefore, an inactive lifestyle leads to malfunctioning of the body (Booth, Chakravarthy et al. 2002). This relationship is demonstrated clearly for cardiovascular disease. For example, it has been estimated that if every Canadian met current recommendations for daily physical activity, 33% of all deaths related to coronary heart disease, 25% of deaths related to stroke, 20% of deaths related to type 2 diabetes, and 20% of deaths related to hypertension could be prevented (Katzmarzyk, Gledhill et al. 2000; Heart and Stroke Foundation of Canada 2003; Katzmarzyk, Church et al. 2004; Warburton, Nicol et al. 2006; Warburton, Katzmarzyk et al. 2007).

The current physical activity guidelines in Canada recommend 60 minutes of daily physical activity, or 30 minutes of moderate or vigorous exercise on at least 4 days of the week. According to the Canadian Community Health Survey of 2005, 57% of British Columbia residents (age 20+) were classified as active based on the Canadian physical activity guidelines versus 49% of all adults (age 20+) from a national perspective (Canadian Fitness and Lifestyle Research Institute 2005; Statistics Canada 2005; Warburton, Katzmarzyk et al. 2007). More recently, evidence has shown that the accumulation of at least 150-180 minutes per week of moderate intensity physical activity, or 90 minutes per week of vigorous intensity physical activity reduces the risk of all-cause mortality by 30%, as well as the incidence of several chronic diseases including cardiovascular disease, stroke, and hypertension. In addition, there is evidence suggesting that this total amount of physical activity can be accumulated in bouts as short as 10 minutes and that the benefits are greatest if activity is distributed over the week (Kesaniemi, Riddoch et al. 2010; Warburton, Charlesworth et al. 2010). Apart from increasing the total physical activity levels of most Canadians, the importance of decreasing total time spent in sedentary behaviour (i.e., sitting specifically) has been noted as well, as total sedentary time has been associated with cardio-metabolic risk independent of central adiposity (Thorp, Healy et al. 2010). Canadians, generally, would benefit from increased physical activity and decreased sedentary behaviour.

1.2.1.1 Cardiovascular Risk Factors

Cardiovascular disease risk factors are categorized as either modifiable (a characteristic we can change) or non-modifiable (a characteristic we cannot change). The following section briefly describes modifiable and non-modifiable risk factors for cardiovascular disease.

1.2.1.1.1 Non-modifiable Risk Factors

Sex and Menopausal Status: For females, menopause is associated with a drastic climb in cardiovascular risk (Welty 2004). In fact, one’s age at natural menopause is predictive of cardiovascular mortality (Jansen, Temme et al. 2002). Males are at a greater risk of cardiovascular disease earlier in life, although rates among females exceed those seen in males after menopause. This is attributed, in part, to the protective (potentially atheroprotective) effect of endogenous estrogens (Welty 2004; Mendelsohn and Karas 2005) but may also be related to differing levels of HDL-C between sexes and differential protective effects (Fan and Dwyer 2007).

With menopause comes a change in several cardiovascular risk factors. Specifically, menopause is associated with plasma lipid composition changes, such as increases in total cholesterol, low density lipoprotein cholesterol, and triglycerides (Welty 2004). The prevalence of hypertension increases dramatically after menopause also, and actually exceeds levels seen in males of the same age (Victor and Kaplan 2008). As males never benefit from the protective influence of estrogens they are susceptible to atherogenesis throughout life.

Ethnicity: There are significant differences in the prevalence of some cardiovascular risk factors as a function of ethnicity (Kurian and Cardarelli 2007). For instance, a recent review of racial and ethnic differences in cardiovascular disease risk factors rates found that hypertension and diabetes were significantly more common among African American compared to Caucasian people in the United States (Kurian and Cardarelli 2007). Some differences in risk factor rates seem to be related to lifestyle and dietary choices. However, others are more likely to be inherent differences in physiology, such as increased risk at lower BMIs and waist girths in Asian populations as compared to Caucasian populations (Kurian and Cardarelli 2007). Additionally, cultural, socioeconomic, and biologic differences may all play into differing treatment and outcome rates (Morrissey, Giacovelli et al. 2007). Because the mechanisms behind some racial and ethnic health disparities are not yet understood there is significantly more research needed in this area.

Advanced Age: Age itself does not necessarily cause increased risk for cardiovascular disease. However, older individuals are more likely to exhibit other risk factors, such as elevated blood lipid levels, glucose intolerance and excess adiposity and hypertension (McArdle, Katch et al. 2001; Victor and Kaplan 2008). Additionally, since degenerative changes in the vessel walls progress with time, advanced age can be associated with further progressed conditions. Age can be considered a measure of exposure time, rather than a causal risk factor (Cooney, Dudina et al. 2009).

Familiar History of Cardiovascular Disease: Cardiovascular disease risk appears to have one or more genetic components which make an individual more likely to develop cardiovascular disease. Familiar history as a risk factor is defined as having a history of cardiovascular disease among a first-degree relative, before age 55 for a male relative or before age 65 for a female relative (Young and Libby 2007). Having a familiar history of cardiovascular disease, based on this definition, has been shown to increase the 10-year risk two fold (McPherson, Frohlich et al. 2006). Additionally, parental cardiovascular disease has been shown to independently predict cardiovascular disease in middle-aged adults (Lloyd-Jones, Nam et al. 2004).

1.2.1.1.2 Modifiable Risk Factors

Hypertension: Hypertension (or elevated blood pressure) is defined as resting blood pressure at or above 140/90 mmHg. One third of the world's population is expected to be hypertensive by the year 2025. This is in part due to our aging population, but can also be linked to the growing obesity epidemic (Victor and Kaplan 2008). Hypertension accelerates atherosclerosis. This happens because of increased haemodynamic stress, the contribution of hypertension to inflammation, and injuries to the vascular endothelium, which subsequently increases the permeability of the vessel wall to lipoproteins (Young and Libby 2007). Increasing severity of hypertension (higher values of either systolic or diastolic blood pressure) is associated with increased risk of atherogenesis. Systolic pressure, however, better predicts adverse events than diastolic pressure (Young and Libby 2007). In the vast majority of hypertension cases blood pressure is elevated for unidentifiable reasons. This kind of hypertension is called essential hypertension (Zamani, Williams et al. 2007). What we know about essential hypertension is that it is highly correlated with obesity, central obesity in particular, and when individuals lose significant amounts of weight, their systolic blood pressure generally lowers.

Exercise also decreases blood pressure independent of weight loss. This occurs through post-exercise hypotension (i.e., after every bout of exercise blood pressure is acutely lowered (Zamani, Williams et al. 2007). This effect generally occurs after at least moderate intensity exercise, and can last up to 16 hours post exercise. This means that individuals who are generally hypertensive can spend a majority of their day at lower blood pressures if they are physically active at a sufficient level. The amount of decrease in both systolic and diastolic blood pressure is higher in hypertensive individuals, with systolic decreases of 18-20 mmHg and diastolic decreases of 7-9 mmHg in individuals with stage one hypertension (Thompson, Crouse et al. 2001).

To prevent chronic hypertension the Canadian Hypertension Education Program recommends a combination of eating a healthy diet including low dietary sodium and moderate alcohol consumption, regularly being physical active and limiting stress where possible (Campbell, Khan et al. 2009). Treating hypertension is often a combination of lifestyle changes based on the above recommendations as well as pharmacotherapy.

<u>Smoking</u>: Cigarette smoking, and even exposure to second hand smoke, increases one's risk of developing atherosclerosis and ischemic heart disease (Ambrose and Barua 2004; Young and Libby 2007). There are numerous mechanisms by which cigarette smoking potentially increases cardiovascular risk, with free-radical mediated oxidative stress potentially playing a central role (Ambrose and Barua 2004). Cigarette smoking is thought to increase blood pressure, decrease sympathetic tone, increase oxidation of low-density lipoprotein cholesterol and cause endothelial dysfunction (Van Gaal, Mertens et al. 2006). Risk increases with heavier smoking. However, light smoking and second hand smoke also put people at an elevated risk (Young and Libby 2007). Smoking cessation can have very positive effects on cardiovascular risk; smoking reduction, however, only seems to have a marginal effect (Godtfredsen, Holst et al. 2002).

Dyslipidemia: Dyslipidemia, or abnormal circulating lipid levels, is a major risk factor for cardiovascular disease because of its association with the development of atherosclerosis (Young and Libby 2007). Elevated levels of low density lipoprotein cholesterol (LDL-C) in particular are associated with an increased incidence of atherosclerosis and coronary artery disease. This is because of the ability of this type of lipoprotein to accumulate in the sub-endothelial space of the arterial wall and initiate atherosclerotic lesions (Van Gaal, Mertens et al. 2006; Young and Libby 2007).

High-density lipoprotein cholesterol, alternatively, can be protective against atherosclerotic plaque (Fan and Dwyer 2007). This is thought to be explained by the process of reverse cholesterol transport, or the ability of HDL particles to transport cholesterol away from peripheral tissues back to the liver for disposal (Young and Libby 2007). The concentration of HDL-C within the blood has an inverse and apparently independent association with coronary artery disease and ischemic stroke (Simons, McCallum et al. 1998; Maron 2000; Fan and Dwyer 2007). A ratio of total cholesterol (TC) to HDL-C is a very strong predictor of cardiovascular risk (Ridker and Libby 2008). A ratio greater than 4.5 is associated with high risk of cardiovascular disease (McArdle, Katch et al. 2001). To improve cholesterol ratios (TC/HDL cholesterol), there needs to be a reduction in TC and/or an increase in HDL-C. Low-density lipoprotein cholesterol (a component of TC) levels can be lowered by means of diet modifications (such as decreasing consumption of saturated fats) or via medication (e.g., using a class of drugs called statins which decrease cholesterol production in the liver or resins which decrease absorption of cholesterol in the intestines). These same medications are also able to increase levels of HDL-C (statins significantly more so than resins). High-density lipoprotein cholesterol levels are influenced by genetics, can be increased through increased dietary consumption of unsaturated fats such as omega-3 and omega-6 fatty acids, or with moderate daily alcohol consumption (Hardman 1999; McArdle, Katch et al. 2001).

Being physically active can also improve dyslipidemia by increasing production of HDL-C and decreasing triglycerides (Leon, Rice et al. 2000; Van Gaal, Mertens et al. 2006). A single bout of exercise is generally insufficient to exert change on HDL-C levels. For example, research has shown that healthy trained men had to expend, on average, 1100 kcal in one session to acutely elevate HDL-C levels (Ferguson, Alderson et al. 1998). A recent review of the effects of aerobic exercise on HDL-C levels also showed that regular aerobic exercise (a minimum of 900 kcal of energy expenditure or 120 minutes per week) only modestly increased HDL-C. Specifically, the meta-analysis found a significant association between exercise duration and increased HDL-C, where every 10 minute prolongation of aerobic exercise per session was associated with an approximate 0.036 mmol/L increase in HDL-C concentration. The affect was stronger for individuals with lower BMI and higher total cholesterol scores. Non-significant associations were found for exercise intensity and frequency (Kodama, Tanaka et al. 2007). As such, endurance athletes often exhibit relatively high HDL-C concentrations. Total cholesterol can also be lowered by being physically active, specifically by lowering triglyceride levels (Kodama, Tanaka et al. 2007; Young and Libby 2007).

Overweight and Obesity: Being overweight or obese increases one's risk of developing cardiovascular disease independent of other common cardiovascular risk factors. This risk, which has been attributed to changes in cytokines and inflammatory markers as well as increased risk of insulin resistance with obesity, can be attenuated with physical activity, dietary changes, and subsequent weight loss (Van Gaal, Mertens et al. 2006).

The location of adipose tissue appears to radically alter the cardiovascular risk associated with adiposity (Van Gaal, Mertens et al. 2006). Metabolic characteristics of adipose tissue vary depending on its anatomical location, with visceral fat posing a greater cardiovascular risk than subcutaneous fat (Canoy 2008). Abdominal adiposity is made up of a combination of subcutaneous and visceral fat mass. There is still uncertainty regarding the mechanisms behind visceral adipose tissue being related to greater atherogenic risk (Canoy 2008). However, the fact that it is has been commonly accepted. This point is evidenced by a recent physical activity intervention which showed that cardiometabolic health can be improved through decreases in general adiposity and waist circumference without any significant total weight loss (Lee, Kuk et al. 2005). Accordingly, visceral fat has been identified as a primary target of strategies to reduce obesity-related morbidity and mortality (Kuk, Katzmarzyk et al. 2006).

Measuring obesity and specifically fat distribution can provide important information about an individual's cardiovascular risk. There are several ways in which body fatness is commonly measured for estimating cardiovascular risk, two of which are waist girth measurement and BMI. Waist girth specifically measures abdominal adiposity (i.e., the circumference in centimetres of the abdominal region) and is an indicator of visceral adiposity. Body mass index takes into account the whole body. It is the ratio of weight in kilograms to height in metres squared (kg/m^2). It is used to categorize individuals in a range from underweight to severely obese. However, measuring BMI does not provide information about fat distribution.

There are currently specific BMI classifications that have been validated for people of Caucasian ancestry only; however, other groups are still stratified using the Caucasian classification system. It was recognized that cut-offs specific to each ethnicity were required because of data that showed that BMI and waist girth cut-offs derived from primarily Caucasian populations often underestimated the cardiometabolic risk at given BMIs for other ethnicities (Razak, Anand et al. 2007). Waist girth recommendations are 94 and 80 centimetres and below for Caucasian males and females respectively. People ethnic to Europe, Sub-Saharan Africa, the Eastern Mediterranean and the Middle East are all categorized based on these cut-offs. There are new waist girth cut-offs for people of Asian descent. These cut-offs (validated for people of South Asian, Chinese and Japanese descent) are for 90 centimetres and below for males and 80 centimetres and below for females. These cut-offs are currently used for people of South and Central American descent as well (International Diabetes Federation 2006; Razak, Anand et al. 2007). For BMI, traditional, Caucasian validated categories define being overweight as having a BMI between 25.0 and 29.9 kg/m^2, and being obese is defined as having a BMI over 30.0 kg/m^2 (Krauss 2008). There are not yet validated BMI cut-offs for other ethnicities, although some preliminary work has been done towards creating them (Razak, Anand et al. 2007).

Although obesity and overweight status are a product of more than just energy balance, (e.g., metabolism and genetics) adiposity can certainly be decreased through physical activity. Physical activity leads to favourable body composition changes. In fact there is generally an inverse relationship between physical activity and body mass, and a greater inverse relationship between physical activity and fat mass. Additionally, visceral and total body fat can both be reduced through regular physical activity without any changes in maximal aerobic power (Hills and Byrne 1998). This shows that high intensity physical activity is not necessarily required in order to lose fat mass and weight and to improve body composition. In fact, results of a recently published 15-year longitudinal study of walking, which is often performed as a relatively low intensity form of physical activity, showed that walking throughout adulthood can attenuate the progressive weight gain that most adults experience (Gordon-Larsen, Hou et al. 2009).

Diabetes: Diabetes, and associated insulin resistance and hyperglycemia, are major risk factors for cardiovascular disease. Specifically, having diabetes has been shown to confer an equivalent cardiovascular risk to aging 15 years (Booth, Kapral et al. 2006). Another investigation has shown that being diabetic attributes as much additional risk as previously having experienced a myocardial infarction (Nesto 2008).

The elevated risk associated with having diabetes is in part due to clustering of traditional cardiovascular risk factors such as hypertension, dyslipidemia, and obesity. However, this alone does not account for all of the increased risk. Rather, factors such as having lipid-rich atherosclerotic plaque (which is more susceptible to rupturing) (Moreno, Murcia et al. 2000), enhanced vascular inflammatory reaction, and other factors which contribute to thrombus formation make diabetic individuals at greater risk of cardiovascular disease morbidity and mortality. This is particularly because of greater atherosclerotic burden (Nesto 2008; Ridker and Libby 2008).

Adiposity is the leading risk factor for diabetes, and as such, avoiding weight gain in adulthood has been described as the cornerstone of diabetes prevention (Schulze and Hu 2005). This too speaks to the important role that being physically active can play in minimizing cardiovascular risk.

Physical Activity: Physical activity is associated with reduced risk of cardiovascular mortality (Wannamethee and Shaper 2001; Warburton, Nicol et al. 2006). As mentioned previously, this can be attributed to improvements in cardiovascular risk factors that come with being physically active, such as lower blood pressure, improved glucose tolerance, improvements in one's lipid profile (lowering triglycerides and raising HDL-C) and decreased risk of both central and generalized obesity (Young and Libby 2007; Prasad and Das 2009). Additionally, being physically active contributes to improved myocardial efficiency, improved endothelial function, enhanced parasympathetic autonomic tone and enhanced fibrinolysis (Armstrong 2004; Warburton, Nicol et al. 2006; Prasad and Das 2009). Improved exercise capacity (cardiovascular fitness) leads to decreased myocardial oxygen demand at given workloads, meaning that levels of both cardiovascular disease mortality and symptoms are lowered when someone becomes more fit. This effect is strongest when a individual who leads a sedentary lifestyle becomes active (Erikssen 2001; Prasad and Das 2009).

Research shows that physical activity does not need to be high intensity to decrease cardiovascular risk. Support for the protective effect of moderate physical activity against cardiovascular disease is accumulating (Warburton, Nicol et al. 2006; Warburton, Charlesworth et al. 2010). A review of walking for cardiovascular disease prevention in both males and females concluded that walking has a protective effect across the lifespan. Risk was shown to decrease with increasing duration, distance, and pace of walking (Boone-Heinonen, Evenson et al. 2009). Another investigation, studying females only, found that walking briskly for 30 minutes five times per week led to a 30% reduction in vascular events over a 3.5 yr follow-up. This effect was still present after adjusting for BMI, age, and ethnicity (Manson, Greenland et al. 2002; Boone-Heinonen, Evenson et al. 2009). A similar study investigating cardiovascular disease in males, this time with 30 minutes of walking per day, found an 18% reduction in coronary risk (Tanasescu, Leitzmann et al. 2002). An inverse relationship between walking and cardiovascular disease has been shown with as little walking as ten or more blocks per day (where 12 blocks equalled one mile) (Sesso, Paffenbarger et al. 1999). These findings support the idea that even light and moderate physical activity can substantially decrease cardiovascular risk. This finding is important given our highly sedentary and aging population.

1.2.2 The Built Environment

The built environment is a construct of the field of urban planning, and refers to the physical form of communities. As previously stated, it is a multidimensional concept, which by definition, is comprised of urban design (i.e., the arrangement and appearance of physical elements), land use (i.e., the distribution of activities across space), the transportation system and human activity within the environment (Handy, Boarnet et al. 2002). In addition, the built environment can refer to both human made (e.g., buildings, transportation systems) and natural features (e.g., vegetation, vistas, water-bodies) (Frank and Kavage 2009).

1.2.2.1 Urban versus Rural Settings

Urban areas in Canada are defined as having a population of at least 1000 people and having a population density of no less than 400 persons per square kilometre (Statistics Canada 2006). Alternatively, a rural area in Canada is defined as all areas outside of urban areas (Statistics Canada 2006). There are many differences in the built environment between urban and rural areas, not the least being that typically the built environment dominates urban areas much more so than it does rural areas (Veitch 2009). As such, it could be argued that correlates of physical activity in these two types of environments might vary drastically (Saelens, Sallis et al. 2003). In addition to the conceptual limitations of using measures which were developed for the study of urban areas when studying rural areas, there are also limitations such as the availability and quality of data pertaining to rural areas. This is not to say that research investigating methods of increasing physical activity among residents of rural environment is not constituted. On the contrary, a recent investigation identified rural residents of United States as less likely to meet physical activity recommendations compared with urban residents (Parks, Housemann et al. 2003). The current investigation, however, is focused on urban settings in particular.

1.2.2.2 Explaining Physical Activity Behaviour from an Urban Planning Perspective

The field of urban planning, and more specifically the subfields of urban design and transportation planning, have long been interested in the relationship between the built environment and human behaviour (Handy, Boarnet et al. 2002). Originally this interest stemmed from needs to predict and account for automobile traffic and to design environments which supported active transportation (Sallis, Frank et al. 2004; Brownson, Hoehner et al. 2009). However, this interest has only more recently extended to the influence of the built environment on health. As cardiovascular health, in particular, is affected by total physical activity (i.e., not just transportation related activity) (Weller and Corey 1998) the effect on the built environment on total physical activity is now of interest. Thus the emerging body of research, concerning the influence of the built environment on total physical activity, extends the concept of physical activity from one focused primarily on active transportation to include several additional classifications of physical activity. These classifications include occupational physical activity (i.e., related to work), household physical activity (e.g., related to cleaning, physical movement within the home environment) and recreational (or leisure-time) physical activity (e.g., sport, play, purposeful exercise) (Sallis, Cervero et al. 2006). Conceptual models required to explain physical activity behaviour, within the urban planning field, have thus had to expand as well. The staff and national advisory committee of Active Living Research, an American national programme established by the Robert Wood Johnson Foundation, developed a model in which they attempt to explain the multiple levels of environmental influence on total physical activity, with each of the above sub-classifications of physical activity being addressed (Sallis, Cervero et al. 2006). The model is ecological in nature, meaning that it describes "people's interactions with their physical and sociocultural surroundings" (Sallis, Cervero et al. 2006, p.299). The model encompasses a range of variables which are hypothesized to be determinants of physical activity behaviour, from intrapersonal variables (e.g., psychological, biological) to objective environmental variables (e.g., land use zoning codes, transportation systems, public recreational facilities). Within this model, an individual's neighbourhood (including pedestrian and cycling facilities, aesthetics, traffic, walkability, parking and transit) influences recreational and transportation related physical activity. Generally, these two types of physical activity behaviour demonstrate distinct correlates to the neighbourhood built environment (Li, Harmer et al. 2009).

1.2.2.2.1 Active Transportation

Active transportation is considered a utilitarian form of physical activity, meaning that the physical activity has a useful function such as to reach a specific destination (Handy, Boarnet et al. 2002). Specifically, active transportation is performed for the purpose of getting from one place to another, and the physical activity that is accumulated during the behaviour is considered an additional benefit. The most commonly exhibited modes of active transportation are walking and cycling (Transport Canada 2006). Therefore, walking and cycling have often been the focus of the majority of research investigating the affect of the built environment on active transportation.

Promoting active transportation has long been a goal of urban planners, and thus research methods concerning this behavioural class of physical activity and built environment correlates are relatively developed. There are several built environment characteristics, operationalized in various objective ways, which are commonly included in investigations of the built environment's influence on active transportation. The most commonly included measures are residential density, land use mix (or diversity) and street connectivity (also known as street pattern, or pedestrian-oriented design) (Sallis 2009). Additionally there are a handful of less commonly employed measures including, but not limited to, retail floor area ratio (a relatively new addition and likely to be employed extensively in future investigations, specifically those using the Neighbourhood Walkability Index), sidewalk coverage, vehicular traffic, indicators of slope, street lighting, and public transit (Brownson, Hoehner et al. 2009).

Street Connectivity: Street connectivity is used to capture the pattern of streets within an environment and speaks to the variety and directness of potential active transportation routes (Frank, Schmid et al. 2005; Brownson, Hoehner et al. 2009). It is most commonly operationalized as the number of intersections (3-way or more) per unit of area within the area of interest (Frank, Schmid et al. 2005). Alternative methods of operationalizing connectivity have often included measures of block length and size (Feng, Glass et al. 2010).

Residential Density: Residential density is employed as a component of the concept of proximity. Proximity addresses the number and variety of destinations that can be accessed via active transportation. Residential density is theoretically related to active transportation as areas of higher density are likely to be able to support a greater variety and number of businesses (Handy, Boarnet et al. 2002; Frank, Schmid et al. 2005; Feng, Glass et al. 2010). Census data is generally used to assess residential density. Generally, dwelling counts and spatial area (i.e., in Canada: dissemination area or block, in the United States: census tracts or census blocks) are used to approximate the residential density of a neighbourhood. Some investigations have alternatively employed population or employment density (Feng, Glass et al. 2010).

Land Use Mix: Land use mix, like residential density, is a component of the concept of proximity. It speaks to the diversity of land uses within the environment. The amount of land use mix influences distances between destinations and, subsequently, travel mode choice (Feng, Glass et al. 2010). Methods of defining and measuring this variable have differed across investigations, partially because availability of land-use data varies across geographical areas

(Brownson, Hoehner et al. 2009; Feng, Glass et al. 2010). Land use mix has been defined in some previous investigations as the evenness of residential, commercial and office development (Frank, Schmid et al. 2005; Frank, Saelens et al. 2007). Regardless of the categories of land use employed, land use mix has often been calculated using the following entropy index:

$$\text{Land use mix} = -\sum_{i=1}^{n}\left(\frac{p_i \times \ln p_i}{\ln n}\right)$$

where, p_i is the proportion of total neighbourhood buffer area that is categorized as land use i, and n is the number of the relevant land uses present within the specific neighbourhood buffer (Frank, Schmid et al. 2005; Frank, Saelens et al. 2007). Using the above equation results in values ranging from 0 and 1, with a score of 0 indicating that only one land use (e.g., residential) is present, and a score of 1 indicating that there is an even distribution of all possible land uses (Leslie, Coffee et al. 2007).

Others have alternatively calculated land use mix as a ratio of residential to non-residential usage, the percent of non-residential uses within a given area, mean entropy indices, or dissimilarity indices (Feng, Glass et al. 2010).

<u>Retail Floor Area Ratio</u>: Retail floor area ratio is an indicator of how pedestrian-oriented businesses are designed (i.e., whether the retail area design affords pedestrian access or vehicular access). It is defined as the ratio of building area to land area within a land parcel. Lower ratios indicate that substantial space is likely being used for parking and therefore the area is not likely to cater to pedestrians (Brownson, Hoehner et al. 2009).

<u>The Neighbourhood Walkability Index</u>: The Neighbourhood Walkability Index is a composite scoring system which has been developed to objectively measure the “walkability” (i.e., friendliness to active transportation) of the built environment around one’s home. The index combines several of the above built environment constructs into a single composite index. The

index was adapted to its current form by Frank and colleagues (2009), and stems from a body of research investigating neighbourhood accessibility, transportation alternatives, and mode choice (Cervero and Kockelman 1997; Cervero and Duncan 2003; Krizek 2003; Levine, Inam et al. 2005; Frank, Sallis et al. 2009). It is used as a composite score so as to decrease the affect of spatial collinearity (Brownson, Hoehner et al. 2009; Frank, Sallis et al. 2009). Neighbourhoods low on walkability are said to increase car dependence and decrease the use of active transportation. Construct validity of the Neighbourhood Walkability Index (including street connectivity, land use mix, residential density and retail floor area ratio) was examined as a portion of the Neighbourhood Quality of Life Study (NQLS). Results of an examination of 2-day travel diaries of individuals living within neighbourhoods of varying walkability in King County, Washington, showed that those living in the highest walkability decile reported 6.45 times more walking trips and 52% less vehicle miles travelled when compared to those individuals living in neighbourhoods within the lowest walkability decile (Frank, Sallis et al. 2009). The Neighbourhood Walkability Index has been adapted by several research groups across multiple countries and continents, and its computation has varied slightly across groups and with advancements in knowledge (Feng, Glass et al. 2010).

1.2.2.2.2 Leisure-time Physical Activity

Leisure-time physical activity refers to that which is performed either for enjoyment or purposeful exercise. It is recreational physical activity, and as the name suggests, it is accomplished during discretionary, or leisure time (Frank, Engelke et al. 2003). Compared to active transportation the range of common forms of leisure-time physical activity is large. For example, leisure-time physical activity could include anything from light-intensity walking to a high-intensity team sport event. Logically, the range of equipment and facilities required to take part in leisure-time physical activity pursuits can vary substantially as well.

Certain aspects of the built environment are commonly investigated as correlates of leisure-time physical activity. These include, but are not limited to, sidewalks (quality, width, coverage), neighbourhood aesthetics, vehicular traffic, crime rates, park and recreation facilities, access to coastal locations, slope and green space (Hillsdon, Panter et al. 2006; McGinn, Evenson et al. 2008; Brownson, Hoehner et al. 2009; Potestio, Patel et al. 2009). In addition, the Neighbourhood Walkability Index, originally designed to explain active transportation, has been shown to be related to leisure-time walking (Sallis, Saelens et al. 2009).

The methods of measuring potential leisure-time physical activity correlates within the built environment vary substantially according to the correlate of interest and are much less developed than active transportation measurement methods. Brownson and colleagues (2009), in a review of common methodology employed to study the built environment – physical activity relationship, categorized leisure-time physical activity correlate measurement techniques into accessibility and intensity measures. For example, access to recreational facilities could be operationalized as the distance to the nearest facility (as the crow flies, or via the street network), or as the number of recreational facilities per area. The vast array of methodology which has been used in this body of research has been noted as a limitation because of the subsequent inability to estimate pooled effects (Feng, Glass et al. 2010).

1.2.2.3 Methodological Considerations

1.2.2.3.1 Objective versus Perceived Measurement of the Built Environment

Perceived measures (i.e., questionnaire based) are the most practical method of obtaining detailed observations of the built environment (Brownson, Hoehner et al. 2009). For example, using perceived measures one can assess fine points such as the quality of sidewalk surfaces or the aesthetic quality of local parks. However, collecting this type of data is somewhat subjective and time consuming making it difficult to conduct on a large scale. Comparatively, investigations using objective measures of the built environment may only be able to detect the presence or absence of roads and parks, but can include thousands more participants, across a greater number of neighbourhoods (Brownson, Hoehner et al. 2009).

Objectively evaluating the built environment on a large scale requires the use of Geographical Information Systems (GIS), spatial referenced data (e.g., road network data, land use data) and census data. The validity of these measures depends on the validity of the data used, and the extent to which those data reflect the real-world environment being studied (Brownson, Hoehner et al. 2009). This in turn is dependent on how recently, how often, and how thoroughly the geographical data are updated. Data sources across investigations differ because different geographical areas have been investigated (Brownson, Hoehner et al. 2009). Components of the built environment that are explored also vary across investigations (Brownson, Hoehner et al. 2009). Determining which components to include depends on numerous factors. For example, the behavioural and literal forms of physical activity of interest, the target age group, and the data available for the location. To-date there has been many investigations that have explored various combinations of the above factors at numerous geographical scales using perceived environmental data, objective environmental data, or alternatively, a combination of the two (Brownson, Hoehner et al. 2009).

Using perceived data has brought up the issue of individual perception versus the reality of built environment characteristics. There has been investigation into the agreement between perceived and objective measures of the built environment, with several studies reporting little agreement (McGinn, Evenson et al. 2007; Lackey and Kaczynski 2009; Prins, Oenema et al. 2009) and others reporting fair agreement (Gebel, Bauman et al. 2009). It appears that objective and perceived built environment data may differ not only on the method of data collection, but also on the construct which is being measured (Townshend and Lake 2009). There is some evidence that combining these two types of measures may best explain physical activity behaviour within the built environment (McGinn, Evenson et al. 2007). Others have suggested that perception of the built environment may be more strongly correlated to behaviour than objective measures. The agreement between the reality of the built environment and perception of it may well be moderated by individual-level factors (Gebel, Bauman et al. 2009). Methods for perceived and objective measurement of the built environment are both still being refined (Brownson, Hoehner et al. 2009).

1.2.2.3.2 Defining Neighbourhoods

The body of research which has attempted to measure the built environment in relation to physical activity and health has been negatively affected by its wide range of methodological approaches. Methods employed to spatially define the research areas (often attempting to define a participant's neighbourhood) have most commonly involved either using pre-existing administrative boundaries (e.g., census tracts, counties) or geographic buffers (e.g., circular radius, street network based). Investigations employing the Neighbourhood Walkability Index have often used the latter, geographic buffers, to define participant neighbourhoods. There are differing methods of defining this buffer, specifically circular and network buffers. The circular buffer defines the neighbourhood as a circle of a given radius around the participant's place of residence. The validity of this method may decrease in areas with more natural features, such as rivers and cliffs, which may influence community layout (Oliver, Schuurman et al. 2007). Network buffers similarly encompass an area around an individual's place of residence; however, they only follow roads and trails. Network buffers, compared to circular buffers, have shown greater association with walking and have been hypothesized to more accurately capture the built environment as it is experienced by pedestrians (Oliver, Schuurman et al. 2007).

1.2.2.4 Previous Findings

1.2.2.4.1 Built Environment Correlation with Physical Activity

Physical activity outcome measures within this area of investigation can be divided several ways: by the specific behavioural group (or domain) of physical activity examined (i.e., active transportation and/or leisure-time physical activity), the form of physical activity examined (e.g., walking, cycling), or the type of data collected (i.e., subjective (self-report via questionnaires or telephone surveys) versus objective (accelerometers)). Similarly, built environment outcome measures can be divided into perceived and objective measures, as well as individual and composite scores. Given all possible combinations of the above, there are a large number of investigations into the relationship between the built environment and physical activity which have been performed. Even still, although there appears to be a relationship between the built environment and physical activity, the most important variables within this complex relationship are not entirely clear (Townshend and Lake 2009).

Overall it seems that there is consensus that the perceived and actual built environment both influence physical activity levels and that regardless of progress in measurement techniques for objectively examining the built environment, perceived built environment measures are still important (McGinn, Evenson et al. 2007). Alternatively, in the case of physical activity, objective measures are considered generally to have greater validity. However, objective measures of total physical activity are hard to administer at the scale required for investigations of the built environment. Furthermore, investigations using objective measures of physical activity benefit from being able to provide appropriate distinction between various types of physical activity behaviour. Accomplishing this requires not only the use of such technology as accelerometers, but also instruments such as travel diaries, geographical positioning systems or specifically designed questionnaires which can still be somewhat subjective (e.g., the International Physical Activity Questionnaire).

Self-Reported Physical Activity: Several investigations have shown increased self-report physical activity in areas identified as ‘activity friendly’. Most notably, an investigation by Sallis and colleagues (2009), which was entirely survey based (using both the International Physical Activity Questionnaire and several items from the Physical Activity Neighbourhood Environment Survey), found that the most activity-supportive neighbourhoods, compared with neighbourhoods with no supportive attributes, had 100% higher rates of residents accumulating sufficient physical activity. However, a systematic review of the agreement between self-report and directly measured (objective) physical activity found agreement to be low (Prince, Adamo et al. 2008). Thus, objective measures of physical activity are required to better understand this relationship.

Objectively Measured Physical Activity: Few investigations have examined the influence of the built environment on objectively measured physical activity. In two known investigations a version of the Neighbourhood Walkability Index was used to assess objectively built environment characteristics (Frank, Schmid et al. 2005; Sallis, Saelens et al. 2009). The most recent investigation included a measure of retail floor area ratio within the index. Both employed accelerometers set at one minute epochs.

Frank and colleagues (2005) collected two days of accelerometry data per participant and used average minutes per day of moderate intensity physical activity as an outcome measure. Their findings showed that land use mix and intersection density, within a one kilometre network-based buffer from participants' homes, and residential density at a census block group scale, were positively related to average minutes of moderate physical activity per day. The Neighbourhood Walkability Index (a combination of the three aforementioned variables) explained a significant amount of additional variance after controlling for sociodemographic variables. Furthermore, those living in neighbourhoods in the highest walkability quartile were 2.4 times more likely to accumulate thirty or more minutes per day of moderate physical activity than those living in neighbourhoods in the lowest walkability quartile (Frank, Schmid et al. 2005).

Sallis and colleagues (2009) collected seven days of accelerometry data per participant and used average minutes per day of moderate-to-vigorous physical activity as the outcome measure. In addition, this investigation used several questions from the International Physical Activity Questionnaire to separately assess self-reported walking for transportation and leisure purposes as outcome measures. Neighbourhoods were also divided into low- and high-income groups to examine whether walkability affected neighbourhoods differentially as a function of income. Last, Sallis and colleagues attempted to control for individual preference for activity-friendly environments because self-selection for “walkable” environments is proposed as an alternative explanation for self-reported higher physical activity rates in these neighbourhoods. The results revealed that individuals living in high-walkability neighbourhoods (compared to low-walkability neighbourhoods) accumulated 5.8 more minutes per day of moderate-to-vigorous physical activity. Higher self-reported transportation walking (44.3 compared to 12.8 minutes per week) and leisure walking (18.5 compared to 14.2 minutes per week) was also reported across income groups. The difference in self-reported transportation related walking between high- and low-walkability neighbourhoods was greater in high-income neighbourhoods (5.1 min differential versus 2.3 min differential). The walkability and physical activity associations remained significant after adjusting for self-selection for activity-friendly neighbourhoods in all cases except leisure walking (Sallis, Saelens et al. 2009).

Overall both of these investigations support the theory that living in neighbourhoods which score high on the Neighbourhood Walkability Index is associated with increased objectively determined moderate physical activity.

1.2.2.4.2 Built Environment Correlation with Cardiovascular Disease Risk

Overweight and Obesity: Numerous studies have shown that living in less “walkable” neighbourhoods is correlated with an increased incidence of overweight and obesity as measured by body mass index (Ewing, Schmid et al. 2003; Giles-Corti, Macintyre et al. 2003; Saelens, Sallis et al. 2003; Frank, Andresen et al. 2004; Lopez 2004). Sallis and colleagues (2009) found that American adults (age 20 to 65 years old) living in neighbourhoods with high versus low neighbourhood walkability was associated with 35% greater odds of being overweight or obese. A cross-sectional Canadian investigation which examined BMI in separate Toronto and Vancouver samples showed mixed results in terms of the association between neighbourhood walkability, its component parts and BMI (Pouliou and Elliott 2010). For instance, they found that, in both samples residential density was negatively associated with BMI. However, only in Vancouver was living in an area of mixed land-use and street connectivity significantly and negatively associated with BMI. Comparatively, a review of investigations of the built environment and obesity found that land use mix, of all the components of the Neighbourhood Walkability Index, had the most consistent association with weight status (Feng, Glass et al. 2010).

Other cardiovascular risk factors: There is an emerging body of research, primarily examining Finnish populations, which has investigated the cardiovascular effects of active commuting. A recent meta-analysis of this research showed an 11% reduction in cardiovascular risk associated with active commuting (defined as bicycling and/or walking), when controlling for other physical activity. An American investigation looking at active commuting found that active commuting was negatively associated with BMI, obesity, triglyceride levels, blood pressure and insulin level. However, these findings were only significant in males (Gordon-Larsen, Boone-Heinonen et al. 2009).

There has been very little investigation into the influence of living in neighbourhoods of varying levels of walkability on cardiovascular risk factors beyond weight status. One known investigation looked at changes in blood pressure over a one-year period and found that low neighbourhood walkability was significantly related to increases in blood pressure over time, while high neighbourhood walkability was related to decreased blood pressure over time (Li, Harmer et al. 2009).

The relative lack of investigations into the effect of the built environment on chronic disease risk factors beyond physical activity rates and overweight/obesity status is likely due to the fact that the majority of investigations have come from the perspective of researchers in Urban Planning. Objectively measuring cardiovascular disease risk factors on the number of participants required to complete such investigations can be very difficult logistically. It requires trained personal, time, space, and a significant budget. However, given the noted potential for the built environment to affect physical activity behaviour, weight status and potentially even blood pressure, investigation into the built environment's relationship with cardiovascular disease is warranted clearly.

1.2.2.5 Rationale

A growing body of literature suggests that the built environment influences physical activity rates, both via active transportation and leisure-time physical activity. If built environment design does, indeed affect total physical activity, whereby changes to the built environment result in increased total physical activity, then, by means of decreased disease risk, morbidity, and mortality, changes to the built environment could result in increased quality of life, increased productivity, and decreased health care costs.

To reiterate, previous research has shown that individuals living in traditional, walkable urban neighbourhoods report participating in 30 minutes more walking as active transportation per week (Saelens, Sallis et al. 2003). Using an objective measure of physical activity, individuals living in high-walkability neighbourhoods, compared to low-walkability neighbourhoods have been shown to accumulate 5.8 more minutes of moderate-to-vigorous physical activity per day (Sallis, Saelens et al. 2009). Differences of this scale are meaningful when we consider that there is evidence of dose-response relationship between physical activity and the incidence of several chronic diseases, including cardiovascular disease and hypertension (Warburton, Charlesworth et al. 2010). Although evidence exists to show that residents of neighbourhoods which are more supportive of physical activity are more likely to be sufficiently physical active (Frank, Schmid et al. 2005; Sallis, Bowles et al. 2009), living in such environment does not guarantee that residents will accumulate sufficient additional physical activity to meet physical activity guidelines. However, as our guidelines state "every little bit counts"; therefore, increases of 5.8 minutes per day, or 40.6 minutes per week are be meaningful in terms of decreased disease risk. The potential capability of the environment to influence physical activity rates is accentuated when we consider that every member of a given population interacts, to some degree, with the built environment, and thus small effects can be considered meaningful.

Furthermore, the permanence of the built environment infers that effects may be long lasting. Thus, given the noted potential for the built environment to affect physical activity rates, and thereby affect disease risk, investigation into the cardiovascular effects of living in environments which vary in their level of supportiveness for physical activity is warranted. Additionally, despite the importance of understanding the relationship between the built environment and health, and despite some previous research which has aimed to improve this understanding, a causal relationship between the built environment and physical activity has been difficult to establish. This is in part due to the significant challenge of objectively measuring total physical activity throughout daily living. It is here that the well-established relationship between physical activity and cardiovascular disease risk can be utilized to support this body of research.

It is well known that physical activity and several cardiovascular disease risk factors are causally linked, whereby increased physical activity is associated with decreased cardiovascular risk. If cardiovascular risk were to vary predictably between residents of neighbourhoods of varying built environment design, then it would provide evidence of relationship between the built environment and total physical activity. Such evidence could assist in supporting bids for future research on this relationship. Additionally, as a lack of financial backing has consistently been identified as a barrier to promoting and creating healthier neighbourhood designs (Clark, Berry et al. 2010) evidence of a relationship and an estimation of the magnitude of effect, could support future policy and infrastructural changes. Accordingly, a goal of the research presented within this thesis is to further the use of a built environment as a tool for creating healthier urban environments.

CHAPTER 2

Cardiovascular Disease Risk Factors, Neighbourhood Walkability and Leisure-Time Physical Activity Correlates[1]

2.1 Introduction

Cardiovascular disease refers to a group of conditions affecting the form and function of the heart and its vasculature (Young and Libby 2007). It is one of four non-communicable diseases (along with diabetes, cancer and chronic respiratory disease) which account for the majority of mortality worldwide (International Diabetes Federation, World Heart Federation et al. 2009). Among Canadians, cardiovascular disease causes more deaths than any other disease and is also the leading contributor to both direct and indirect health care costs (Heart and Stroke Foundation of Canada 2003; CHHS-AP Steering Committee 2009).

Physical activity, defined as bodily movement produced by skeletal muscles which results in increased caloric expenditure (Pate, Pratt et al. 1995), is associated with reduced risk of cardiovascular mortality (Wannamethee and Shaper 2001; Warburton, Nicol et al. 2006). This can be attributed to improvements in several independent cardiovascular risk factors that come with being physically active (Ridker and Libby 2008). These include decreased blood pressure, improved glucose tolerance, improved lipid profiles and decreased risk of both central (i.e., abdominal) and generalized obesity (Young and Libby 2007; Prasad and Das 2009).

Traditionally, efforts to decrease cardiovascular risk, by means of increasing physical activity, have been in the form of population wide educational campaigns or high cost per participant physical activity interventions (Sallis, Cervero et al. 2006). Recently, there has been an increase in research pertaining to the potential of the shape of the built environment (a construct from the field of urban planning which refers to the physical form of communities) to facilitate or hinder physical activity and indirectly affect the cardiovascular health of residents (Giles-Corti, Timperio

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[1] A version of this chapter is to be submitted in manuscript form for publication. Johnson, M.Z., Warburton, D.E.R., Blanchard, C., & Bredin, S.S.D. Cardiovascular Disease Risk Factors, Neighbourhood Walkability and Leisure-Time Physical Activity Correlates.

et al. 2005). Well informed environmental and policy interventions based on this concept are attractive alternatives to traditional efforts to increase physical activity because of their potential to reach a greater percentage of the population and to have a sustained effect once implemented (Sallis, Cervero et al. 2006).

Changes to built environment infrastructure at the neighbourhood level have the potential to increase physical activity levels by affecting two types of physical activity behaviour: (1) purposeful exercise or play (referred to as leisure-time physical activity) and (2) utilitarian forms of physical activity (i.e., physical activity performed for another purpose), specifically active transportation. Active transportation refers to human-powered forms of transportation such as walking and cycling (Handy, Boarnet et al. 2002). Compared to many European countries for which data is available, Canadians report low levels of active transportation (Pucher and Dijkstra 2003). According to a 2004 survey performed by the Heart and Stroke Foundation of Canada, only 34% of residents of major urban centres used walking, biking or public transit as their primary means of getting to work (Heart and Stroke Foundation of Canada 2005), and intuitively public transit likely makes up a large portion of the 34%. Leisure-time physical activity rates in Canada are low as well. The Heart and Stroke Foundation of Canada reported in 2009 that nearly half of all Canadians age 12 and over report being physically inactive (Heart and Stroke Foundation of Canada 2009).

Several factors within the built environment of urban settings in particular have been correlated to active transportation and leisure-time physical activity respectively. An urban setting is defined in Canada as an area having a population of at least 1000 people and having a population density of no less than 400 persons per square kilometre (Statistics Canada 2006).

Neighbourhoods with increased population and/or residential density, a greater variety of land uses (i.e., mixture of residential, commercial and office land use), and more connected, grid-like streets, are said to be more “walkable”, or conducive to active transportation (Saelens, Sallis et al. 2003). The degree of “walkability” of a neighbourhood has commonly been assessed using various versions of the Neighbourhood Walkability Index (Frank, Sallis et al. 2009). High, compared to low neighbourhood walkability has in one instance been associated with 30 minutes more walking as active transportation per week (Saelens, Sallis et al. 2003). Several investigations have also shown that living in less walkable neighbourhoods is correlated with an increased incidence of overweight and obesity (Ewing, Schmid et al. 2003; Giles-Corti, Macintyre et al. 2003; Saelens, Sallis et al. 2003; Frank, Andresen et al. 2004; Lopez 2004; Frank, Sallis et al. 2006; Sallis, Saelens et al. 2009).

Understanding the built environment's influence on leisure forms of physical activity has proven more difficult (Saelens and Handy 2008). For example, there is a wider breadth of activities which are commonly pursued as leisure-time physical activity compared to active transportation. Additionally, leisure forms of physical activity can be performed in alternative locations, such as private recreational facilities, or outdoor destinations far from one's home and therefore difficult to identify using popular methodology. Finally, individuals may put significantly more effort into taking part in their preferred leisure-time physical activity pursuits, as they are often times being performed for enjoyment. Regardless, several correlates of leisure-time physical activity which would take place around one's neighbourhood have been identified. Neighbourhoods with features such as greater access to park and recreational facilities, more thorough sidewalk and street-lighting infrastructure, and more pleasing aesthetics have been described as more conducive to leisure-time physical activity (Ball, Timperio et al. 2007; Sallis, Bowles et al. 2009). For instance, a recent review including investigations from Belgium, Brazil, Canada, Colombia, China (Hong Kong), Japan, Lithuania, New Zealand, Norway, Sweden and the United States, showed a linear relationship between supportiveness of the environment for physical activity (assessed as the number of perceived neighbourhood attributes that are commonly linked to physical activity) and likelihood of meeting total physical recommendations (assessed using the International Physical Activity Questionnaire). Significant predictors within this investigation included having retail locations, transit stops and low-cost recreational facilities near one's home and having facilities for cycling and sidewalks present.

The association between the built environment and obesity has also been examined. Sallis and colleagues (2009) found that individuals living in low versus high walkability neighbourhoods (as measured using the Neighbourhood Walkability Index, including retail floor area ratio) had 53% greater odds of being obese (measured as self-report weight and height). A Canadian investigation, which looked at samples from Vancouver and Toronto specifically, found that 6% of the variance of BMI could be explained by neighbourhood walkability. When the components of the Neighbourhood Walkability Index were investigated separately, residential density was significantly negatively associated with BMI in both samples and land use mix and street connectivity were significantly negatively associated with BMI in Vancouver only (Pouliou and Elliott 2010).

Despite the support for increased physical activity and decreased rates of overweight and obesity among residents of activity friendly neighbourhoods, there are only a few known investigations which have examined the relationship between the built environment and cardiovascular risk factors besides BMI. One investigation examined changes in blood pressure over a one-year period in environments varying on neighbourhood walkability and density of fast food outlets. Findings from this investigation showed that living in a neighbourhood which scored high on the Neighbourhood Walkability Index could improve risk of hypertension. This was concluded based on data which showed that living in a neighbourhood which scored equal to or above the 75^{th} percentile on the Neighbourhood Walkability Index predicted decreases in both systolic and diastolic blood pressure over the one year period. Conversely, living in neighbourhoods which were below the 75^{th} percentile of scores was associated with a moderate increase in both systolic and diastolic blood pressure (Li, Harmer et al. 2009).

Objectively measuring cardiovascular disease risk factors on the number of participants required to complete such investigations can be logistically very difficult. However, given the noted potential for the built environment to affect physical activity behaviour, weight status and potentially even blood pressure, investigation into the built environment's relationship with cardiovascular disease, via physical activity, is warranted. The uniqueness of this investigation lies in its evaluation of cardiovascular risk factors which have not previously been investigated with respect to the built environment. Four indicators were chosen because of their relationships with physical activity. These include body mass index (BMI), waist girth, systolic blood pressure and serum concentration of high-density lipoprotein cholesterol (HDL-C).

Body mass index and waist girth can both be considered indicators of body fatness. Although neither are direct measures of body composition, they are commonly used in cardiovascular health literature (Canoy 2008; D'Agostino, Vasan et al. 2008). Body mass index takes into account the whole body and is an indicatory of general adiposity (i.e., fatness). Waist girth, alternatively, measures abdominal adiposity only and is an indicator of visceral adiposity (i.e., fat tissue which surrounds the internal organs of the body). Total adiposity and abdominal adiposity have both been shown to be independently related to cardiovascular risk (Van Gaal, Mertens et al. 2006). Additionally, each is negatively correlated with levels of physical activity (Hills and Byrne 1998; Lakka and Bouchard 2005).

Systolic blood pressure refers to the peak arterial pressure reached during ventricular contraction of the heart (Saladin 2001). Chronic hypertension, or elevated blood pressure, increases risk of atherogenesis (Young and Libby 2007). Systolic blood pressure, specifically, is predictive of adverse cardiovascular events such as heart attacks and strokes (Young and Libby 2007). Exercise can decrease blood pressure through weight-loss and independent of weight-loss (Ross and Janiszewski 2007; Zamani, Williams et al. 2007). The first may occur because of chronic decreased peripheral vascular resistance (Fagard 2006) and thus has a chronic effect of lowering blood pressure. The latter is termed post-exercise hypotension and has an acute (i.e., temporary) effect of lowering blood pressure.

High-density lipoprotein cholesterol is a component of dyslipidemia, a condition characterized by abnormal circulating blood lipid levels. Dyslipidemia is a major risk factor for cardiovascular disease because of its association with the development of atherosclerosis (Young and Libby 2007). Serum HDL-C concentration is an independent risk factor for cardiovascular disease (Kodama, Tanaka et al. 2007) and is negatively associated with cardiovascular risk (Ridker and Libby 2008). This is because HDL-C can be protective against atherosclerotic plaque development (Young and Libby 2007). Physical activity can improve dyslipidemia in part by increasing production of HDL-C (Enger, Herbjornsen et al. 1977; Kodama, Tanaka et al. 2007). Because of the relationships of these four cardiovascular disease risk factors with physical activity, they are the focus of the current investigation.

The purpose of this investigation was to compare cardiovascular risk factor rates (BMI, waist girth, HDL-C concentration and systolic blood pressure) of groups of individuals living in urban neighbourhoods varying on levels of leisure-time physical activity correlates and walkability. Groups were also stratified by income, as previous investigations have reported lower BMI scores among residents of high versus low income neighbourhoods with similar levels of walkability (Sallis, Saelens et al. 2009).

We hypothesized that living in neighbourhoods with access to more leisure-time physical activity correlates (defined as parks and or water bodies) would be associated with less cardiovascular risk. Therefore, we expected to see lower BMI, waist girth and blood pressure scores and higher HDL-C concentrations among residents of neighbourhoods with more leisure-time physical activity correlates. Similarly, we hypothesized that living in neighbourhoods which were more supportive of active transportation (i.e., scored higher on the Neighbourhood Walkability Index) would be associated with less cardiovascular risk. Therefore, we expected to see lower BMI, waist girth and blood pressure scores and higher HDL-C concentrations among residents of neighbourhoods that were more walkable. Our sample was divided into high and low income groups based on their neighbourhood median after-tax income. We hypothesized that both groups would respond similarly to increased leisure-time physical activity correlates and increased walkability, but that the lower income group would exhibit higher cardiovascular risk overall.

2.2 Methodology

2.2.1 Participants

Cardiovascular data was collected on a total of 4924 participants (3002 females; 1922 males) at dedicated testing facilities across the province of British Columbia, Canada, during the years of 2007, 2008 and 2009. All participants were self-selected and provided written informed consent prior to participation. Of this original group, 4270 individuals provided valid British Columbian postal codes (2599 females; 1672 males) (to be deemed invalid the postal code was either missing, represented a residential location outside of British Columbia or was not in a valid Canadian postal code format). Participants were excluded from analyses if cardiovascular data was incomplete, if they were below the age of majority (i.e., 19 in British Columbia) or above 82 years of age or if they had previously experienced cardiovascular disease (defined as having previously experienced angina, a myocardial infarction, coronary bypass surgery, and/or a stroke). Those who provided a rural postal code or provided a postal code which fell outside of land use data were also excluded from analyses. Finally any participants who had zero dollars as their neighbourhood media after-tax income value were excluded. The greatest contributors to participant loss were previously having experienced cardiovascular disease (approximately 200 individuals), providing a rural postal code (approximately 600 individuals) and providing a postal code which fell outside of land use data (approximately 500 individuals), with some overlap of these circumstances. The sample deemed appropriate for this investigation based on the above criteria totalled 2999 individuals (1848 Females and 1151 Males). This investigation was executed in accordance with the ethical guidelines set forth by the University of British Columbia's Clinical Research Ethics Board for research involving human participants (See Appendix A).

2.2.2 Cardiovascular Data Collection

Cardiovascular data collection was performed by qualified health care professionals (e.g., Canadian Society for Exercise Physiology-Certified Exercise Physiologists® (CSEP-CEPs), registered nurses) on location in communities across British Columbia. All measurements were conducted by the same research team who traveled across the province to each testing location. Data was collected according to the order and procedure outlined below (See Figure 2.1). Following data collection participants were provided the opportunity to fully discuss their results with an on-site cardiac nurse.

Consent Forms and Demographics: Participants arrived and were invited to take part in the research project. Consent forms and surveys on demographics (age, sex, ethnicity and postal code) were then filled out with assistance from research team members. Personal history of cardiovascular disease was assessed by self-report.

Anthropometrics: Waist girth was measured using the Canadian Society of Exercise Physiology protocol (measurement taken midway between the bottom of the 12th rib and the top of the iliac crest) and recorded in centimetres to one decimal place. Standing height was measured using a stadiometer (Seca 214 Portable Stadiometer, Hamburg, Germany) and was recorded to one decimal place. Weight was measured using an electronic scale (Health-o-meter Professional Model 320KL Medical Model, Boca Raton, FL), recorded in kilograms and rounded to one decimal place. Measurements of height and weight were then used to calculate body mass index.

Blood Pressure: Participants were first asked if they were currently on blood pressure medication. Seated blood pressure (following 3 minutes of rest) was then assessed using a BpTRU BPM-100 automated blood pressure monitor (BpTRU Medical Devices, Coquitlam, BC). Blood pressure was measured in triplicate with the average of the second and third measurements taken.

Cholesterol: Participants were first asked if they were currently on cholesterol medication. A

Figure 2.1 Cardiovascular Data Collection Procedure

Demographics:

1) Healthy Heart Society of BC Surveys on age, sex, ethnicity and postal code

2) Personal history of cardiovascular disease via self-report

Anthropometrics:

1) Waist girth

2) Standing height

3) Weight

Blood Pressure:

1) Current blood pressure medication use assessed by self-report

2) Seated blood pressure (following 3 minutes of rest) assessed using BpTRU BPM-100 automated blood pressure monitor (measured in triplicate, with average of 2^{nd} and 3^{rd} measures recorded)

Cholesterol:

1) Current cholesterol medication use assessed by self-report

2) Non-fasting screening measurement of HDL-C taken using finger-prick blood sample and Cholestech LDX system

non-fasting screening measurement of HDL-C (mmol/L) was then taken by a registered nurse using a finger-prick blood sample and a Cholestech LDX system (Cholestech, Hayward, CA).

2.2.3 Built Environment Assessment

2.2.3.1 Defining the Participant's Neighbourhood

To evaluate the characteristics of each participant's neighbourhood, we first identified their place of residence. This was approximated via postal code information provided by participants during the cardiovascular data collection. Each postal code was converted to a latitude and longitude co-ordinate using the CanMap Multiple Enhanced Postal Code file, as published by DMTI Spatial in their 2008 report (CanMap 2008 Postal Geography, Markham, ON). This product identifies unique dominant postal code coordinate locations; thus, the proxy place of residence for each participant was weighted based on population distribution within each postal code delivery area. Each participant's proxy place of residence was then mapped, using ESRI ArcGIS version 9.3.1, on a map of the province of British Columbia, projected in BC Albers. These residence points were then snapped to the closest road point on the map, up to a maximum of one kilometre away.

Once a proxy point of residence was established for each participant, a network buffer around each residence was created using ArcGIS Network Analyst. Participants' neighbourhoods were defined as any area that could be reached within a ten minute walk, at a walking pace of five kilometres per hour (i.e., 750 metres). The network followed all roads for 700 metres from the participant's proxy place of residence. This area was then padded with an additional 50 metres in every direction to encompass any potential destinations along these routes and to exclude land that would not likely be accessible to a pedestrian in these environments. Furthermore, the 50 metre buffer functioned to extend the total network distance along roads and trails to the desired 750 metre total. The neighbourhoods were thus defined as a combination of all the possible routes, extending a total of 750 metres and 50 metres of padding along each side of every road or trail (Oliver, Schuurman et al. 2007).

2.2.3.2 Examining Neighbourhood Physical Activity Correlates

As is commonly done to assess neighbourhood conduciveness to physical activity, physical activity was behaviourally divided into active transportation and leisure-time physical activity. Neighbourhood correlates of these two separate behavioural groups were then examined.

2.2.3.2.1 Active Transportation

Conduciveness to active transportation was assessed via several neighbourhood design variables, namely, street connectivity, residential density and land use mix.

Street Connectivity: Street connectivity was operationalized as the number of intersections (3-way or more) per square kilometre within the area of interest (Frank, Schmid et al. 2005). The area of interest was each participant's neighbourhood buffer excluding any buffer area that was part of a water body. Data, in the form of a roads network file was attained through the University of British Columbia in agreement with DMTI Spatial (Markham, ON) (2009). The road network was then projected with participant neighbourhood buffers and the number of intersections (3-way or more) within each neighbourhood was divided by the area in kilometres squared.

Residential Density: In order to assess residential density participants' postal codes were joined with 2006 Canadian Census data at the dissemination area level. Dwelling counts and spatial area of the dissemination areas were then used to approximate residential density in each participant's neighbourhood. Data used to determine residential density was obtained from Canada's 2006 Census (GeoSuite 2006, Statistics Canada, Ottawa) and CanMap® Route Logistics, Version 2009.4 (DMTI Spatial, Markham, ON).

Land Use Mix: Land use mix was defined as the evenness of “Residential”, “Commercial” and “Government and Institutional” development within each neighbourhood buffer. This eliminated areas deemed to be “Resource and Industrial”, “Parks and Recreation”, “Open Space”, and “Water” from the land use mix calculation. Land use mix was calculated using the following formula, adopted from previous similar investigations (Frank, Schmid et al. 2005; Frank, Saelens et al. 2007):

$$\text{Land use mix} = -\sum_{i=1}^{n}\left(\frac{p_i \times \ln p_i}{\ln n}\right)$$

where, p_i is the proportion of total neighbourhood buffer area that is categorized as land use i, and n is the number of the relevant land uses present within the specific neighbourhood buffer. Data was attained through the University of British Columbia in agreement with DMTI Spatial (Markham, ON) in the form of a geospatial shapefile (CanMap® Route Logistics Version 2009.4). Participants whose neighbourhood buffers fell outside of land use mix data were excluded from analyses.

Walkability Index*:* The sum of z-scores of each participant's residential density, land use mix, and street connectivity (weighted twice as heavily as the other two scores) was calculated. This score was used as a composite score for the level of conduciveness to active transportation of each participant's neighbourhood.

Walkability = [(2 x z-score of street connectivity)
+ (z-score of residential density)
+ (z-score of land use mix)

2.2.3.2.2 Leisure-Time Physical Activity

Conduciveness to leisure-time physical activity was assessed as the number of park facilities or water-bodies that intersected with each neighbourhood buffer. Participants were given a point for each incidence of intersection between park polygons or water-body polygons and their neighbourhood buffer. In order to assess the presence of a water-body, an additional 50 metre buffer was added in all directions around the original neighbourhood buffer. In cases where the same leisure-time physical activity correlate (i.e., park or water-body) was accessible via multiple routes from the proxy place of residence and led to different end points within or along the park or water-body, the intersection was counted multiple times. Data used to assess the presence of leisure-time physical activity correlates was obtained from DMTI's land-use geospatial shapefile (CanMap® Route Logistics Version 2009.4).

2.2.3.3 Income

Participants were grouped based on their neighbourhood median after-tax income into low income (0-49th percentile scores) and high income (50-100th percentile scores) neighbourhoods. Median after-tax income data was retrieved from the Canadian 2006 Census (Statistics Canada 2007) and was operationalized as the median-after tax income, in Canadian dollars, of the dissemination area which the postal code centroid fell within.

2.3 Results

Between-group mean comparisons [analyses of variance (ANOVAs) and one multivariate analysis of variance (MANOVA)] were used to assess the influence of neighbourhood walkability and number of leisure-time physical activity correlates on low- and high-income groups for four dependent variables: BMI, waist girth, systolic blood pressure and HDL-C concentration. Body mass index and waist girth were analyzed together using a two-way multivariate analysis of variance. Systolic blood pressure and HDL-C concentration were analyzed using a subsample of the original population, which included only those participants that reported no current use of blood pressure or cholesterol medication. Additionally, this sample eliminated the 2009 cohort, as these participants were not asked about their medication use. Systolic blood pressure and HDL-C concentration were not analyzed together in a multivariate analysis because they did not exhibit a linear relationship. Significance was set *a priori* at $p<.05$ for all analyses and then adjusted as required.

<u>Outliers</u>: Initial checks for outliers were performed by visually inspecting the data to ensure that all values were physiologically reasonable, and were not the result of errors in data entry. In addition, box-plots were used to search for outliers on each of the dependent variables. One extreme outlier (defined as a point which lies three box-lengths from the edge of the box) on

BMI was eliminated for the MANOVA and the additional outliers for HDL-C concentration (n=3) and systolic blood pressure (n=12) were eliminated for the subsequent analyses of these variables. There were no extreme outliers for waist girth. Moderate outliers were retained in each case. Eighteen participants were eliminated from the BMI and waist girth MANOVA due to Mahalanobis distance scores which exceeded the critical value for two dependent variables (13.82) and thus identified them as multivariate outliers.

Neighbourhood Walkability: Participants were divided into groups based on level of neighbourhood walkability. The entire group (including dependent variable outliers, and extreme income outliers who were later eliminated) was divided into halves based on their score on their neighbourhood walkability score (Table 2.1). Each of these two groups was then divided into high and low income groups, giving this independent variable four levels (Table 2.2).

Leisure-Time Physical Activity Correlates: For the independent variable, leisure-time physical activity correlates, participants were divided into three groups based on the number of correlates intersecting their neighbourhood. The groups consisted of those that had zero, one to two and three or more leisure-time physical activity correlates intersecting their neighbourhood (Table 2.3). Each of these three groups was then divided into high and low income groups, giving a total of six levels to this independent variable (Table 2.2).

2.3.1 Body Mass Index and Waist Girth

Body mass index and waist girth were analyzed using a sample consisting of 2980 participants, 1830 females (61%) and 1150 males (39%). Table 2.4 outlines scores on BMI and waist girth for this sample. This sample included participants from all three years of data collection. The sample was 73% Caucasian and was, on average 47.7 years of age, SD=14.9, range =19-82. A two-way MANOVA was conducted to assess the effect of walkability according to income level and leisure-time physical activity correlates according to income level on a linear combination of BMI and waist girth scores. This analysis also allowed univariate analyses of these two dependent variables.

Table 2.1 Walkability Group Sizes and Mean Walkability Scores and Ranges across Walkability Levels

	Walkability Scores		Sample Size by Dependent Variables		
	Mean (± SD)	**Range**	**BMI and Waist Girth** N	**Systolic Blood Pressure** N	**HDL-C Concentration** N
Low Walkability (0-49th Percentile)	-.004 (±.677)	-1.988 – .928	1499	1183	1190
High Walkability (50-100th Percentile)	2.663 (±1.835)	932 – 19.323	1481	1222	1224
Total	1.321 (±1.919)	-1.988 – 19.323	2980	2405	2414

Note:

*walkability groups have uneven numbers because percentiles were scored before dependent variable outliers and extreme income outliers were eliminated

Table 2.2 Sample Size for Body Mass Index and Waist Girth, High-Density Lipoprotein Concentration, and Systolic Blood Pressure Grouped by Neighbourhood Income Level

	Median After Tax Income (CAN$)		Leisure-Time Physical Activity Correlate Groups			Walkability Groups	
BMI and Waist Girth Sample							
	Range	**Mean (± Standard Deviation)**	**0 (n)**	**1-2 (n)**	**3+ (n)**	**Low (n)**	**High (n)**
Low Income	9706 – 24564	20207.82 (±2869.76)	416	633	440	602	887
High Income	24571 – 62882	29348.40 (±3849.32)	562	551	378	897	594
HDL-C Concentration Sample							
	Median After Tax Income (CAN$)		**Leisure-Time Physical Activity Correlate Groups**			**Walkability Groups**	
	Range	**Mean (± Standard Deviation)**	**0 (n)**	**1-2 (n)**	**3+ (n)**	**Low (n)**	**High (n)**
Low Income	9706 – 24564	20259.14 (± 2825.95)	338	494	343	462	713
High Income	24571 – 62882	29369.81 (±3871.15)	453	460	326	728	511
Systolic Blood Pressure Sample							
	Median After Tax Income (CAN$)		**Leisure-Time Physical Activity Correlate Groups**			**Walkability Groups**	
	Range	**Mean (± Standard Deviation)**	**0 (n)**	**1-2 (n)**	**3+ (n)**	**Low (n)**	**High (n)**
Low Income	9706 – 24564	20261.76 (±2827.40)	338	491	344	461	712
High Income	24571 – 48487	29343.53 (±3759.41)	448	458	326	722	510

Table 2.3 Leisure-Time Physical Activity Correlate Group Sizes across Variable Levels

Leisure-Time Physical Activity Correlate Groups	BMI and Waist Girth Sample (n)	Systolic Blood Pressure Sample (n)	HDL-C Concentration Sample (n)
0	978	786	791
1-2	1184	949	954
3+	818	670	669
Total	2980	2405	2414

Table 2.4 Mean Scores of Body Mass Index and Waist Girth, by Sex

	Total Sample (N=2980)	Males (n=1150)	Females (n=1830)
	Mean ± Standard Deviation	Mean ± Standard Deviation	Mean ± Standard Deviation
BMI	26.78 ± 4.60	27.49 ± 3.95	26.33 ± 4.91
Waist Girth (cm)	87.84 ± 13.71	94.54 ± 11.88	83.62 ± 13.10

Estimated marginal mean scores of participants across walkability levels, stratified by income, are outlined in Table 2.5. Estimated marginal mean scores of participants across leisure-time physical activity correlate level, stratified by income, can be found in Table 2.6. Before running the two-way between-groups multivariate analysis of variance for BMI and waist girth several assumptions were checked. Normality was visually inspected using histograms for each of the dependent variables. Furthermore, because of the sample size, this analysis was robust to violations of this assumption. Linearity, the assumption of the presence of a straight-line relationship between the two dependent variables, across all groups, was checked and no violations were found. Box's Test of Equality of Covariance Matrices had a non-significant value ($p=.002$) and therefore, we had not violated the assumption of homogeneity of variance-covariance matrices. Levene's Test of Equality of Error Variances gave a significant result for BMI ($p=.007$) and therefore the alpha level used to assess the univariate F-test of this variable was adjusted to a more conservative value, $p<.01$. The result for waist girth was non-significant, indicating equality of variance.

Multivariate analyses showed that there was a statically significant effect for both walkability according to income level [$F(4, 5934)=4.989$, $p=.001$, Wilks' Lambda =.993, partial eta squared=.003] and leisure-time physical activity correlates according to income level [$F(8,5934)=3.498$, $p=.000$, Wilks' Lambda=.991, partial eta squared=.005] on the linear combination of the two dependent variables. To evaluate tests of between-subject effects we applied a Bonferroni adjustment making the alpha level $p<.025$ for multivariate analyses. This was to compensate for the inflated risk of type 1 error that came with testing two separate dependent variables. Using this alpha level, we found statistically significant effects for BMI and waist girth by walkability according to income group [BMI; $F(2, 2968)=9.402$, $p=.000$; partial eta squared=.006] [waist girth; $F(2, 2968)=8.610$, $p=.000$, partial eta squared=.008], and by leisure-time physical activity correlates according to income group [BMI; $F(4, 2968)=5.682$, $p=.000$;

Table 2.5 Estimated Marginal Means across Walkability Groups, Stratified by Neighbourhood Income Level

	Walkability Groups			
	High Walkability, High Income Estimated Marginal Mean ± SE	Low Walkability, High Income Estimated Marginal Mean ± SE	High Walkability, Low Income Estimated Marginal Mean ± SE	Low Walkability, Low Income Estimated Marginal Mean ± SE
BMI	26.096 ± .193	26.789 ± .174	26.632 ± .167	27.582 ± .222
Waist Girth (cm)	85.949 ± .576	87.698 ± .518	87.460 ± .498	90.346 ± .662
HDL-C (mmol/L)	1.366 ± .018	1.342 ± .017	1.298 ± .016	1.291 ± .022
Systolic Blood Pressure (mmHg)	114.593 ± .683	117.014 ± .632	114.920 ± .601	115.191 ± .808

*For BMI and waist girth n=2980, for HDL-C n=2414, and for systolic blood pressure n=2405

Table 2.6 Estimated Marginal Means across Leisure-Time Physical Activity Correlate Groups, Stratified by Neighbourhood Income Level

Number of Leisure-Time Physical Activity Correlates and Income Level	**BMI**	**Waist Girth (cm)**	**HDL-C (mmol/L)**	**Systolic Blood Pressure (mmHg)**
	Estimated Marginal Mean ± SE	Estimated Marginal Mean ± SE	Estimated Marginal Mean ± SE	Estimated Marginal Mean ± SE
0, High Income	27.264 ± .225	89.446 ± .672	1.326 ± .022	115.977 ± .811
0, Low Income	27.313 ± .232	89.620 ± .693	1.257 ± .023	115.580 ± .834
1-2, High Income	26.314 ± .200	86.043 ± .596	1.349 ± .019	115.317 ± .711
1-2, Low Income	27.009 ± .183	88.779 ± .547	1.321 ± .018	115.949 ± .686
3+, High Income	25.748 ± .248	84.981 ± .739	1.388 ± .024	116.116 ± .887
3+, Low Income	26.998 ± .293	88.309 ± .875	1.306 ± .029	114.092 ± 1.056

* For BMI and waist girth n=2980, for HDL-C n=2414, and for systolic blood pressure n=2405

partial eta squared=.006] [waist girth; $F(4, 2968)= 6.183$, $p=.000$, partial eta squared =.008]. The interaction effect was non-significant for both dependent variables.

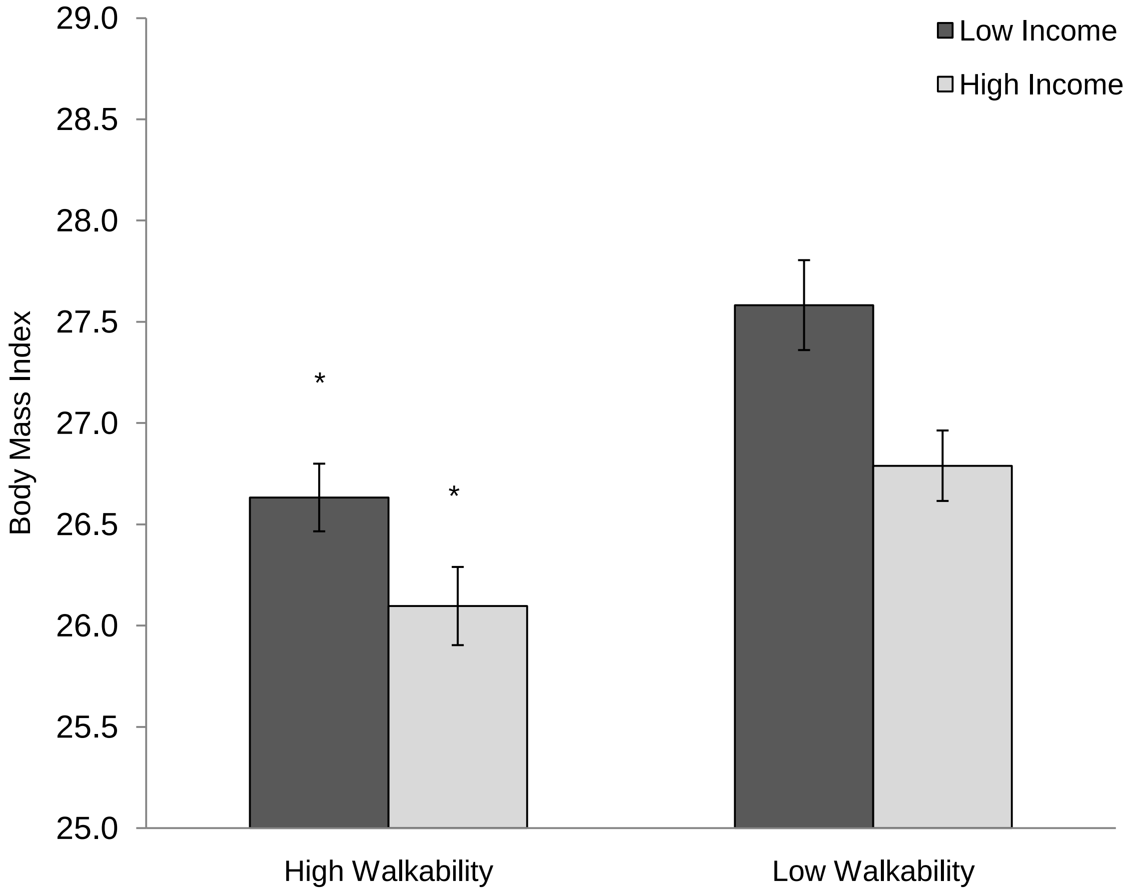
Post-hoc Analyses; BMI: Multiple comparisons, using Tukey's HSD, were evaluated for BMI at an alpha level of $p<.01$. Results for the independent variable, walkability, showed that groups in the same income level, but differing on walkability level were significantly different, in the expected directions. The estimated marginal mean of the low walkability, low income group ($\mu=27.582$, SE=.222) was significantly higher than that of the high walkability, low income group ($\mu=26.632$, SE=.167) ($p=.000$). Similarly, the estimated marginal mean of the low walkability, high income group ($\mu=26.789$, SE=.174) was significantly higher than that of the high walkability, high income group ($\mu=26.096$, SE=.193) ($p=.000$).

However, when it came to groups which shared walkability level, but differed on level of income, there were no statistically significant differences for BMI. The high walkability, high income group ($\mu=26.096$, SE=.193) was not significantly different from the high walkability, low income group ($\mu=26.632$, SE=.167) ($p=.016$), nor was the low walkability, high income group ($\mu=26.789$, SE=.174) significantly different from the low walkability, low income group ($\mu=27.582$, SE=.222) ($p=.071$).

In the case of groups which differed in walkability level and income level, only one of two estimated marginal mean differences were significant. The estimated marginal mean of the low walkability, low income group ($\mu=27.582$, SE=.222) was significantly greater than that of the high walkability, high income group ($\mu=26.096$, SE=.193) ($p=.000$). However the estimated marginal mean of the high walkability, low income group ($\mu=26.632$, SE=.167) was not significantly different from that of the low walkability, high income group ($\mu=26.789$, SE=.174) ($p=.309$). A graphical representation of these results can be found in Figure 2.2.

Results for the independent variable, leisure-time physical activity correlates, showed that between high income groups, differing in number of leisure-time physical activity correlates the estimated marginal mean of the 0 leisure-time physical activity correlates, high income group

Figure 2.2 Estimated Marginal Means of Body Mass Index across Walkability Groups, Stratified by Neighbourhood Income Level



* Statistically significant difference (p<.01) between:

1) High Walkability, High Income group and:

- Low Walkability, High Income Group
- Low Walkability, Low Income Group

2) High Walkability, Low Income group and:

- Low Walkability, Low Income Group

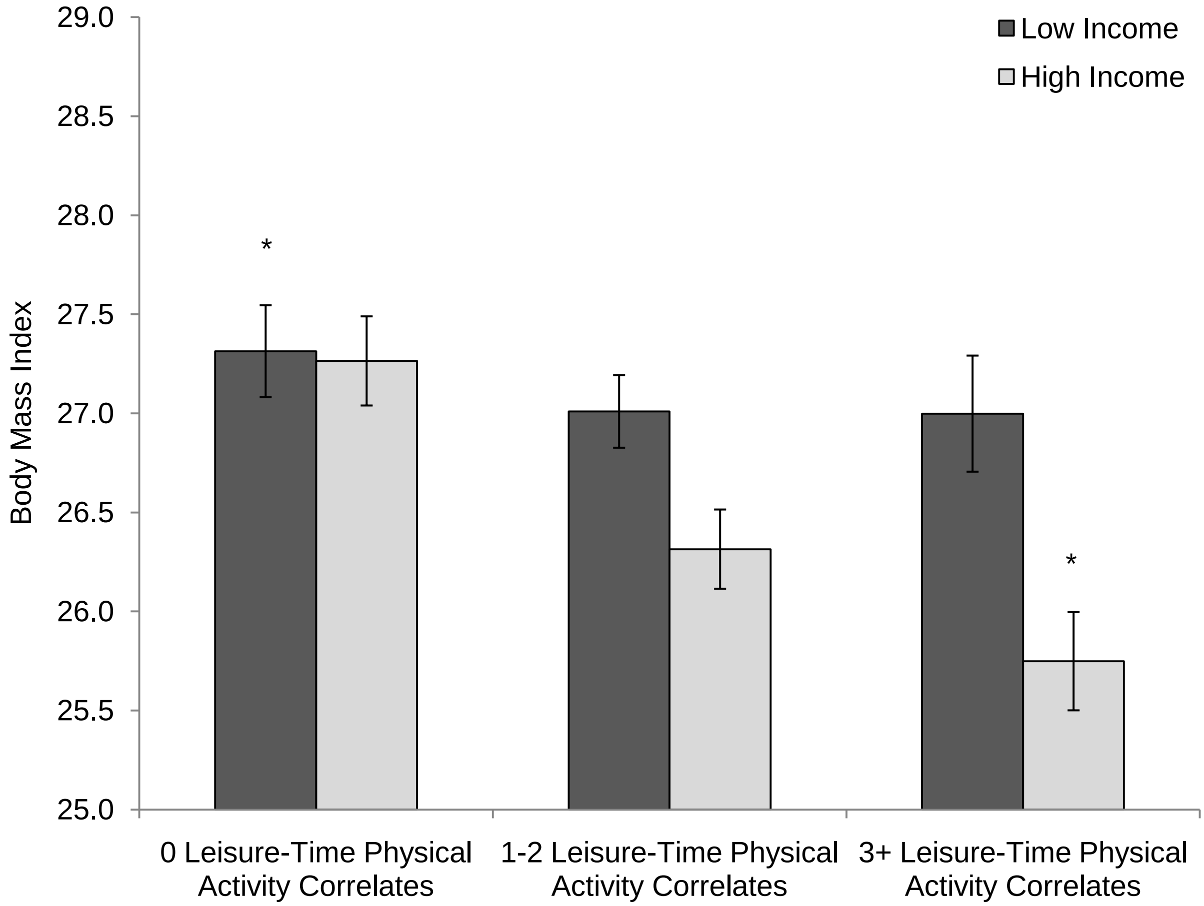
(μ=27.264, SE=.225) was not significantly higher than that of the 1-2 leisure-time physical activity correlates, high income group (μ=26.314, SE=.200) (p=.024) but was significantly higher than the 3+ leisure-time physical activity correlates, high income group (μ=25.748, SE=.248) (p=.000). There were no significant differences between estimated marginal means of the low income groups with varying numbers of leisure-time physical activity correlates.

Between groups differing only on income level there were no statistically significant differences. However, estimated marginal mean differences increased with increasing leisure-time physical activity correlates.

There were several statistically significant differences between estimated marginal means of groups not sharing the same income level or the same number of leisure-time physical activity correlates. The estimated marginal mean of the 0 leisure-time physical activity correlates, low income group (μ=27.313, SE=.232) was significantly higher than that of the 1-2 leisure-time physical activity correlates, high income group (μ=26.314, SE=.200) (p=.006). There was also a significant difference between the estimated marginal mean of the 0 leisure-time physical activity correlates, low income group (μ=27.313, SE=.232) and that of the 3+ leisure-time physical activity correlates, high income group (μ=25.748, SE=.248) (p=.000), and finally between the estimated marginal mean of the 1-2 leisure-time physical activity correlates, low income group (μ=27.009, SE=.183) and that of the 3+ leisure-time physical activity correlates, high income group (μ=25.748, SE=.248) (p=.000). A graphical representation of these results can be found in Figure 2.3.

Post-hoc Analyses; Waist Girth: Multiple comparisons, using Tukey’s HSD, were evaluated for waist girth at an alpha level of $p<.05$. Results for the independent variable, walkability, showed that there were statistically significant differences between groups with the same income level, but differing on walkability, and that these differences were in the expected direction. The estimated marginal mean of the low walkability, low income group (μ=90.346, SE=.662) was significantly greater than that of the high walkability, low income group (μ=87.460, SE=.498)

Figure 2.3 Estimated Marginal Means of Body Mass Index across Leisure-Time Physical Activity Correlate Groups, Stratified by Neighbourhood Income Level



*Statistically significant difference (p<.01) between:

1) 3+ Leisure-Time Physical Activity Correlates, High Income Group and:

- 0 Leisure-Time Physical Activity Correlates, High Income Group
- 0 Leisure-Time Physical Activity Correlates, Low Income Group
- 1-2 Leisure-Time Physical Activity Correlates, Low Income Group

2) 0 Leisure-Time Physical Activity Correlates, Low Income group and:

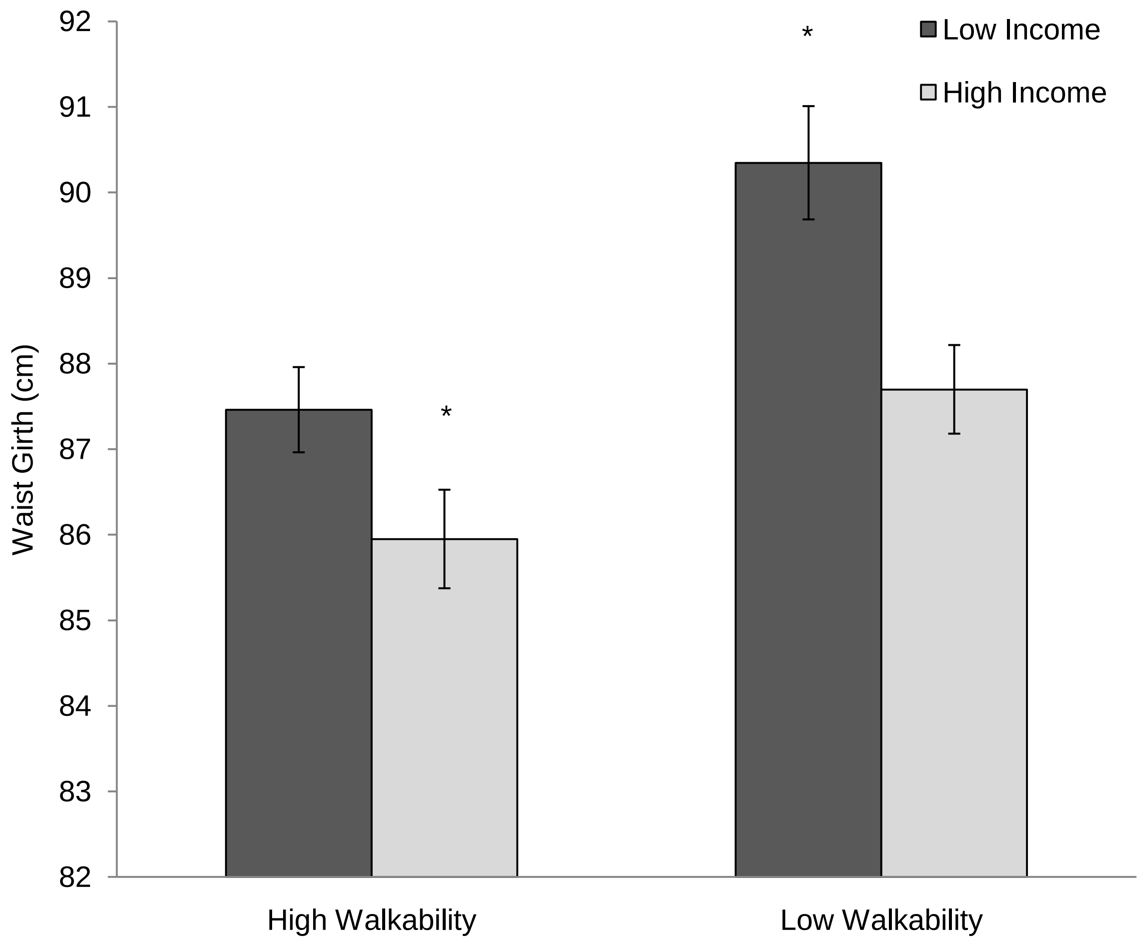
- 1-2 Leisure-Time Physical Activity Correlates, High Income Group (p=.000). Similarly, the estimated marginal mean of the low walkability, high income group (μ=87.698, SE=.518) was significantly greater than that of the high walkability, high income group (μ=85.949, SE=.576) (p=.000).

Between groups of the same walkability level, but differing on income level there were also statistically significant differences, with trends in the expected directions. The estimated marginal mean of the high walkability, low income group (μ=87.460, SE=.498) was significantly higher than that of the high walkability, high income group (μ=85.949, SE=.576) (p=.024). Similarly, the estimated marginal mean of the low walkability, low income group (μ=90.346, SE=.662) was significantly higher than that of the low walkability, high income group (μ=87.698, SE=.518) (p=.007).

Furthermore, the estimated marginal mean of the low walkability, low income group (μ=90.346, SE=.662) was significantly higher than that of the high walkability, high income group (μ=85.949, SE=.576) (p=.000), making it significantly higher than all other groups. A graphical representation of these results can be found in Figure 2.4.

Results for the independent variable, leisure-time physical activity correlates showed that across high income groups there were statistically significant differences in the expected direction. The estimated marginal mean of the 0 leisure-time physical activity correlates, high income group (μ=89.446, SE=.672) was significantly higher than that of both the 1-2 leisure-time physical activity correlates, high income group (μ=86.043, SE=.596) (p=.005) and the 3+ leisure-time physical activity correlates, high income group (μ=84.981, SE=.739) (p=.000). Comparatively, between low income groups there was only one statistically significant difference, which was between the 0 leisure-time physical activity correlates, low income group (μ=89.620, SE=.693) and the 3+ leisure-time physical activity correlates, low income group (μ=88.309, SE=.875) (p=.026). Between groups which had the same number of leisure-time physical activity correlates but different incomes there were no statistically significant differences. The estimated marginal mean of the 0 leisure-time physical activity correlates,

Figure 2.4 Estimated Marginal Means of Waist Girth across Walkability Groups, Stratified by Neighbourhood Income Level



*Statistically significant difference (p<.05) between:

1) High Walkability, High Income Group and:

- Low Walkability, High Income Group
- High Walkability, Low Income Group
- Low Walkability, Low Income Group

2) Low Walkability, Low Income Group and:

- High Walkability, Low Income Group
- Low Walkability, High Income Group

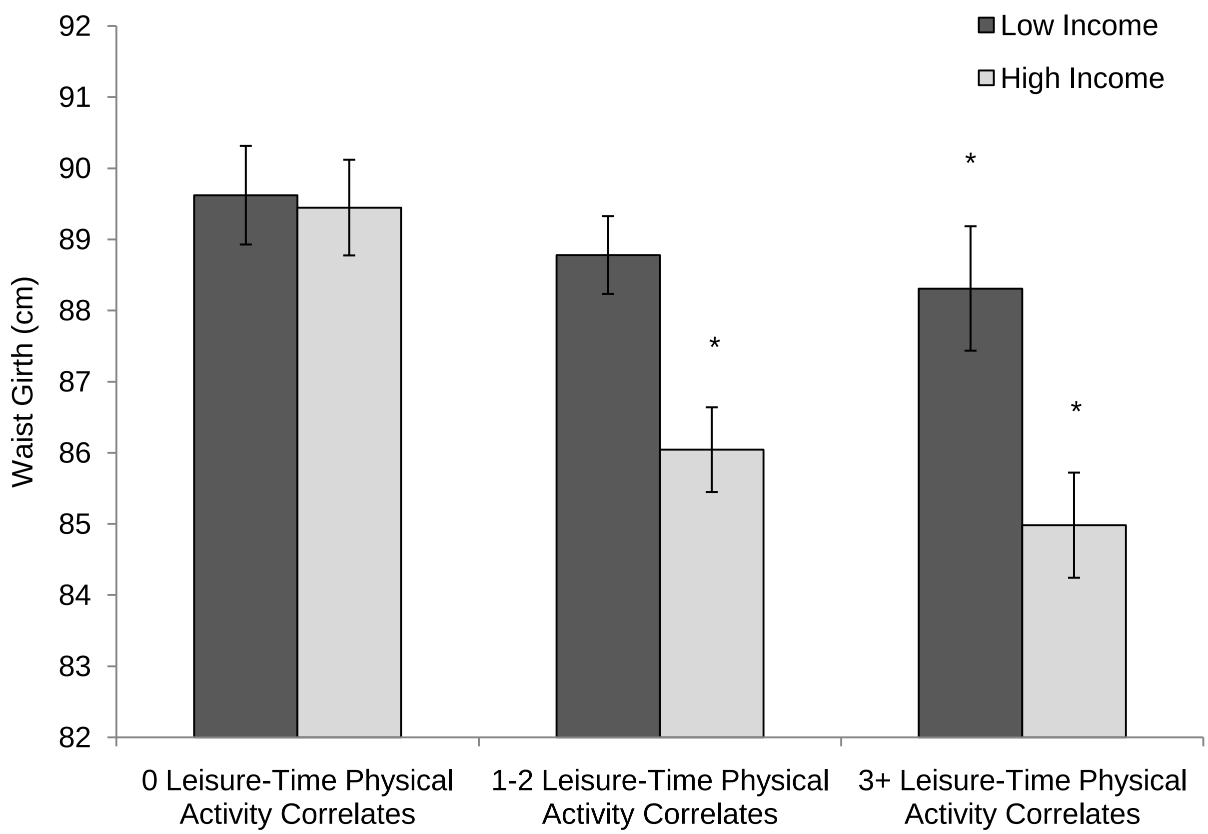
low income group (μ=89.620, SE=.693) was not significantly different from that of the 0 leisure-time physical activity correlates, high income group (μ=89.446, SE=.672) (p=.947). The estimated marginal mean of the 1-2 leisure-time physical activity correlates, low income group (μ=88.779, SE=.547) was not significantly different from that of the 1-2 leisure-time physical activity correlates, high income group (μ=86.043, SE=.596) (p=.065), and the estimated marginal mean of the 3+ leisure-time physical activity correlates, low income group (μ=88.309, SE=.875) was not significantly different from that of the 3+ leisure-time physical activity correlates, high income group (μ=84.981, SE=.739) (p=.055).

There were several statistically significant differences between groups which did not share the same number of leisure-time physical activity correlates or the same income level. The estimated marginal mean of the 0 leisure-time physical activity correlates, low income group (μ=89.620, SE=.693) was significantly different from that of the 1-2 leisure-time physical activity correlates, high income group (μ=86.043, SE=.596) (p=.000) and that of the 3+ leisure-time physical activity correlates, high income group (μ=84.981, SE=.739) (p=.000). Lastly, the estimated marginal mean of the 1-2 leisure-time physical activity correlates, low income group (μ=88.779, SE=.547) was significantly different from that of the 3+ leisure-time physical activity correlates, high income group (μ=84.981, SE=.739) (p=.000). A graphical representation of these results can be found in Figure 2.5.

2.3.2 High-Density Lipoprotein Cholesterol

After elimination of the 2009 cohort, those individuals using blood pressure and/or cholesterol medication (n=429), and elimination of extreme outliers on HDL-C concentration (n=3), participants used for the analysis of HDL-C concentration consisted of 2414 individuals, 1478 females (61%) and 936 males (39%). Table 2.7 outlines scores on HDL-C concentration for this sample. The sample was 75% Caucasian with an average age of 45.5 years, SD=14.1, range=19-82. A two-way ANOVA was conducted to assess the influence of walkability level and

Figure 2.5 Estimated Marginal Means of Waist Girth across Leisure-Time Physical Activity Correlate Groups, Stratified by Neighbourhood Income Level



*Statistically significant difference (p<.05) between:

1) 3+ Leisure-Time Physical Activity Correlates, High Income Group and:

- 0 Leisure-Time Physical Activity Correlates, High Income Group
- 0 Leisure-Time Physical Activity Correlates, Low Income Group
- 1-2 Leisure-Time Physical Activity Correlates, Low Income Group

2) 1-2 Leisure-Time Physical Activity Correlates, High Income Group and:

- 0 Leisure-Time Physical Activity Correlates, High Income Group
- 0 Leisure-Time Physical Activity Correlates, Low Income Group

3) 3+ Leisure-Time Physical Activity Correlates, Low Income Group and:

- 0 Leisure-Time Physical Activity Correlates, Low Income Group

Table 2.7 Mean Scores of High-Density Lipoprotein Cholesterol Concentration, by Sex

	Sub-Sample (N=2414)	**Males (n=936)**	**Females (n=1478)**
	Mean ± Standard Deviation	Mean ± Standard Deviation	Mean ± Standard Deviation
HDL-C (mmol/L)	1.32 ± .40	1.10 ± .33	1.46 ± .38

leisure-time physical activity correlate level on HDL-C concentration scores across income groups. Estimated marginal mean scores of participants, for HDL-C concentration are outlined in Table 2.5 for walkability groups and Table 2.6 for leisure-time physical activity correlate groups. A two-way between groups ANOVA was used to examine the influence of walkability and leisure-time physical activity correlates on HDL-C concentration. Normality of the dependent variable was visually inspected using a histogram. Levene's Test of Equality of Error Variances gave a non-significant result (p=.059), and thus the assumption of homogeneity of variance was not violated. Walkability had a non-significant effect [F(2, 2402)=.476, p=.621, partial eta squared=.000], but observed power of the analysis was extremely low (observed power=.128). Leisure-time physical activity correlates also had a non-significant effect [F(4, 2402)=2.149, p=.072, partial eta squared=.004), as did the interaction effect [F(4, 2402)=1.378, p=.239, partial eta squared=.002). The observed power values of these two tests were more reasonable, although still slightly low (observed power; leisure-time physical activity correlates=.639, Interaction=.434). A graphical representation of the results of the analysis of HDL-C concentration can be seen in Figure 2.6 for the independent variable walkability and in Figure 2.7 for the independent variable leisure-time physical activity correlates.

2.3.3 Systolic Blood Pressure

After elimination of the 2009 cohort, of those individuals using blood pressure and/or cholesterol medication (n=429), and of extreme outliers on systolic blood pressure (n=12), participants used for the analysis of systolic blood pressure consisted of 2405 individuals, 1475 females (61%) and 930 males (39%). Table 2.8 outlines scores on systolic blood pressure for this sample. The sample was 75% Caucasian with an average age of 45 years, SD=14, range=19-82. A two-way ANOVA was conducted to assess the influence of walkability level and number of leisure-time physical activity correlates on systolic blood pressure across the two income levels.

Figure 2.6 Estimated Marginal Means of High-Density Lipoprotein Cholesterol Concentration across Walkability Groups, Stratified by Neighbourhood Income Level

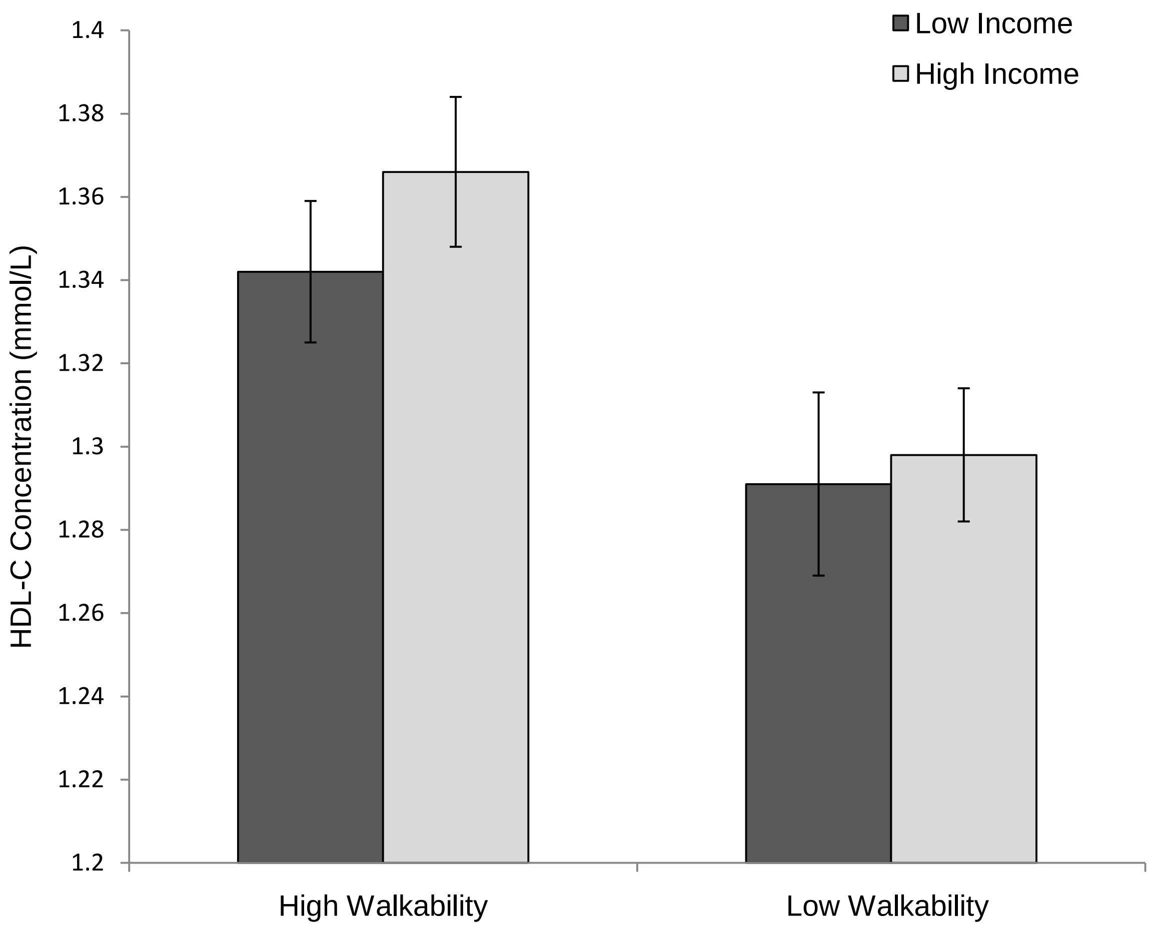


Figure 2.7 Estimated Marginal Means of High-Density Lipoprotein Cholesterol Concentration across Leisure-Time Physical Activity Correlate Groups, Stratified by Neighbourhood Income Level

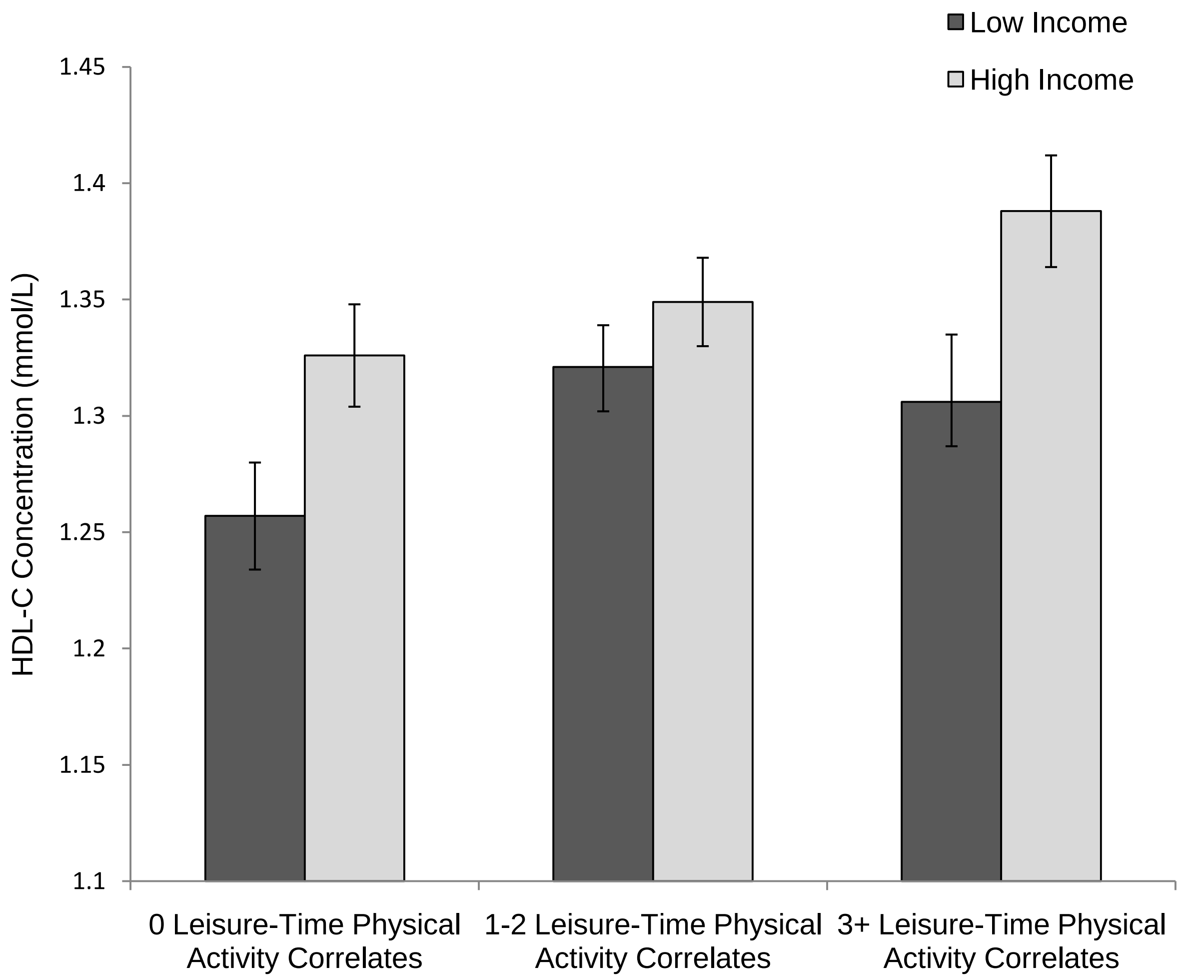
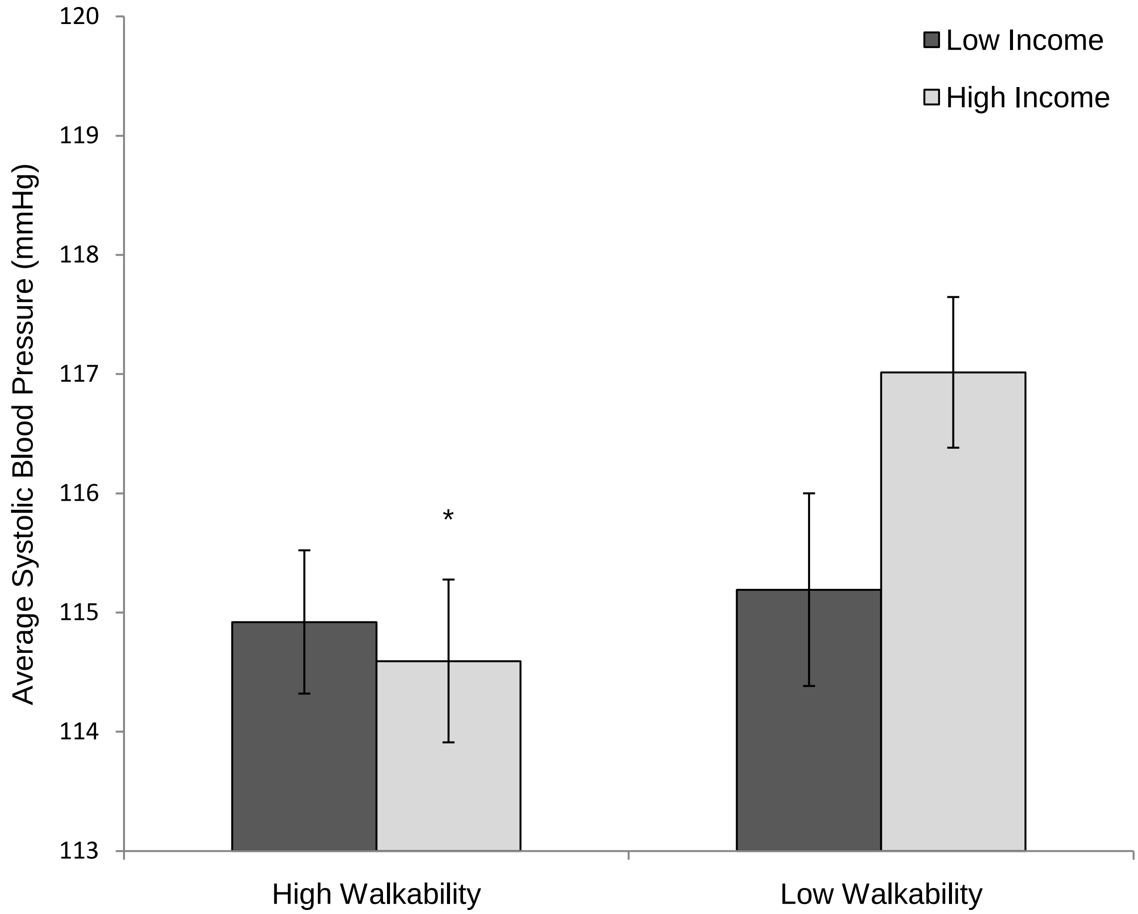


Table 2.8 Mean Scores of Systolic Blood Pressure, by Sex

	Sub-Sample (N=2405)	**Males (n=930)**	**Females (n=1475)**
	Mean ± Standard Deviation	Mean ± Standard Deviation	Mean ± Standard Deviation
Systolic Blood Pressure (mmHg)	115.6 ± 14.8	119.5 ± 13.7	113.1 ± 14.9

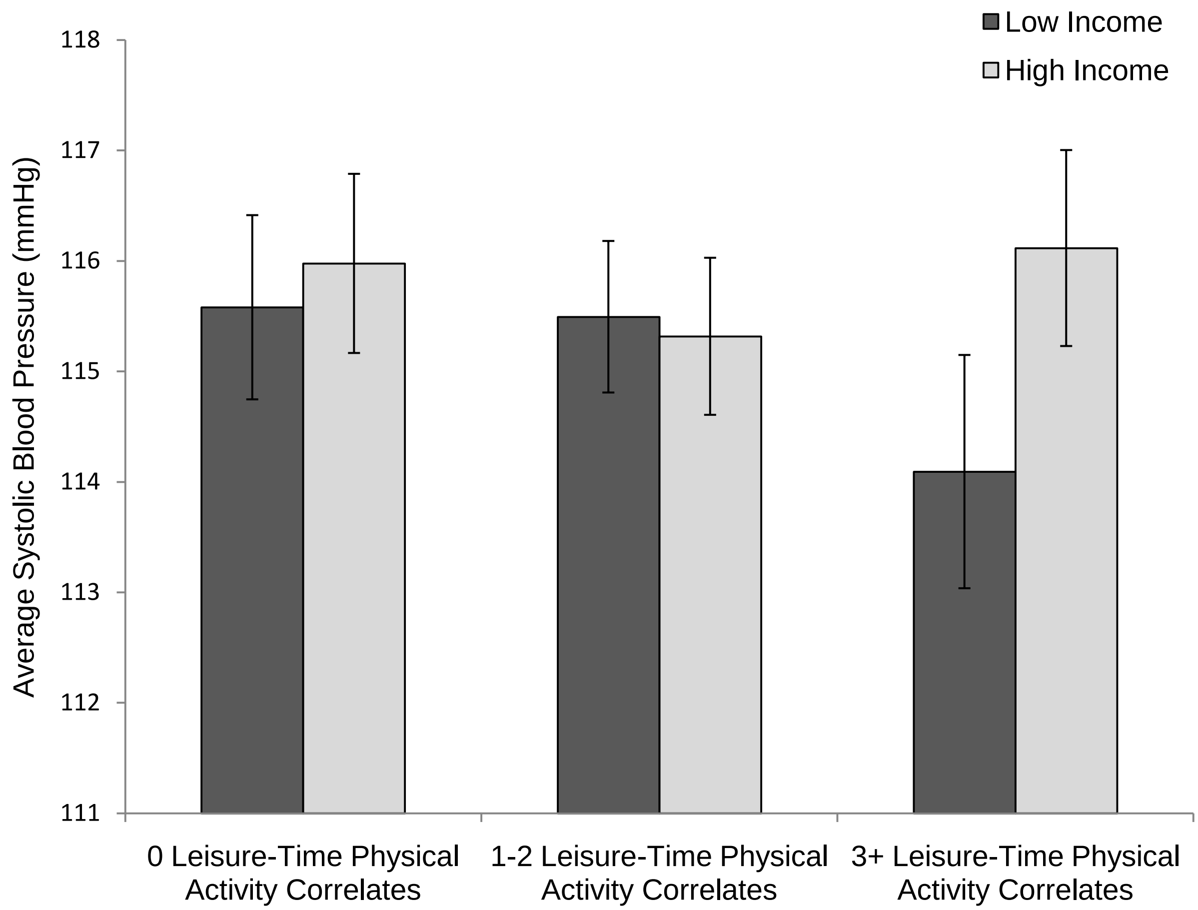
Estimated marginal means of participants' systolic blood pressure, across walkability groups, are outlined in Table 2.5. Table 2.6 outlines estimated marginal means of participants across leisure-time physical activity correlate groups. A two-way between groups analysis of variance was used to examine the influence of walkability and leisure-time physical activity correlates on systolic blood pressure. Normality of the dependent variable was visually inspected using a histogram. Levene's Test of Equality of Error Variances gave a non-significant result ($p=.390$), and thus the assumption of homogeneity of variance was not violated. Leisure-time physical activity correlates had a non-significant effect [$F(4, 2393)=.526$, $p=.717$, partial eta squared=.001), as did the interaction effect [$F(4, 2393)=.303$, $p=.876$, partial eta squared=.001). There was, however, a statistically significant main effect for walkability [$F(2, 2393)=3.416$, $p=.033$; partial eta squared=.003). Post-hoc comparisons, performed using Tukey's HSD, revealed only one statistically significant difference, which was between estimated marginal means of the high walkability, high income group ($\mu=114.593$, SE=.683) and the low walkability, high income group ($\mu=117.014$, SE=.632)($p=.030$). A graphical representation of the results of the analysis of systolic blood pressure can be seen in Figure 2.8 for the independent variable walkability, and in Figure 2.9 for the independent variable leisure-time physical activity correlates.

Figure 2.8 Estimated Marginal Means of Systolic Blood Pressure across Walkability Groups, Stratified by Neighbourhood Income Level



*Statistically significant difference (p<.05) between High Walkability, High Income group and Low Walkability, High Income group

Figure 2.9 Estimated Marginal Means of Systolic Blood Pressure across Leisure-Time Physical Activity Correlate Groups, Stratified by Neighbourhood Income Level



2.4 Discussion

The primary purpose of this research was to extend investigation into the relationship between the neighbourhood-level, urban, built environment and cardiovascular risk. Specifically, it was to observe levels of several physical activity-moderated cardiovascular risk factors in environments varying on level of walkability and number of leisure-time physical activity correlates. The current investigation is the first to measure objectively levels of several physical-activity moderated cardiovascular risk factors in relation to level of objectively measured neighbourhood walkability and number of leisure-time physical activity correlates.

2.4.1 Methodological Considerations

The Neighbourhood Walkability Index was used to evaluate the level of walkability of each participant's neighbourhood in an effort to reduce the effect of the spatial collinearity of the built environment variables and to remain consistent with previous investigations. This, or similar, composite scores have been employed by numerous previous investigations for the same purpose (Frank, Schmid et al. 2005; Kerr, Rosenberg et al. 2006; Norman, Nutter et al. 2006; Frank, Saelens et al. 2007; Kligerman, Sallis et al. 2007; Frank, Sallis et al. 2009; Pouliou and Elliott 2010). The z-score of street connectivity was weighted twice as heavily as residential density and land use mix because of the strong relationship between street connectivity and non-motorized travel choice (Saelens, Sallis et al. 2003; Frank, Sallis et al. 2009). The current version of the walkability index, which previously included an additional variable (i.e., retail floor area ratio) was chosen because it has been checked for face validity (Frank, Sallis et al. 2009).

Network buffers of 750 metres in length were employed to define participant neighbourhoods. The goal of this process was to accurately capture the area in which individuals were most likely to exhibit neighbourhood-affected physical activity. Network buffers were chosen because, compared to circular buffers, they have shown greater association with walking and have been hypothesized to more accurately capture the built environment as it is experienced by pedestrians (Oliver, Schuurman et al. 2007). The distance of 750 metres was chosen as it represents the distance that an individual could travel in ten minutes time, at a walking pace of five kilometres per hour.

Our use of the land use mix entropy equation differed slightly from previous investigations. As the current investigation utilizes a Canadian sample, available land use data differed from American examples (Frank, Schmid et al. 2005; Frank, Saelens et al. 2007). Land use mix has been defined in some previous investigations as the evenness of residential, commercial and office development within each neighbourhood (Frank, Schmid et al. 2005; Frank, Saelens et al. 2007). However, for the purpose of this investigation, land use mix was defined as the evenness of “Residential”, “Commercial” and “Government and Institutional” development within each neighbourhood. Substitution of the “Government and Institutional” category of land use, for the previous employed “Office” category (Frank, Schmid et al. 2005; Frank, Saelens et al. 2007) was decided on because, hypothetically, this category of land use would similarly represent the presence of jobs and a labour force within the area.

In contrast to commonly employed methodology which would retain one size of geographic buffer to assess all correlates of physical activity, our geographic buffers were extended by 50 metres in all directions to assess the presence of a water-body within a participant’s neighbourhood. This was done because our buffer size was based on the distance that individuals were presumed to be willing to walk within their neighbourhood and because hypothetically one would not have to actually be able to get to a water-body, but rather be able to see it, in order for its presence to potentially increase leisure-time physical activity.

2.4.2 Neighbourhood-Level Income

Previous research has identified socioeconomic status as a correlate of cardiovascular risk (Sallis, Saelens et al. 2009; Karlamangla, Merkin et al. 2010) each group in the current investigation, categorized by neighbourhood walkability and number of leisure-time physical activity correlates, were additionally stratified by neighbourhood income level.

It should be noted that in contrast to previous investigations which have sampled individuals from the highest and lowest portions of the income percentiles and eliminated central percentiles, in the current investigation the two income groups were not separated by an average income group. Additionally, our sampling techniques were not designed to select extremes of high and low income. The result is that our sample is likely made up of predominantly middle-class individuals, and thus findings can likely not be compared to earlier investigations which have employed the previously explained sampling methods.

Despite methodological variation from previous investigations, our findings did show some similarities to those previously observed. For instance, as expected based on previous research, groups from lower income neighbourhoods exhibited consistently trends towards more risk compared to groups from higher income neighbourhoods, which were otherwise similarly categorized (based on either level of walkability or number of leisure-time physical activity correlates). Similar observations have been made in the past in relation to BMI and neighbourhood walkability (Sallis, Saelens et al. 2009). One exception to this observation was systolic blood pressure. Although the one statistically significant group difference observed for this variable was in the expected direction, other estimated marginal mean differences, which did not reach statistical significance, were in an unexpected direction; in several instances high income groups exhibited marginally higher systolic blood pressure compared to low income groups. This is likely explained by measurement issues and the effect size of neighbourhood-related physical activity on blood pressure. Systolic blood pressure has been shown to be sensitive to a variety of acute factors (e.g., recent bouts of physical activity, stress, anxiety) (Thompson, Crouse et al. 2001; Fagard 2006) and also a variety of long-term factors (e.g., air pollution, smoking behaviour, salt and alcohol intake, age) (Saladin 2001; Campbell, Khan et al. 2009; Chuang, Yan et al. 2010) which may have masked affects of neighbourhood-related physical activity on our measure of systolic blood pressure.

Another exception to the observation of groups from high income neighbourhoods exhibiting less risk than groups from low income neighbourhoods was between high and low neighbourhood income groups with zero leisure-time physical activity correlates. Interestingly, these two groups had very similar BMI scores and very similar waist girths. Differences between groups with the same number of leisure-time physical activity correlates but differing on neighbourhood income increased with the number of leisure-time physical activity correlates. These findings could support a hypothesis that high neighbourhood income groups are more strongly affected by increased presence of neighbourhood-level leisure-time physical activity correlates, than low income groups. As an explanation of this observation, it is possible that individuals living in high income neighbourhoods have more leisure-time in which to use and enjoy such attributes of their neighbourhoods. This would be in line with previous research which similarly examined a west-coast Canadian sample, and identified the belief of regular recreational physical activity (walking in particular) taking too much time as negatively associated with leisure-time walking (Rhodes, Blanchard et al. 2009). Alternatively, it is possible that residents of high and low income neighbourhoods perceive leisure-time physical activity correlates differently. Wilson and colleagues (2004) reported that low-socioeconomic groups perceived sidewalk and recreational facilities to be less, compared to high-socioeconomic status groups, despite objective measures indicating otherwise. Alternatively, parks and water-bodies could be qualitatively different between high and low income neighbourhoods (e.g., access, cost, aesthetic quality, infrastructure present).

2.4.3 Neighbourhood Walkability

High neighbourhood walkability groups were hypothesized to exhibit significantly lower physical activity-moderated cardiovascular risk factor scores (i.e., lower BMI, lower waist girth, lower systolic blood pressure and higher HDL-C concentration) than groups with low neighbourhood walkability.

Our observation of significantly lower BMI scores in areas of higher walkability are in line with previous research (Ewing, Schmid et al. 2003; Giles-Corti, Macintyre et al. 2003; Saelens, Sallis et al. 2003; Frank, Andresen et al. 2004; Lopez 2004; Frank, Sallis et al. 2006; Sallis, Saelens et al. 2009). These observations can be explained by findings that residents of high walkability neighbourhoods exhibit higher rates of objectively measured physical activity than residents of low walkability neighbourhoods (Frank, Schmid et al. 2005; Sallis, Saelens et al. 2009). Specifically, being a resident of a low versus high walkability neighbourhood in this investigation was associated with BMI scores which were .95 and .69 larger in low and high income neighbourhoods respectively.

However, important cardiometabolic risk markers are missed when BMI alone is reported (Lee, Kuk et al. 2005). Waist girth is an indirect measure of abdominal adiposity which provides additional information, beyond that provided by BMI, about the distribution of adipose tissue (Canoy 2008). This is important because the location of adipose tissue appears to radically alter the cardiovascular risk associated with adiposity (Van Gaal, Mertens et al. 2006). Additionally, total and visceral fat have both been shown to decrease despite total body-weight maintenance (and thus maintenance of BMI) (Lee, Kuk et al. 2005). Therefore, our findings of lower waist girths among residents of high versus low walkability neighbourhoods are important. Specifically, being a resident of a low versus high walkability neighbourhood was associated with waist girths which were 2.9cms and 1.7cms larger, in low and high income neighbourhoods, respectively.

Significant differences were found also for systolic blood pressure between high and low walkability neighbourhoods for high income groups only, whereby being a resident of a low versus high walkability neighbourhood was associated with systolic blood pressure scores 2.4mmHg higher. Together, these findings regarding BMI, waist girth and systolic blood pressure support the role of neighbourhood walkability in affecting cardiovascular risk. Additionally, the trends observed for BMI, waist girth and HDL-C concentration identify neighbourhoods which are low on walkability and low income, relatively speaking, as high risk areas.

2.4.4 Leisure-Time Physical Activity Correlates

The hypothesis that residents of neighbourhoods with more leisure-time physical activity correlates would exhibit lower risk associated with several physical activity-moderated cardiovascular risk factors was supported. This is in line with previous research which has shown that individuals living closest to formal parks were more likely to achieve physical activity recommendations, and were less likely to be overweight or obese (Coombes, Jones et al. 2010). In the current investigation, significantly lower scores were exhibited in the cases of BMI and waist girth. The current investigation is the first to measure objectively levels of several physical-activity-moderated cardiovascular risk factors in relation to number of neighbourhood-level leisure-time physical activity correlates. Our findings seem to suggest that there is an association between access to leisure-time physical activity correlates (defined as having parks and/or water-bodies within one's neighbourhood) and physical activity.

Number of leisure-time physical activity correlates, with groups stratified by neighbourhood income level, showed statistically significant differences across high income groups only for BMI, and across high and low income groups for waist girth.

High-density lipoprotein cholesterol concentrations exhibited similar trends to BMI and waist girth in relation to number of leisure-time physical activity correlates, which is logical as research has shown that serum lipid concentrations are strongly associated with waist girth (Brenner, Tepylo et al. 2010), and visceral adipose tissue accumulation is a strong independent predictor of dyslipidemia (Kuk, Katzmarzyk et al. 2006). No statistically significant differences were found for this variable, despite group HDL-C concentration differences which were similar in magnitude to mean net changes in HDL-C concentration (0.065mmol/L) found in a recent review of the effect of exercise interventions on serum HDL-C concentration (Kodama, Tanaka et al. 2007). Average HDL-C concentration is higher among females, compared to males

(Maron 2000). It is likely that failing to analyze separately male and female groups negatively affected our likelihood of obtaining statistically significant results. Future investigations could potentially obtain different results if able to separately analyze male and female samples.

Systolic blood pressure results did not follow hypothesized trends, and no statistically significant differences were found for this variable either, in relation to number of leisure-time physical activity correlates. It is possible that confounding factors such as smoking behaviour, dietary intake, air pollution, or psychological stress may be influencing blood pressure and masking any effects of neighbourhood-level leisure-time physical activity correlates on physical activity rates (Fredrickson, Maynard et al. 2000; Ross, Tremblay et al. 2007; Campbell, Khan et al. 2009; Chuang, Yan et al. 2010).

Overall, our findings regarding the affect of leisure-time physical activity correlates contribute to evidence demonstrating that parks within close proximity to residential locations can have a positive effect on public health. Additionally, residents of low income neighbourhoods with zero leisure-time physical activity correlates exhibited lower estimated marginal means than all other leisure-time physical activity correlates groups in all cases except systolic blood pressure. Such findings advocate for creation of parks in areas where there are none, and policy which would require new residential development to include parks.

2.4.5 Conclusion

Overall, the trends within our results show decreased risk amongst populations living in areas of greater walkability, populations living in areas with more access to leisure-time physical activity correlates and in higher income populations. These findings provide support for the hypothesis that the presence of such built environment features, or alternatively a lack thereof, affects physical activity levels to the extent of influencing several independent cardiovascular risk factors. Specifically we have seen significantly lower BMI scores, significantly lower waist girths and trends towards higher serum HDL-C concentrations in residents of more walkable neighbourhoods, in residents of neighbourhoods with more leisure-time physical activity correlates and in residents of higher income neighbourhoods. There is some support for similar effects on systolic blood pressure, however this was limited to high income populations and was only seen in relation to level of walkability.

Investigations into the relationship between the built environment, and both physical activity and weight status are relatively abundant. However, investigations using Canadian populations and objectively measuring more than one cardiovascular risk factor are limited. Several novel observations were made in this investigation. To the best of our knowledge the relationships between neighbourhood walkability and both waist girth and HDL-C concentration have not been previously examined. Our research adds to a growing body of literature and is also to the best of our knowledge the first to investigate additional physical activity-moderated cardiovascular risk factors, all of which were objectively measured. Evidence of a relationship between the neighbourhood-level built environment and resident health is growing. Changing environments which may currently inhibit physically active lifestyles and requiring new development to facilitate physically active lifestyles should likely be considered as potential components of obesity and cardiovascular disease risk reduction initiatives.

CHAPTER 3

Conclusion

3.1 Conclusion

The manuscript presented within this thesis is, to the best of our knowledge, the first to examine several objectively measured cardiovascular risk factors in relation to either neighbourhood walkability or access to leisure-time physical activity correlates. Investigations into these relationships are important in light of the current obesity epidemic and subsequent focus on the built environment as a means to improve population health. Our findings, for the most part, support the hypothesis that, on average, individuals living in neighbourhoods of lower walkability and with less access to leisure-time physical activity correlates exhibit less total physical activity. The exception is with regards to systolic blood pressure and leisure-time physical activity correlates, which may be a result of a lack of increased intense physical activity with increased access to leisure-time physical activity correlates. Overall, however, our results support claims that built environment features which facilitate physical activity within one's environment exert an influence on population levels of total physical activity and subsequently several markers of cardiovascular risk.

Our investigation has focused on positive potential effects of changing built environment design to facilitate physical activity. However, negative potential effects on health, safety and crime, amongst other things, need to be considered as well. For instance, environmental health effects such as increased air pollution may be associated with increased walkability. A recent investigation, which examined walkability in relation to ambient concentrations of nitric oxide and ozone, found that air pollution was higher in areas of greater walkability (Marshall, Brauer et al. 2009). However, as greater walkability infers increased residential density, communities were likely to have expanded vertically. This means that a greater percentage of the population is likely to live in high-rises where air pollution concentrations are less than at ground level. Regardless, it is possible that individual exposure to air pollution would be increased in neighbourhoods of greater walkability. This negative effect can be countered, however, with evidence that in areas of increased walkability total emissions decrease due to decreased dependence on automobiles and less vehicle miles travelled per individual, per day (Marshall, Brauer et al. 2009). Decreased reliance on automobiles infers an increased dependence on one's neighbourhood to provide amenities such as healthy food options, recreational opportunities and educational facilities. A factor which decreases a pedestrian's reliance on his or her neighbourhood for such resources is adequate public transportation. Cycling also extends the definition of one's neighbourhood by increasing mobility; with increased speed and efficiency, individuals can travel further from their home to find resources, without using an automobile. Thus, the importance of considering public transportation in addition to street connectivity and land use policy is important.

The geographic interconnectedness of built environment features, resident behaviours, and health emphasizes the importance of adopting a holistic approach to new urban design. As outlined by the Robert Wood Johnson Foundation, there are many steps, including performing additional research, weighing evidence and synthesizing results which need to occur before policy development and ultimately built environment changes should be considered. The results presented within the manuscript of this thesis represent only a small step in that greater goal of utilizing the built environment as a tool to improve, rather than hinder, population health .

3.1.2 Practical Significance

All the statistically significant group differences observed in this investigation were associated with small effect sizes, as calculated using partial eta squared. This infers that although statistically significant, these differences may not be of practical significance. However, as is well understood, small effect sizes may be relevant at the population level. Interest in the influence of the built environment on physical activity is based on its potential to affect entire populations. The persisting presence, and thus hypothetically the persisting influence of the built environment also potentially makes small influences practically significant.

In addition to these inherent characteristics of the built environment which position it as an influential factor at a population level, there is also the fact that no purposeful ‘treatment’ was performed in the current investigation. Thus, the effect sizes observed relate to the naturally occurring differences in physical activity associated with living in various environments. If a treatment, for instance in the form of a public education campaign, were implemented, individual attitudes as well as the social norm may change and the effects may well become stronger (Ajzen 1991). Using an ecological model of physical activity, the built environment is only the place in which individual behaviour occurs. Although the place is said to influence behaviour, intra- and inter-individual psychosocial influences would also be at play (Sallis, Cervero et al. 2006). Therefore, effect sizes may be stronger if future investigations were able to incorporate a treatment designed to increase awareness of the potential for the built environment to facilitate physical activity, and the further potential for this to effect health.

3.1 Strengths and Limitations

This investigation has several strengths, including objective measures of several cardiovascular risk factors, and objective measures of neighbourhood walkability and number of leisure-time physical activity correlates. Additionally, we were able to include participants from a large number of communities, whereas other investigations have often compared residents of only a few neighbourhoods. Furthermore, our built environment data source was the same for the entire sample, and thus we do not have to be concerned about differences in data quality or detail across neighbourhoods.

Collecting objectively measured cardiovascular data on such a large and geographically broad sample had its logistical difficulties. Thus it was not possible to control for several factors which would generally be controlled for in laboratory settings. For example, we were unable to control for physical activity sessions which may have taken place prior to cardiovascular data collection, which could potentially have acutely lowered blood pressure and increased HDL-C concentrations (Warburton, Nicol et al. 2006). Fasting lipid measures were not logistically possible. Therefore, only HDL-C measures were used, as opposed to total cholesterol / HDL-C ratio which is more sensitive to daily fluctuations but is more regularly employed to infer cardiovascular risk (Enger, Herbjornsen et al. 1977; Tan, Seshadri et al. 2003). Additionally, participants were self-selected for participation in cardiovascular data collection.

Measurement of the built environment has several limitations as well. The majority of investigations using the Neighbourhood Walkability Index have employed parcel based land use data, often aerial images, from which building footprints can be determined. Because our data was not able to provide building footprints, we were unable to calculate retail floor area ratio, a construct which has been employed in several of the most recent investigations using the Neighbourhood Walkability Index (Norman, Nutter et al. 2006; Frank, Sallis et al. 2009; Kerr, Norman et al. 2010). Additionally, we did not have information about our participants' personal or household income, which several investigations have used as an alternative to, or in conjunction with, neighbourhood-level income. Personal education level has also been employed in several similar investigations, and this information was not available in the current study.

We did not use any measure of participants' physical activity levels. Categorical data was available on self-reported frequency of accumulating 30 minutes or more of moderate intensity physical activity per week. However as this did not speak directly to one specific behavioural group of physical activity, nor did it speak to total physical activity (i.e., likely would not include all utilitarian physical activity), this measure was not employed in any statistical analyses. The strength of this investigation would have been increased if physical activity (preferably distinguishing between leisure-time and utilitarian pursuits) had been assessed, as physical activity is the mediating factor of interest between the built environment and improved cardiovascular risk.

With a greater sample size, it may have been possible to compare effects of several factors, such as sex, ethnicity, or age. All of these variants have been proposed as moderators of the built environment – physical activity relationship (Frank, Andresen et al. 2004; Shigematsu, Sallis et al. 2009). A larger sample size would have facilitated the analysis of sex groups separately. This may have been appropriate in the case of HDL-C concentration analyses and waist girth, as each are generally markedly different in males and females (Maron 2000).

3.2 Future Research

As others have stated, this body of research would benefit from longitudinal investigations with the potential to infer causality between the built environment, physical activity, and cardiovascular health. However, such investigations are appreciably difficult to design and run. Although they have been suggested by others (Frank and Kavage 2009; Feng, Glass et al. 2010) very few have emerged. As an alternative, consistency in measures of the built environment across investigations would facilitate greater synthesis of findings (Feng, Glass et al. 2010). Measurement consistency has been identified as an important factor for consideration in the future design of investigations examining the relationship between the built environment and physical activity behaviour (Brownson, Hoehner et al. 2009). Consensus, however, on which methodology should be replicated in multiple populations, first requires substantial investigation into the validity and reliability of varying methodological approaches.

More investigations of the built environment (and specific attributes of it) using objective measures of physical activity as outcome measures would be beneficial in quantifying the forms, frequencies, durations and intensities of physical activity exhibited in the built environment. Additionally, although understanding the neighbourhood built environment's effect on physical activity is important, a large portion of each day is generally spent around one's place of work and so opportunities for physical activity in this environment may well be important to increasing total physical activity as well. This being said, previous research has reported that, in the United States, approximately 83% of trips are for non-work purposes (Frank, Sallis et al. 2009).

Our observations speak to a specific need for initiatives that target neighbourhoods that are both low walkability and low income, as well as neighbourhoods with no leisure-time physical activity correlates, as risk was almost consistently highest in these areas. Of greater immediate importance then increasing affordance for physical activity in North American society in general, may be decreasing built environment barriers to physical activity within disadvantaged neighbourhoods.

Finally, future research should consider specific physical activity classes, as different environmental factors seem to be related to different forms of physical activity, and different physical activity behaviours have different physiological effects. This is emerging in the most recent literature (e.g., Sallis, Saelens et al. 2009), but objectively measuring specific physical activity behaviours has proven difficult.

3.3 Summary of Document

The investigation presented within this thesis document extends previous knowledge about the rates of several cardiovascular risk factors in environments varying on level of affordance to active transportation and leisure-time physical activity. The design does not allow causality to be inferred. However, the trends within the data are relatively clear, especially in regards to BMI, waist girth and HDL-C. These results provide a foundation for further investigation. We observed significantly lower BMI scores, waist girths and systolic blood pressures, as well as marginally lower concentrations of HDL-C, among residents of high versus low walkability neighbourhoods. Similarly, we observed significantly lower BMI and waist girth scores among groups living in neighbourhoods with increased number of leisure-time physical activity correlates. Again, HDL-C trends were comparable to BMI and waist girth trends, although no significant differences were found. These findings speak to lesser adiposity and cardiometabolic risk associated with living in environments which score higher on the Neighbourhood Walkability Index and which have more leisure-time physical activity correlates. These findings are among the first of their kind, and provide evidence that the relationship between the built environment and physical activity which has been postulated to exist, and examined in other countries applies to the Canadian population as well.

Transportation research from 1995 which investigated the percentage of trips in urban areas made by walking or bicycling, showed that, in Canada, approximately 12% of trips were made using either walking, cycling, or a combination of the two. Ten of this 12% was walking specifically. Comparatively, seven European countries for which data was available (France, Italy, Switzerland, Germany, Austria, Sweden, Denmark and the Netherlands) ranged from 28-46% of trips which were made using one of these two modalities. Furthermore, in five of the above countries, 10% or more of all trips in urban areas were by bicycle. Cycling is generally associated with a higher level of physical exertion compared to walking, and so its potential to improve cardiovascular health could be considered greater. With low rates of active transportation generally reported in Canada, and much of that which is exhibited being in the form of walking as compared to cycling, the need for initiatives to increase active transportation across the nation is accentuated. Pucher and Dijkstra (2003) attributed differences between American and European active transportation rates (which are similar to Canadian European differences) in part, to increased risk of death and injury among pedestrians and cyclists in the United States compared to Europe. Logically, if active transportation is dangerous, or even is perceived as dangerous, then it will not be recognized as a reasonable pursuit. Thus, increasing environmental affordance for cycling as an active form of transportation, and overall promotion and affordance for walking may be reasonable components of future health promotion initiatives (Pucher and Dijkstra 2003). Knowledge about the potential of active transportation, and neighbourhood physical activity in general, to improve cardiovascular health may be able to provide support for bids to run such initiatives.

Obesogenic environments have been identified in several aspects of the North American lifestyle. Limiting features of the built environment which may negatively affect cardiovascular health seems to be paramount to combating the current obesity epidemic. Organizations such as Smart Growth BC, Health Communities BC and 8 – 80 Cities aim to eliminate built environment design which fosters inactivity and limits affordance for healthy, active lifestyles in

Canada. Alongside our Canadian Physical Activity Recommendations which call for “More Physical Activity, More Often” could go the recommendation for policy and environmental development of “More Opportunities, More Often”. Preferred means of accumulating sufficient physical activity can vary widely between individuals. For one, a new bike path in their neighbourhood will in no way increase their physical activity. For another, that same bike path may mean a switch to active commuting year-round. If we expect individuals to be physically active and responsible for their own cardiovascular health, then we need to increase the ease of accessing physical activity and certainly decrease design which hinders active lifestyle efforts.

This new body of research suggests that designing our communities to be more conducive to both leisure and utilitarian physical activity will increase levels of physical activity and, in turn, improve the cardiovascular health of certain individuals. Certainly more research is warranted to better understand how investments into education about neighbourhood opportunities for physical activity and neighbourhood physical activity infrastructure can increase physical activity (subsequently decreasing cardiovascular risk). Some initiatives may increase total physical activity the most amongst individuals who are already active, individuals who prefer and prioritize active lifestyles, and individuals who have a preference for active transportation. However, there is also evidence that infrastructural and community design may affect physical activity levels independent of intention (Rhodes, Courneya et al. 2007). The latter infers that currently sedentary or unmotivated individuals may also experience increased physical activity as a result of environmental interventions. Furthermore, built environment changes have the potential to affect a large portion of the population and have a lasting effect once implemented (Sallis, Cervero et al. 2006). At the very least, our knowledge of the relationship between the built environment and physical activity advocates limiting new development within Canada which restrains active lifestyles.

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Appendix A: Ethics Certificate

The University of British Columbia
Office of Research Services
Clinical Research Ethics Board – Room 210, 828
West 10th Avenue, Vancouver, BC V5Z 1L8

ETHICS CERTIFICATE OF FULL BOARD APPROVAL

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC CREB NUMBER:
Darren Warburton	UBC/Education/Human Kinetics	H07-03187

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
N/A

CO-INVESTIGATOR(S):

Mika Z. Johnson
Lindsay Nettlefold
Shannon S.D. Bredin

SPONSORING AGENCIES:

N/A

PROJECT TITLE:
The effectiveness of a novel community-based physical activity program on the risk for cardiovascular disease and diabetes in persons of different ethnicities

THE CURRENT UBC CREB APPROVAL FOR THIS STUDY EXPIRES: April 22, 2009

The full UBC Clinical Research Ethics Board has reviewed the above described research project, including associated documentation noted below, and finds the research project acceptable on ethical grounds for research involving human subjects and hereby grants approval.

REB FULL BOARD MEETING REVIEW DATE:

April 22, 2008

DOCUMENTS INCLUDED IN THIS APPROVAL:			DATE DOCUMENTS APPROVED:
Document Name	Version	Date	
Protocol:			
Research Proposal	2	March 19, 2008	
Consent Forms:			
Consent form Version 3	3	May 8, 2008	
Advertisements:			
Recruitment Notice	2	March 14, 2008	
Questionnaire, Questionnaire Cover Letter, Tests:			
Godin Leisure Time Exercise Questionnaire	N/A	January 10, 2008	
Physical Activity Log for Accelerometry	N/A	April 10, 2008	**May 23, 2008**
Physical Self Perceptions Profile	N/A	January 10, 2008	
Seven day food diary	N/A	January 10, 2008	
Health History Questionnaire	1	March 19, 2008	
Home Environment Scale	N/A	January 10, 2008	
Neighbourhood Environment Walkability Scale	N/A	January 10, 2008	
Letter of Initial Contact:			
Letter of Initial Contact	2	March 14, 2008	

CERTIFICATION:
In respect of clinical trials:
1. The membership of this Research Ethics Board complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations.
2. The Research Ethics Board carries out its functions in a manner consistent with Good Clinical Practices.
3. This Research Ethics Board has reviewed and approved the clinical trial protocol and informed consent form for the trial which is to be conducted by the qualified investigator named above at the specified clinical trial site. This approval and the views of this Research Ethics Board have been documented in writing

The documentation included for the above-named project has been reviewed by the UBC CREB, and the research study, as presented in the documentation, was found to be acceptable on ethical grounds for research involving human subjects and was approved by the UBC CREB.

Approval of the Clinical Research Ethics Board by one of:

Dr. Gail Bellward, Chair

Appendix B: Residential Locations of Participants According to Postal Code

Abbotsford, Aldergrove, Anmore, Brentwood, Burnaby, Cambell River, Castelgar, Chilliwack, Coldstream, Comox, Coquitlam, Courtenay, Cranbrook, Dawson Creek, Delta, Duncan, Fort St. John, Kamloops, Kelowna, Kimberly, Kitimat, Ladysmith, Langley, Maple Ridge, Mission, Nanaimo, Nelson, New Westminster, North Saanich, North Vancouver, Oyama, Parksville, Penticton, Pitt Meadows, Port Alberni, Port Coquitlam, Port Moody, Powell River, Prince George, Prince Rupert, Qualicum Beach, Quesnel, Richmond, Saanichton, Salmon Arm, Sidney, Sooke, Surrey, Terrace, Thornhill, Trail, Vancouver, Vernon, Victoria, West Vancouver, Westbank, White Rock, Williams Lake, Winfield