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The Association Between Neighbourhood Walkability And Adult Body Mass Index In Urban Canada: A Cross-sectional Analysis.

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Abstract

This study sets out to examine whether there was a cross-sectional association between neighbourhood walkability and obesity in adults aged 18 to 64 years. The data source was the 2010/11 cycle of the National Population Health Survey merged with the 2011 Census and DMTI built environment data. A mediation analysis was undertaken to investigate whether physical activity was a mediator in the pathway between a measure of neighbourhood walkability and obesity. Multivariable regression results revealed no statistically significant associations between any of the neighbourhood walkability measures and adult BMI. Similar results were found for males and females. This study did not find that physical activity mediated an association between neighbourhood walkability and adult obesity.

Keywords

Built Environment; Walkability; Obesity; Body Mass Index; Physical Activity; Mediation

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List of Abbreviations

BMI – Body Mass Index

CCHS – Canadian Community Health Survey

CI – Confidence Interval (95%)

CMA – Census Metropolitan Area

CVD – Cardiovascular Disease

GIS – Geographical Information Systems

IPAQ – International Physical Activity Questionnaire

LSOA – Layer Super Output Area

LTPA – Leisure-time physical activity

MVPA – Moderate-to-vigorous physical activity

NPAQ – Neighbourhood Physical Activity Questionnaire

NPHS – National Population Health Survey

OECD – Organization for Economic Co-operation

OLS – Ordinary least squares

OR – Odds ratio

PHAC – Public Health Agency of Canada

PBC – Perceived Behavioural Control

SE – Standard Error

SES – Socioeconomic status

WTHR – Waist-to-hip-ratio or Waist Circumference

WHO – World Health Organization

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Chapter 1

1 Background and Introduction

1.1 Adult Obesity Prevalence

Over the last two decades the world has witnessed a sharp rise in obesity rates, steering public health authorities to prioritize their efforts towards health behaviours influencing energy intake and expenditure, and environmental factors.[1] In 2014, the global prevalence of overweight and obese adults 18 years of age and older was 39% and 13%, respectively. The World Health Organization (WHO) and Health Canada measure obesity using the body mass index (BMI), which is calculated using an individual's weight in kilograms divided by the square of height, in meters (kg/m^2). This obesity classification system assigns a BMI greater than or equal to 25 kg/m^2 and less than 30 kg/m^2 as overweight, and a BMI greater than or equal to 30 kg/m^2 as obesity.[23] According to this definition, approximately 54% of the adult population (i.e. 61.8% of men and 46.2% of women) 18 years of age and older in Canada were categorized as being overweight or obese.[2,4]

1.2 Burden of Obesity in Canada

1.2.1 Health-related Consequences

The risk of all-cause mortality is higher for overweight and obese individuals.[2] Obesity is a risk factor for a number of chronic diseases such as cardiovascular diseases (e.g. heart disease and stroke), musculoskeletal disorders (e.g. osteoarthritis), certain cancers, and other health conditions such as sleep apnea.[2,3] Other consequences of this preventable disease are psychological and mental health illnesses such as depression, anxiety, poor self-esteem and a low quality of life.[5]

1.2.2 Economic Cost

The economic burden of obesity in Canada corresponds to the direct and indirect costs of related diseases. Direct medical care costs of obesity in Canada were estimated at $6 billion in 2010, comprising 4.1% of the total health care costs.[6] Indirect costs of obesity are attributed to morbidity and mortality costs which are defined as the loss of income from time off of work (e.g. absenteeism and loss of productivity), and the loss of future income due to obesity.[5] Based on earlier PHAC statistics illustrating the proportion of direct to indirect costs of obesity in Canada, indirect costs is an additional two times that of direct costs.

1.3 Contributing Factors to the Obesity Epidemic

Overweight and obesity risks are influenced by a number of factors (e.g. age, sex, diet, family or medical history, and physical activity). A number of studies recognize that the obesity epidemic is influenced by individual, behavioural, social and built environment (or community-level) factors. It is possible that improving these factors may be able to reduce the burden of cardiovascular disease at the community-level by supporting walking and other physical activities.[7] The present study focuses on a key construct of the built environment, neighbourhood walkability, and its impact on obesity through physical activity. The next section defines walkability and other built environment metrics and explains how the built environment affects obesity.

1.3.1 Built environment metrics

The built environment encompasses human-modified aspects of the physical environment in which individuals spend their daily lives. The built environment has been commonly measured through structural compositions of the physical environment, such as ‘density,’ ‘connectivity,’ and ‘land-use mix’.[8] As such, these terms are metrics for phenomena such as “sprawl” and “walkability”.

Sprawl is a term that evolved from modifications to land development patterns, dating back to the construction of highways so that people could travel to and from work.[9] Sprawl corresponds to the migration of people from dense urban areas to outskirts or suburban areas.[9] In the built environment literature, there is a tendency to characterize more sprawling areas by reduced population densities, disjointed street patterns, and extended distances between homes and destinations (e.g. schools, work places, supermarkets).[9] Increasing sprawl is thought to be one of the main contributing factors to society’s increased reliance on automobiles and more driving.[9,10] The evolution of sprawl is much more complex than described here and its operational definition is generally simplified to be able to understand effects on public health and test hypotheses.[9]

In contrast, *walkability* is "the extent to which the built environment facilitates or hinders walking for purposes of daily living" or more simply, how 'walkable' an environment is.[11] Sprawl and walkability are not concretely defined in the built environment literature since different indices often consist of one or more urban forms (i.e. street connectivity, density and land-use mix).[7] Often, these urban forms describe the design, organization, and location of towns and cities.[7] Even if similar index components represent and measure these phenomena, they are measured on different spatial scales[7] and walkability and sprawl are not opposite in meaning to each other. As such, 'highly walkable' environments are commonly characterised by areas of higher population density, greater land use mix, higher street connectivity or intersection density, as well as safety, clean and aesthetically appealing environments that are supportive of walking behaviours.[12] *Urban sprawl or walkability indices* are used to quantify the extent of sprawl and walkability on an ordinal scale. For example, a value of 1 on the walkability index represents 'low walkability' or 'less walkable' environment, and a value of 5 represents 'high walkability' or 'highly walkable' environment.

Street connectivity is generally defined as the means by which destinations are linked, for instance, through block paths, street arrangements, number of street intersections and grid patterns. Conceptually, the travel behaviours or active modes of transportation are critically influenced by the way in which routes are connected. Density is defined as a "quantity of people or households over a unit of area such as an acre, a square kilometer or square miles." [9] Population density, residential density, and dwelling density are common measures for density in the built environment literature. Land development is often described by the degree of heterogeneity (i.e. the number of different uses for a particular land area), and proximity to other designated land uses/spaces.

Researchers have constructed the term 'land use mix' to describe the degree to which land areas comprise of commercial, retail, residential, institutional, and park lands or green space and the proportion devoted to these spaces.[9] A common way to describe land-use mix is within a defined buffer region (e.g. 1 km radius).[13] Some patterns of land use are more homogeneous than others. For instance, a cluster of households constituting a residential-only area is more homogeneous than urban cores that incorporate some residential, commercial, institutional, recreational and transportation-related spaces.

The degree of proximity is an overlap of how densely populated land spaces are, the availability of multiple destinations, and how well-connected they are.[9] One argument made about the relationships between these built environment features is that more mixed uses of land (i.e. residential, commercial, institutional, recreational and transportation-related spaces) tend to be located in areas of high density and high proximity. The higher density of destinations in a particular area is thought to draw individuals forward and perhaps incite them to make multiple trips due to the ease of access (greater connectivity) and shorter commute. In theory, these characteristics are expected to encourage individuals to pursue active modes of transportation compared to destinations of low proximity.[9] Greater distances between places may influence travel behaviours in such a way that individuals may rely on cars more heavily to shorten lengthy commute times.

Many features of ‘highly walkable’ environments are cited as being independently associated with daily physical activities such as walking and cycling.[10] Highly walkable environments may implicitly describe less sprawling areas whereas increasingly sprawling areas may share some attributes of ‘low walkability’ like low density and less mixed land uses.[9] Higher population density is thought be a characteristic of higher land-use mix, comprised of destinations higher in proximity to each other and well-connected. This is believed to result in a number of positive outcomes, for example greater social interaction and improved accessibility to amenities (e.g. recreational facilities) [13] On the other hand, higher density may also raise traffic density, raise safety concerns for children and older adults, and may discourage walking behaviours.[13]

Thus, the effects of sprawl and walkability on physical activity belong to a continuum that exists because of environmental complexities.[9] Several indices were constructed for the purpose of examining the combined influence of the built environmental factors on physical activity levels.[10] The walkability index developed by Frank et al. (2005) is popular in the built environment literature, which calculates z-scores for each of the components included (residential density, street network connectivity and land use mix) to mitigate the effect of their strong correlations to each other.[14] A downside of composite measures, like Frank et al, (2005) is that the effects of their individual components cannot be observed. Therefore, some studies explored the relevant associations using an index and also conducted separate analyses for each of the individual measures.[14]

1.3.2 The association between neighbourhood walkability and adult obesity

A growing body of cross-sectional literature finds associations between neighbourhood walkability and obesity even after controlling for individual-level risk factors such as physical activity and diet, as well as socioeconomic factors.[14,15] The majority of Canadian studies have examined this association using a number of walkability measures. One systematic review suggested that the neighbourhood characteristics might exert their effects on obesity through physical activity.[16] Another study called for identifying mediators in the causal pathways linking the neighbourhood features and obesity.[17] One prospective study suggested that certain risk factors of obesity, such as physical inactivity, may mediate rather than confound effects of the built environment.[13] Since places of residence have a profound influence on obesity,[3] the major focus of this study is to examine the association between neighbourhood walkability and adult BMI in urban Canada and to assess whether this association is mediated by physical activity.

1.4 Research Objectives

The main objective of this study was to examine the association between the neighbourhood walkability measures and obesity among adults residing in Canada's census metropolitan areas (CMAs). The secondary objective is to investigate whether this association, if found, is mediated by physical activity.

The last cycle of longitudinal data from the Canadian National Population Health Survey (NPHS) (Cycle 9, Year 2010/11) was used to address the following specific objectives:

1. To examine the association between neighbourhood walkability and physical activity.
2. To examine the association between physical activity and adult BMI.
3. To identify whether physical activity is a potential mediator in the association between neighbourhood walkability and obesity, and to estimate its indirect influence.

1.4.1 Hypotheses

The corresponding hypotheses were as follows:

1. Lower walkability will be associated with lower levels of physical activity among adults.
2. Lower levels of physical activity will be associated with higher prevalence of adult obesity.
3. Less walkable neighbourhoods will be associated with higher prevalence of adult obesity.
4. Physical activity may mediate the association between neighbourhood walkability and adult obesity.

Chapter 2

2 Literature Review

The intent of this literature review chapter is to describe existing evidence on the relationships between the built environment and physical activity, and the built environment and obesity. This review is structured so that the comprehensive search strategy and results from the literature search is presented first. This is followed by a discussion of the overarching theoretical framework to understand these relationships. Next, it will discuss potential mechanisms describing associations between the built environment variables and both physical activity and obesity. Finally, this chapter summarizes the challenges and limitations and gaps in the literature.

2.1 Search Strategy

A comprehensive search strategy was designed to identify published literature on the association between the built environment and physical activity, and between the built environment and obesity. The PubMed, Medline, EMBASE, Geobase, Physical Education Index, Scopus, Google Scholar, Dissertations and Theses, Web of Science, and the Canadian Health Research Collection databases were searched using key words described later in the search strategy.

To achieve a comprehensive search strategy, synonyms or interchangeable terms for key constructs of the built environment were used in all of the databases so that all potentially relevant studies and epidemiologic reviews could be identified. All searches were restricted to OECD countries and filtered by the English language & humans, adults, and publication date from 2004/01/01 to the end of January 2015. These restrictions were applied to ensure that the most recent studies could be identified and any papers prior to 2004, which may have been updated, were also included in the literature review.

Initially, a search for studies examining the association between the built environment and obesity within an adult population was performed in PubMed, and incorporated Mesh terms combined with keywords describing or defining concepts related to the built environment and BMI:

((((("Urban Population"[Mesh] OR "Urban Health"[Mesh] OR "Urban Renewal"[Mesh] OR "City Planning"[Mesh] OR "Urbanization"[Mesh] OR "Population Dynamics"[Mesh])) OR (Urban sprawl OR Street connectivity OR Street network* OR Town planning OR City planning OR Urban planning OR Urban renewal OR Urban development OR Urbaniz* OR Neighborhood* OR Neighborhood* OR Population density OR Housing density OR Residential density OR Built environment* OR Intersection density OR Walkability OR Walkable))) AND (((((((((("Obesity"[Mesh]) OR "Body Mass Index"[Mesh]) OR "Body Size"[Mesh]) OR "Body Height"[Mesh]) OR "Body Weight"[Mesh]) OR "Waist Circumference"[Mesh]) OR "Skinfold Thickness"[Mesh]) OR "Waist-Hip Ratio"[Mesh])) OR (((((obes*[Title/Abstract]) OR anthropom*[Title/Abstract]) OR body mass index[Title/Abstract]) OR BMI[Title/Abstract]) OR waist circumference[Title/Abstract]))) AND Motor Activity [MeSH Major Topic]

To find relevant studies examining the association between the built environment and physical activity, the search strategy was modified to include key terms that described or defined built environment concepts, as well as physical activity and socioeconomic factors:

((("Social Environment"[Mesh] OR "Environment and Public Health"[Mesh] OR "Environment Design"[Mesh] OR "Environment"[Mesh])) AND (((((("Urban Population"[Mesh] OR "Urban Health"[Mesh] OR "Urban Renewal"[Mesh] OR "City Planning"[Mesh] OR "Urbanization"[Mesh] OR "Population Dynamics"[Mesh])) OR (Urban sprawl OR Street connectivity OR Street network* OR Town planning OR City planning OR Urban planning OR Urban renewal OR Urban development OR Urbaniz* OR Neighborhood* OR Neighborhood* OR Population density OR Housing density OR Residential density OR Built environment* OR Intersection density OR Walkability OR Walkable))) AND (((((((((("Obesity"[Mesh]) OR "Body Mass Index"[Mesh]) OR "Body Size"[Mesh]) OR "Body Height"[Mesh]) OR "Body Weight"[Mesh]) OR "Waist Circumference"[Mesh]) OR "Skinfold Thickness"[Mesh]) OR "Waist-Hip Ratio"[Mesh])) OR (((((obes*[Title/Abstract]) OR anthropom*[Title/Abstract]) OR body mass index[Title/Abstract]) OR BMI[Title/Abstract]) OR waist circumference[Title/Abstract]))) AND Motor Activity[MeSH Major Topic])) AND ((((((((("Obesity"[Mesh]) OR "Body Mass Index"[Mesh]) OR "Body Size"[Mesh]) OR "Body Height"[Mesh]) OR "Body Weight"[Mesh]) OR "Waist Circumference"[Mesh]) OR "Skinfold Thickness"[Mesh]) OR "Waist-Hip Ratio"[Mesh])) OR (((((obes*[Title/Abstract]) OR anthropom*[Title/Abstract]) OR body mass index[Title/Abstract]) OR BMI[Title/Abstract]) OR waist circumference[Title/Abstract]))

Articles were screened by title and abstract to include studies that met the following inclusion criteria: empirical exposures regarding the built environment and/or walkability (urban sprawl, land use mix, street connectivity, and population density) and main outcomes of interest (physical activity or exercise and overweight, obesity, weight status, or BMI) within an adult population between ages 18 to 65, and using at least one built environment exposure measure. Reference lists of all original articles were also reviewed to find other relevant citations. Furthermore, a number of published epidemiologic reviews on research about environmental determinants of physical activity and obesity were consulted. Reviews were selected if they examined associations between the built environment and/or walkability on physical activity, or walking, or obesity, or provide a summary of the built environment/ walkability literature.

The literature search identified a total of 72 articles that studied the relationship between the built environment and physical activity and/or obesity in a specified adult population. From this collection, each paper was examined thoroughly for whether or not it met the inclusion criteria. From these, twenty-one studies examined associations between the built environment and physical activity, forty-two studies investigated associations between the built environment and obesity and/or physical activity, and ten papers were (comprehensive or systematic) reviews of the literature on the built environment and physical activity, and obesity. Appendix A at the end of this thesis provides a summary of the studies that were reviewed.

2.2 Theoretical Models Describing the Association between the Built Environment and Physical Activity, and Obesity

2.2.1 The Ecological Modelling Framework for Understanding Obesity

Researchers generally agree that the physical environment broadly determines human behaviours (i.e. physical activity) and health outcomes (i.e. obesity).[18] From a theoretical point of view, some argue that the best way to conceptualize relationships between the physical environment, human behaviours and health outcomes is under an ecological modeling framework. [19] One review of the epidemiologic evidence on the association between the built environment and obesity[17] suggested that "mass influences" were responsible for substantial increases in obesity prevalence at the population level. Recent population patterns of obesity have shown that the epidemic is driven by factors beyond biological and individual-level determinants. The complexity of this disease is not exclusive to 'lifestyle choices'; rather, there are many environmental influences that affect energy balance.[17]

The ecological model for understanding obesity posits that interconnected environmental factors can be grouped according to size: macro- and microenvironments.[19] 'Macro' is reflective of the wider population and broader sectors (i.e. the government and health systems) while 'micro' refers to settings that individuals closely interact with.[19] Other examples of the macro-environment are transport systems, food marketing and advertising, the media, and technology, while factors at the micro-environmental level include workplaces, schools, supermarkets, restaurants, and neighbourhoods.[19] Thus, the ecological model advocates that energy imbalance is a result of the macro-and micro interplay. Macro-environmental factors influence the microenvironment, which in turn alters individual lifestyles and behaviours. Governing bodies at the macro-level are responsible for policy-making, and implement policies that may operate at the micro-level (i.e. the quantity and type of food outlets or physical activity facilities in a given neighbourhood). The ecological model of obesity requires public health efforts to be targeted at broader levels (i.e. communities) rather than at individuals, to improve health behaviours and favourable health outcomes.[20]

Neighbourhoods are one micro-environment that affect human behaviour (e.g. walking or biking).[20] Unique differences between (e.g. urban versus rural) and within neighbourhoods (e.g. design and surrounding amenities) have differential impacts on the weight status of individuals. In recognizing this, geographers labeled neighbourhoods as "obesogenic" environments, that is, how powerfully residential conditions collectively promote weight gain in individuals.[21,19,22] A higher prevalence of obesity in some communities versus others may be attributed to their respective social contexts (e.g., crime rates, pedestrian supports and traffic densities). Additionally, the way neighbourhoods are designed may impact an individual's perceptions about the environment, or impact their likelihood to pursue neighbourhood-based physical activities. All of these factors together illustrate the web of interaction between individual (intrapersonal, biological, and genetic) and environmental (built, social, physical and economic) factors; this is the major underlying principle of ecological models.[18,20,23,24]

2.2.2 'Neighbourhood' Definitions

A major limitation of the literature is the lack of formal definition of the 'neighbourhood' around an individual's residence. The majority of papers examined in this literature review were from the US. Three common geographical entities used by these studies are census blocks, census block groups and census tract. These are in ascending order of increasing geographical units for which census data were available.[25] Alternatively, zip codes were used to define the neighbourhood area. From the US studies included in this review of the literature, 3 US studies used zip codes[18,26,27], 7 studies used census block groups,[28–34] 5 studies used census tracts.[34–38]

The areal units previously used by Canadian studies were census tracts (CTs), census dissemination areas (DAs), and varying buffer zones around the centroid of postal codes to provide a geographical area for neighbourhoods.[48,49] One Canadian study[19] previously used the DA to define neighbourhoods while other researchers defined neighbourhoods using circular or network buffers of varying distances.[41] Only one UK study[13] was included in this literature review and it used UK Census Layer Super Output Areas (LSOAs) as their geographical scale to define neighbourhood areas. An Australian study[42] used local government areas and a New Zealand study[1] used mesh block levels to establish the geographical region for neighbourhood. Additionally, 7 studies did not explicitly define the geographical scale of their built environmental variables.[43–47]

Inconsistent neighbourhood definitions may be an explanation for the variations of cross-sectional findings in the built environment literature.[10] One study suggested that buffer differences influenced the significance and magnitude of associations between the built environment variables and walking for leisure and errands for 15 minutes or less per day.[41] For example, logistic regression analyses revealed that there were no significant associations found between the proportion of commercial land use and the odds of walking less than 1 hour per week for errands when a circular buffer was used, but there was a significant positive association between these variables when road-network buffer zones were used. Further, an increase in the proportion of institutional land was significantly associated with a reduction in the likelihood of walking for 15 minutes or less per day for leisure when line-based road network buffers were used. Thus, the results of this study supported the hypotheses that different buffer regions or neighbourhood area could impact the strength and significance of associations between the built environment and physical activity and that a change of measures could lead to alternate findings. Still, one review found that additional methodological dissimilarities (i.e. data sources and the combination of metrics used) and varying neighbourhood definitions between studies prevented comparability and reproducibility of reported findings, and the estimation of pooled effects.[17]

2.3 The Role of Neighbourhood Self-Selection

In the built environment literature, neighbourhood self-selection (or preferences for choosing residential neighbourhoods) is commonly described as a major confounding factor for the association between the built environment and physical activity, and for the association between the built environment and obesity. Studies have reported that residents living walkable neighbourhoods may have self-selected those particular environments and consequently had pre-selected better opportunities for walking and physical activity than residents living in less walkable neighbourhoods.[48,47] Neighbourhood selection is impacted by factors such as neighbourhood design and aesthetics, affordability, location of school, work places, income, or the proximity to amenities that may overestimate the magnitude of associations between neighbourhood environmental factors, and related physical activity patterns (e.g. walking or other active modes of travel).[49,50] As such, these factors may confound associations between the neighbourhood built environment features and physical activity.

Existing literature also demonstrates an interest in examining pull factors, or reasons why residents move to new neighbourhoods. Less often does the literature enquire why individuals reside in their current residences, irrespective of the walkability of the neighbourhood.[48] It may be that individual-specific socioeconomic circumstances remained similar over time, but property values increased. For movers, newer neighbourhoods may have also been selected based on what was still desired about the previous location.[48] Regardless of whether or not individuals fall into old patterns for neighbourhood selection, preferences for certain residential features impact neighbourhood selection, which may also affect associations between neighbourhood walkability and physical activity. This is shown from the results of a study that found consistent inverse relationships between neighbourhood walkability and work-related travel behaviours after considering participants' neighbourhood-style preferences (urban or suburban).[49]

A major within-study limitation found across extensive cross-sectional literature is the residential self-selection bias since the majority of cross-sectional studies do not control for neighbourhood self-selection. A number of prior studies and reviews have been particularly clear about the presence of this phenomenon especially in cross-sectional literature, arguing this may explain the majority of positive associations between neighbourhood walkability or other built environment measures, and physical activity or obesity in cross-sectional studies, and further emphasize the need for longitudinal studies in this research area.

While most cross-sectional studies have reported positive associations between a number of built environment metrics and physical activity measures, these reported associations may be biased due to neighbourhood self-selection, and instead, any observed differences in behavioural outcomes across neighbourhoods could be explained by residents' lifestyle preferences or selection for neighbourhoods nearby particular amenities.[51]

2.4 The Role of Mediators

2.4.1 The Role of Physical Activity

Substantial literature has identified associations between a number of built environment features and physical activity, and obesity, implicitly suggesting that the relationship between the built environment and obesity may be mediated through physical activity (or certain types of physical activity). Only a few studies have explored the role of physical activity as a mediator in the pathway between the built environment and obesity.[13,31,43,52]

One Belgian study assessed for mediation between neighbourhood walkability and two adiposity-related measures (BMI and waist-to-hip ratio). The specific mediatory variables were transport-related walking, transport-related cycling, recreational walking, moderate-to-vigorous physical activity (MVPA) and sedentary behaviour.[43] The mediation approach employed by this study was that described by MacKinnon (2007)[53], testing the product of two regression coefficients $\alpha\beta$. In this study, path α represented the association between neighbourhood walkability and each form of physical activity, and sedentary behaviour. Path β represented the pathway between each of these physical activity mediators and adiposity measures separately. Each model adjusted for age, working status, education, and neighbourhood SES. For the association between neighbourhood walkability and BMI, this study found significant mediation through objectively-measured MVPA (β = −0.11 kg/m², 95% CI: −0.18, −0.06), transport-related cycling (β = −0.12 kg/m², 95% CI: −0.20, −0.05), transport-related walking (β = -0.13 kg/m², 95% CI: -0.28, -0.03), and recreational walking (β = -0.02 kg/m², 95% CI: -0.04, -0.01). Through each of these forms of physical activity, the total indirect effect amounted to -0.26 kg/m² (95% CI: -0.47, -0.01). For the association between neighbourhood walkability and waist-to-hip-ratio (WTHR), the study found significant mediation through objectively-measured MVPA (β = -0.003, 95%CI: -0.004, -0.001) and through transport-related cycling (β = -0.002, 95% CI: -0.004, -0.008). Therefore, the total amount of mediation explained by the above-mentioned mediator variables for the effect of neighbourhood walkability on both adiposity-related measures was statistically significant. The more important finding was the total indirect effect of neighbourhood walkability on BMI passing through specific domains of physical activity (β =-0.12 kg/m², 95% CI: -0.47, -0.01). Sedentary behaviour did not mediate any associations.

Brown and colleagues (2013) thought it was plausible for MVPA to mediate associations between walkability and BMI, and “bikeability” and BMI[31] based on the rationale that bikeability (how ‘bikeable’ an environment is) and walkability were more similar than different. Along with other forms of physical activity, both of these environmental constructs required similar activity-friendly environment supports. Bikeable and walkable areas differed on the grounds that bikeable environments required additional ‘bike-friendly’ features, for instance, ‘road-separated bike paths’ or ‘bike signage’ or ‘traffic lights’. This conceptualization of bikeable versus walkable environments provided the theoretical foundation for the study’s mediation analysis. The mediation approach utilized by this study was a test for the difference in coefficients between regression models – one that included MVPA and one that did not include MVPA, as mentioned by MacKinnon et al. (2002). This study found that a higher proportion of employed female residents who walked to work was associated with a lower BMI, while the proportion of males who biked to work was associated with a lower BMI. Despite this study’s descriptive findings for men and women, there were no associations found between any built environment variables (population density or housing age), and weight status in the multivariable analysis without MVPA. When MVPA was added to the multivariable model, the results showed that MVPA was related to BMI and that MVPA was a partial mediator between walkability/ bikeability and BMI. Furthermore, the results showed attenuation from significance in both women and men, although changes in the pseudo-R squared values (ΔR^2) for daily MVPA minutes suggested that MVPA was associated with lower BMI and obesity risks (for female BMI: ΔR^2, F(1,1695)=28.28, p<0.001; for male’s BMI: F(1, 1783)=74.79, p<0.001). Therefore, the study demonstrated that sex-specific associations between walkability/bikeability and BMI were partially mediated by MVPA and that MVPA was independently and significantly associated with BMI and risks of obesity.

Another cross-sectional study tested three potential mediators of the pathway between the built environment and obesity among a slightly older minority population of African Americans: accelerometer-measured MVPA, infrastructure for walking, and self-reported walking. [52] From the neighbourhood walkability variables in the primary statistical model, access to services was not associated with MVPA, but infrastructure for walking was significantly associated with MVPA (β=4.06, p=0.01) and self-reported walking (β=7.39, p=0.03). Furthermore, MVPA was significantly associated with BMI (β= -0.07, *SE*=0.02, p<0.001), but neither infrastructure for walking or access to services were directly associated with BMI. The authors failed to find statistically significant mediation effects for self-reported walking or self-reported exercise from their secondary models even after they adjusted for individual and socio-demographic factors. The study reported that only MVPA mediated an association between infrastructure for walking and BMI, such that it mediated 74% of the absolute total effect.

One UK study used a three-level mixed-effects longitudinal linear model to examine the impact of built environment morphometrics (features that relate to size and shape) on BMI at three different time points over 12 years.[13] The study later hypothesized that physical activity behaviours among older adults were affected by built environmental morphometrics though they did not proceed to formally test this hypothesis. From the results, Sarkar and colleagues (2013) inferred that the relationship between built environment morphometrics and BMI had a probable underlying physical activity-related mechanism since significant associations were found between neighbourhood walkability morphometrics and BMI, even after adjusting for individual-level confounders. From fourteen built environment morphometrics examined in this study, seven were significantly associated with BMI. For example, higher land-use mix was positively associated with BMI (β_1 for z-score=0.378; p<0.05), and the density of specific amenities such as retail density (β_1 for z-score=−0.916;p<0.01), church density (β_1 for z-score=−0.674; p<0.01), and recreation and leisure facility density (β_1 for z-score=−0.424; p<0.05) were inversely associated with BMI. From these findings, the authors speculated that perhaps several confounding factors of the associations analyzed might instead be mediators, not confounders.

2.5 Neighbourhood Walkability, Physical Activity and Obesity

The focus of the present study is on a particular construct of the built environment, neighbourhood walkability. To recap, 'walkability' is a term that has been developed and used extensively by researchers to describe and measure the ease of walking in a neighbourhood. The current section begins with a discussion about objective and perceived neighbourhood walkability measures, which is followed by a discussion on direct and indirect obesity measures. Thereafter, this section summarizes the ways in which different papers have determined neighbourhood walkability compositely or from the use of a single construct, and presents their findings.

2.5.1 Objective and Subjective Measures of Walkability

An ongoing challenge in the built environment literature is the way in which neighbourhood walkability characteristics are measured, both objectively and subjectively. Objective metrics of neighbourhood walkability are commonly derived using Geographical Information Systems (GIS) based measures to provide a physical measure of latent built environment constructs. GIS helps identify the area that an individual perceives to be their neighbourhood and in doing this, GIS helps to map perception.[54] More specifically, it analyzes neighbourhood constructs spatially by measuring the arrangement, organization, design, and shape of the physical environment, which objectively-determines whether a neighbourhood is 'walk-friendly' or 'activity-friendly'.

Perceptions of neighbourhood walkability are generally gathered using subjective measures, for instance, opinion-based questions about feelings of neighbourhood crime and safety, aesthetics and conditions, or level of traffic density. This information is often collected in questionnaires and interviews, and differs from data collection methods that rely on municipal data sources for statistical or quantitative accounts on specific topics. Commonly, the Neighbourhood Environment Walkability Scale (NEWS) questionnaire, and the Neighbourhood Physical Activity Questionnaire (NPAQ) have been used to assess perceived neighbourhood walkability.

The differences between objective and perceived measures of neighbourhood walkability contribute to issues of divergence. Even if objective measures evaluate a neighbourhood as being ‘walkable’, this may not align with subjective assessments of the ease of walking. Choosing one type of measure over the other is a point of concern in the built environment literature because it leads to different conclusions. This may also increase the tendency to overestimate or underestimate the strength of the reported associations. The advantage of using both types of metrics in a study is to help researchers evaluate relationships independently and also ascertain a degree of mismatch between perceived and objective assessments of these associations. A few studies have examined associations between neighbourhood walkability and physical activity, and obesity using both perceived and objective measures, and paid particular attention to the degree of concordance or discordance between measures. [55,46,56]

Gebel and colleagues (2011) examined the degree of mismatch between perceived and objectively assessed neighbourhood walkability attributes and the effect of this discordance on weight gain, prospectively.[55] Over the four-year study period, they reported contrasting findings between residents who perceived ‘objectively-walkable neighbourhoods’ as being less walkable, and those whose perceptions matched empirically determined walkability. For the former, this contributed to a decline in walking for leisure walking and transportation purposes and an increase in weight than the latter.[55]

Montemurro and colleagues (2011) also compared the agreeability between perceived and objective evaluations of the walkability of the built environment,[46] In pursuit of this objective, the researchers conducted focus groups and found that the majority of participants from high and low walkable neighbourhoods felt their neighbourhood was walkable irrespective of the objective determinations. An interesting observation from focus group sessions was that participants might have altered their beliefs about the walkability of their neighbourhoods, knowing beforehand, the purposes and objectives of the study. Not only would the alteration of beliefs have impacted the study’s findings but more importantly, increasing individual awareness about the walkability of their particular neighbourhood could educate them to think more deeply about their neighbourhood choices, or consider other factors when choosing neighbourhoods in the future.

Jack and colleagues (2014) also found mixed associations between neighbourhood walkability characteristics and the prevalence of obesity because of differences in neighbourhood walkability measures. Objectively determined highly walkable neighbourhoods were significantly associated with a lower prevalence of obesity. However, certain associations differed when single neighbourhood walkability constructs) were measured both objectively and with perceived measures. For example, the association between street connectivity and obesity prevalence differed when neighbourhood walkability was measured using positive perceptions even though these variations in associations were not statistically significant. On the contrary, the study reported statistically significant discordance between objective and subjective walkability measures for residents from high versus low walkable neighbourhoods.[56] Jack and colleagues (2014) also reported positive associations between neighbourhood walkability and neighbourhood walking for transportation, after adjusting for socio-demographic characteristics, attitudes towards walking, reasons for neighbourhood self-selection. Interestingly, these latter associations were slightly attenuated after perceived walkability was added to the model. These findings relayed the importance of using both objective and subjective measures to investigate associations between neighbourhood walkability and obesity.

Additionally, a US study investigated associations between the objectively-determined and perceived built environment and MVPA that was measured from an accelerometer and walking levels assessed from self-reported data.[33] Results from a mixed-effects regression model provided evidence of a relationship between several objectively measured environment factors but no associations were reported between perceived environment factors and MVPA.

2.6 Adult Overweight and Obesity

The majority of papers investigating associations between the built environment and obesity use the BMI to assess overweight and obesity in adults[15,28,57] [4,6,27,42]whether they analyze categorical[4,15,28,57] or continuous [13,26,39,58] measures of BMI. Though it is an indirect measure, the BMI is a widely accepted metric for obesity because it is an overall easy and reasonable way to gauge whether an adult is overweight or obese. Only a couple of studies have used other indirect methods (i.e. biometric impedance analysis)[45] and direct methods of assessing body composition in adults such as the waist circumference (or WTHR)[43] and total body water, which is related to the fat-free mass.[45]

For men and women both, the World Health Organization's classification system for the BMI states that a BMI below 18.5 is considered to be underweight, a healthy BMI range adults is between the 18.5 and 24.9, overweight is that between the range of 25 to 29.9 and an obese BMI is one greater than or equal to 30. [2,59] Individuals who meet this standard scale for 'obesity' are further categorized into obese classes: Obese Class I (BMI 30 – 34.9), Obese Class II (35 – 39.9), and Obese Class III (>40). However, obesity measured by BMI does not directly assess body fat or measure fat around the waist, and some argue that both the BMI and the waist-to-hip ratio should be used.[43] Abdominal obesity may not be well reflected in the BMI, and weight-related risks might be better ascertained through waist circumference or other direct measurements of fat.[60]

2.7 Associations between Neighbourhood Walkability and Physical Activity and Obesity

In the present review of the literature, 12 papers have included a walkability index as either a primary measure of the built environment, or as one of many built environmental measures. The majority have used different built environment constructs assessed by GIS or other objective and/or perceived measures. This section summarizes findings from studies that have examined relationships between neighbourhood walkability and physical activity, and/or obesity using a walkability index.

2.7.1 Relationships between the Neighbourhood Walkability Index and Physical Activity, or Obesity

de Sa and Ardern (2014)[40] examined associations between the walkability index and leisure-time physical activity within 500m and 1000m buffer zones around the centroid of the respondents' postal codes.[40] This Canadian study developed indices for each buffer zone that was computed from the sum of weighted measures of land-use mix, net residential density and intersection density variables. Based on a comparison of walkability index scores, a significantly greater likelihood of participating in leisure time physical activity was evident within a 500m buffer region among those who resided in the most walkable neighbourhoods compared to the least walkable neighbourhoods based on quartiles (Q3, OR 1.55 CI 95% [1.07 – 2.26]; Q4, OR: 1.55 CI 95% [1.07 – 2.25]). Similar effects were found within a 1000m buffer zone; however, this pattern of association was not found between higher walkability scores and the odds of walking or cycling for leisure or transportation. On the contrary, these associations were statistically significant within the 1000m buffer region.[40]

Glazier and colleagues (2014)[15] investigated associations between the walkability index and active modes of transportation and overweight and obesity in an urban context, from a novel composite measure developed and validated by their group in Toronto, Ontario in 2012.[61] They examined associations between the composite measure and separate index components (population density, residential density, availability of walkable destinations and street connectivity) and travel and overweight and obesity. Compared to urban areas of higher walkability, those who lived in areas of lower walkability had a higher BMI, and a prevalence of obesity that was nearly 8% higher than in more walkable areas (49.7% compared to 41.3%). Findings from Glazier and colleagues (2014) also revealed that individuals who lived within quintiles of highest walkability owned nearly double the number of vehicles and also travelled by public transport, walking, use of a vehicle or a bike nearly twice as often. Findings remained statistically significant, in the expected direction, for each of the index components except for street connectivity. Irrespective of the number of walkable destinations, individuals residing in areas of low residential density made on average, fewer walking and cycling trips than those living in areas of higher residential density.

Pouliou and Elliott (2010)[14] examined associations between the walkability index and BMI and also examined these associations using separate built environment constructs (land-use mix, street network connectivity, residential density) two different census metropolitan areas (CMAs), Toronto and Vancouver. The study's multivariable regression results revealed non-significant associations between the walkability index and BMI for Toronto, but significant associations for Vancouver. Furthermore, individuals living in areas of higher walkability had a lower BMI than those residing in areas of low walkability. When built environment metrics were measured separately to examine relationships with BMI, significant positive associations between street connectivity and BMI, and negative associations between residential density and BMI were found.

Other studies[62,42,49,27,43] have either modified or used earlier walkability indices originally developed by Frank and colleagues[63–67] to examine associations between neighbourhood walkability and physical activity, and/or obesity. Neckerman and colleagues (2009) found a number of differences between poor and non-poor neighbourhoods when they adjusted for walkability (index measure inclusive of population density, intersection density, street networks, land-use mix, and a ratio of retail building floor area to retail land area). Non-poor neighbourhoods appeared to be marked by more street trees, presence of more landmarked buildings, higher proportion of clean streets; whereas poorer tracts had more park lands and green streets; essentially more developed land mix in non-poor tracts than poor neighbourhoods; emphasized the importance of aesthetics and safety conditions that could help to reduce disparities in physical activities between neighbourhoods of differing socioeconomic advantages. Sallis and colleagues (2009) used a validated measure for the walkability index that included net residential density, retail floor area ratio, land use mix and intersection density that corresponded to earlier concepts about walkability entailing density, diversity and design.

Van Dyck and colleagues (2010) developed a walkability index guided by those used in earlier studies[68,63] and consisted of three different environmental attributes (residential density, intersection density, and land-use mix), that weighted the sum of z-scores for the neighbourhoods in their study. Badland and colleagues (2012) measured relationships between neighbourhood walkability and active travel for work using a previous GIS-derived composite measure for walkability that comprised of four components: dwelling density, street intersection density, land use, and net retail area component.[65]

Freeman and colleagues (2013) included measures for residential density, intersection density, subway stop density, land-use mix and the ratio of retail building floor area to retail land area in a walkability index. For zip codes assessed to be areas of higher walkability, there was a higher likelihood of zero episodes for active travel compared to zip codes representing low walkability. Furthermore, they reported that these associations differed significantly by race; when they compared non-Hispanic White individuals compared to non-Hispanic Blacks and to Hispanics, and individuals from higher income zip codes.

Villanueva and colleagues (2014) included land-use mix, street connectivity, and residential density in their version of the walkability index, based on earlier measures.[66,69] Additionally, these authors performed an interaction analysis to determine how relationships between neighbourhood walkability and walking varied across the lifespan. After adjusting for a number of social and economic indicators in an interaction analysis, Villanueva and colleagues reported positive relationships between neighbourhood walkability and walking irrespective of life stage (age) of individuals, and this finding was also consistent across the range of smaller and larger buffers regions used in the study.

The issue with previously ‘validated’ measures is that many papers have used similar or alternate versions of them and contributed to the irreproducibility of findings in the literature because there are differences between indices (based on the individual components included) and between individual measures. For example, land-use mix is not a standardized measure. There are variations between formulas used for land-use mix, and the number of uses entered for each equation (i.e. it may hold either 3, 4, or 5 different uses) and weighted by different factors even if all land-use mix variables are interpreted the same (i.e. values equal to 0 represent less mix and values closer to 1 represent heterogeneous or more mixed used). Additionally, even if the same components are used in two different studies, they may vary by their scale of measurement.

2.7.2 Relationships between Other Neighbourhood Walkability Measures and Physical Activity, or Obesity

This section summarizes findings from studies that have examined relationships between neighbourhood walkability and physical activity, and/or obesity using only non-index walkability constructs.

In another study, de Sa and Ardern (2014)[20] examined associations between neighbourhood walkability (residential density and intersection density) and total, recreational, and transit-related physical activity outcomes (using separate and combined physical activity indices). Compared to the lowest (first) quartile for residential density and intersection density, participants who were living in areas of higher residential density (fourth quartile) and intersection density (second quartile) had a greater likelihood of participating in walking or cycling for transportation: (OR: 2.67, CI 95% 1.34 – 5.34) and (OR: 2.39, CI 95% 1.25 – 4.56), respectively.[20]

Oakes and colleagues (2007) examined associations between population density and street connectivity and four main physical activity outcomes: travel walking, leisure walking and total walking and total movement (physical activity).[70] They found that the odds of walking for transportation were doubled in areas of higher population density compared to areas that are less densely populated.[70] The study also found that higher street connectivity was associated with a 40% increase in the odds of leisure walking, and an increased odds of physical activity by approximately 44%, in larger block sizes (areas of highest street connectivity).[70] In contrast, no associations were found between population density or street connectivity on total walking Unexpectedly, population density and street connectivity exhibited dissimilar relationships with physical activity outcomes.[70]

Hou and colleagues (2010) examined prospective relationships between three main street network exposures (intersection density, link-node ratio, and road type/classification) and participation in neighbourhood physical activity (walking, biking and jogging) by prospectively following younger adults from 1985/1986 through 2000/2001.[71] Using a spatial and temporal approach, the study found that street network exposures were not associated with the probability of participating in any neighbourhood physical activities, and among the study sample that participated in neighbourhood physical activity, there were significant interaction effects by sex and by degree of 'urbanicity' (i.e. low medium, or high urbanicity corresponded to rural, suburban or urban areas, respectively). As expected, the patterns of association between street network exposures and neighbourhood physical activity varied by the degree of urbanicity. In areas of high urbanicity, mostly positive associations between street network characteristics and jogging, walking, and biking were found, compared to the frequency of engaging in these physical activities in low urbanicity areas. [71] Conceptually, the results of this study agreed with their hypothesis that certain characteristics or structural design within degrees of urbanicity may promote or discourage health behaviours.

McCormack and colleagues (2012) and (2014) investigated relationships between objectively-determined and perceived neighbourhood walkability and walking (i.e. participation in physical activity for transport or recreational purposes) in a number of studies using cluster analysis models.[50,72] In each of these studies, neighbourhoods were classified/grouped into neighbourhood clusters according to the homogeneity of their physical built environmental attributes to measure high, medium, and low walkability. Analyses from these studies also revealed information about which physical characteristics of neighbourhoods were useful for transportation and recreational types of walking. Findings from these studies generally highlighted that despite differences in neighbourhood walkability across neighbourhood clusters and accounting for individual propensity, it was interesting that varying characteristics of each neighbourhood provided different supports for walking. Residents in 'more walkable' neighbourhoods spent more time per week walking for transportation and recreation compared to residents from 'less walkable' neighbourhoods. The study found that a higher level of local walking was common to neighbourhoods that had a higher population density, greater access to sidewalks and pathways, higher density of public transit (i.e. bus stops), a widely connected pedestrian network; these features were found to be considerably more common to 'highly walkable' neighbourhoods.[50] In another study,[72] McCormack and colleagues revealed disparities among socioeconomic groups for neighbourhood-based physical activity. For example, despite neighbourhoods being 'more walkable', the demographic of adults who actually engaged in physical activity differed between white and non-obese adults, and other subgroups. This finding suggested that relationships between neighbourhood walkability and physical activity and obesity does not affect subgroups uniformly.[72]

Based on a review of the literature, it is apparent that ‘walkability’, ‘urban sprawl’ and ‘land-use mix’ are labels for similar proxy measures that are entered into composite indices in different combinations. For example, Ewing and colleagues 2003[73] developed an urban sprawl index that was comprised of development density and street accessibility, which they found was negatively associated with BMI. In 2013, Ewing and colleagues (2013) updated the earlier urban sprawl index so that it would cover additional dimensions of sprawl, land use diversity, and population and employment centering. Such was the new updated sprawl compactness index,[74] which included all four dimensions and was found to be associated negatively with physical activity, even after controlling for confounding variables. Findings from Ewing and colleagues (2013) showed that the less sprawling areas (or more compact areas) was associated with a reduction in car use and increased physical activity levels; this corresponded to areas with a lower prevalence of obesity, as indicated by lower BMIs.

Zhao and Kaestner (2008) followed an instrumental variable estimation procedure to identify the causal effect of urban sprawl (via population density) on obesity and BMI. The two-step instrumental variables estimates of the association between population density and obesity revealed that a decrease in the proportion of the population residing in highest density areas was associated with an increase in obesity by 0.1 to 0.2 percentage points. But the relationship between population density and BMI was found to be statistically non-significant, suggesting that the population density has an effect only on the upper tail of the BMI distribution. Joshu and colleagues (2008) examined associations between adult obesity and a county sprawl index that was comprised of perceived and personal barriers, and neighbourhood barriers that included gross population density, percentage of county population living at low suburban densities, percentage of county population living at moderate to high urban densities, net density in urban areas, average block size, percentage of blocks. Their results demonstrated dose-response patterns between perceived neighbourhood barriers and an increase in the odds of obesity. Later, an Australian study[75] found significant positive relationships between urban sprawl and odds of being overweight, obese, poor physical activity and an absence of walking after adjusting for individual and area-level covariates. Suburbs located in moderately greater sprawling areas were associated with increased odds of overweight/obesity and poor levels of physical activity in, particularly for inner city suburbs than outer city suburbs. In that study, population density was used as a proxy for urban sprawl since a sprawl index was not available.

Smith and colleagues 2008 explored relationships between both established and novel measures of walkability. For already established measures, they found that pedestrian-friendly street networks were associated with a lower prevalence of overweight and obesity in from the majority of their analyses but more novel measures were not associated with BMI. Among men, a greater number of intersections were related to an increase in the odds of overweight and obesity in men, but only a decreased likelihood of overweight for women. Furthermore, their study revealed inconsistent and extraneous associations between population density and weight in the majority of their analyses. Also among men, higher population density was related to a decrease in the odds of overweight though other relationships explored with population density were not statistically significant. Among women, the highest population density quartile was associated with a decreased likelihood of being obese. Unexpected findings among women demonstrated associations between areas of higher population density and high risks of obesity among women. For novel measures of land use diversity, the study reported that both the proportion of those who walked to work and housing age, were inversely associated with BMI in men and women.

Numerous mixed associations have been found between land-use mix and BMI. A study from 2005 [58] found positive associations between land use mix and BMI, unconventional during this time, since studies prior 2005 had not reported this finding. Later, another study[28] reported that land use diversity measures such as median housing age and the proportion of residents that commuted to work by foot were important predictors of overweight and obesity.

More recently, Witten and colleagues (2012) found significant positive relationships between land-use mix and accelerometer-derived physical activity, where an increase in land-use mix was significantly associated with an increase in physical activity on weekdays and weekends, but less so than what was found with other BE measures. Furthermore, the study reported that street connectivity was positively associated with both self-reported and accelerometer-measured physical activity levels, on weekdays. For leisure time PA outcome, a 1-SD increase in street connectivity was significantly associated with a 44% increased odds of any (versus no) total walking, 95% CI (17%, 79%). Also, Sarkar and colleagues (2013) found significant positive associations between land-use mix and BMI, supportive of hypotheses that heterogeneous land use was associated with greater opportunities for physical activity and healthier BMIs. Additionally, Pouliou and colleagues (2014) found that individuals who resided in areas that were homogeneous or dominated by single land uses tended to have lower BMIs than areas that were more mixed or heterogeneous.

Stark and colleagues (2014) found significant inverse relationship between park access and cleanliness and BMI prevalence when adjustments were made for reasons to visit parks. Moreover, this study's multi-level analysis greater park access and cleanliness was associated with a lower prevalence of BMI after adjusting for individual level socio-demographic and zip-code level built environmental characteristics.

2.8 Summary

Although many papers have investigated and found associations either between the built environment and physical activity, or between the built environment and obesity, only a few have examined indirect and direct associations, to assess the potential causality of these pathways. There is a need for a conceptual framework to rationalize the underlying mechanisms by which the built environment factors exert influence on adult obesity. Most studies that have examined relationships between the built environment and obesity, have also examined the role of physical activity in forms of walking, cycling or other measure. The majority have controlled for it rather than observed its role as a potential mediator.

Chapter 3

3 The Conceptual Framework

This chapter begins with an introduction to the conceptual framework to study the following objectives. The first is to examine the association between neighbourhood walkability and physical activity; the second is to examine the association between physical activity and adult BMI; and finally, to examine the extent to which physical activity mediates an association between neighbourhood walkability and adult BMI.

The conceptual framework for the present study is guided by the literature review and the analyses in the present study are presented by sex, similar to previous studies in the built environment literature. Directed acyclic graphs (DAGs) have been used to provide a visual overview of the three main conceptual models that illustrate relationships among confounding variables and the predictor and outcome of interest, and to evaluate the potential for confounding in each of these associations.[76] This is followed by a description of the exposure and outcome variables, key confounders, and the rationale for their inclusion in this study. By definition, a confounder is associated either causally or non-causally with the main predictor and is a causal determinant of the outcome of interest.[76] The statistical analysis of this study is based on the underlying conceptual framework and confounding may be present if there is an approximately 10% change in the coefficient of the main predictor(s) on the outcome variable.[76]

First, socioeconomic and demographic variables were included in Model 1as confounders for the association between neighbourhood walkability and physical activity. In Model 2, lifestyle/behavioural variables were included as confounders for the association between physical activity and BMI. Finally, model 3, an extension of Model 1, is inclusive of the same neighbourhood walkability variables from Model 1, and all confounding variables from Models 1 and 2; the final model examines the association between neighbourhood walkability and BMI.

3.1 The Association between Neighbourhood Walkability and Physical Activity (Model 1)

In reference to the above definition for a confounder, numerous studies have controlled for many covariates in the primary pathways of interest in this study, without a conceptual framework.[77] Theoretically, it is plausible that many of the individual-level demographic and socioeconomic factors discussed in the next section exert their influence on neighbourhood walkability through their influence on residential self-selection. The literature has shown that socioeconomic and demographic characteristics influence the walkability of neighbourhoods by affecting the social profile or social composition of neighbourhoods, and consequently affect health behaviours within these neighbourhoods.

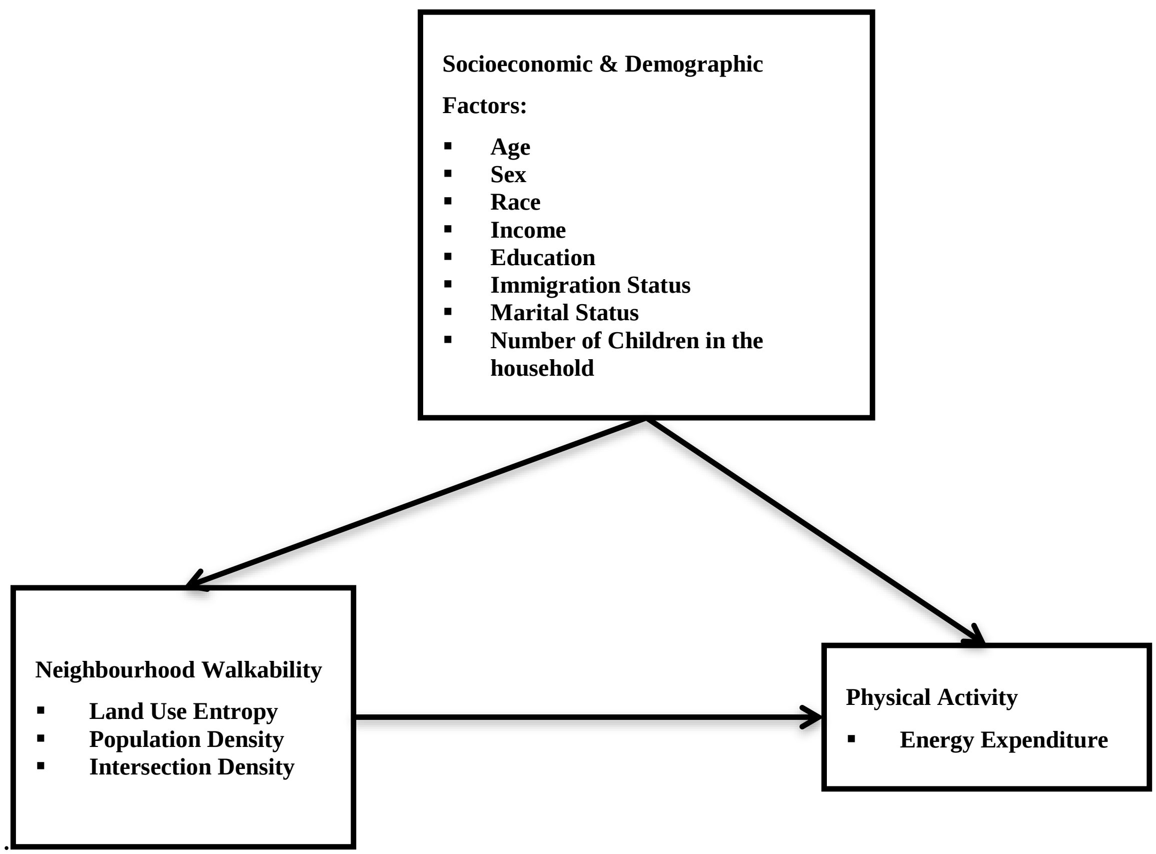

Figure 3-1: Directed Acyclic Graph (DAG) for Model 1, the association between neighbourhood walkability and physical activity.

3.1.1 Model 1: Socioeconomic and Demographic Confounders

Model 1 controlled for plausible socioeconomic and demographic confounders, informed from a comprehensive literature review: age, sex, race, income, education, immigration status, marital status, and the number of children living in the household less than 5 years of age, and between 6 and 11 years of age.

3.1.1.1 Age and Sex

Age and sex were both considered as confounding variables in Model 1 because each is a determinant of neighbourhood walkability and physical activity without being affected by the exposure or outcome. Theoretically, it is plausible that age and sex are non-genetic environmental influences on neighbourhood walkability that contribute their effects on walkability through environment/residential self-selection.[78] Previous studies have suggested that individuals are predisposed to certain environments at birth, and that heritable factors such as age and sex have been found to strongly affect individuals' selection for their environments (i.e. residential location).[78] Some earlier twin studies have pointed to evidence suggesting that residential selection to some extent is heritable while others suggest that non-genetic factors contribute to differences in residential location according to levels of urbanization.[78] This contrasting view is supported by the results of a 2012 study published by Duncan and colleagues, which showed that for all of the twins involved, phenotypic variance on neighbourhood walkability was more explained by environmental factors than additive genetic effects. Even though some of their results supported that environmental attributes may have a larger influence on neighbourhood walkability compared to heritable factors among twins, the authors described that there does exist some minimal variance in neighbourhood walkability that can be explained by shared genetic factors irrespective of twins' age.[78]

Additionally, age and sex may determine neighbourhood walkability because of individual beliefs. Another study reported that focus group participants described likeable features of neighbourhoods that represent walkability constructs: nearness to amenities and services, safety, sidewalks or path availability, natural or green spaces, aesthetics, and season factors. It can be inferred that at a given age, or depending on sex, both men and women may have a stronger or lesser preference for certain neighbourhoods and neighbourhood features.[46]

The same idea can be applied to describe that age and sex are determinants of physical activity. For example, focus group participants from the described study[46] also expressed that their individual physical activity behaviours were influenced by environmental features that positively or negatively swayed their decisions to participate in walking or other types of physical activity. Numerous studies have adjusted for age and sex as part of a broader group of socio-demographic variables, neighbourhood perceptions, and interpersonal and intrapersonal characteristics.[36,47,49,79]

3.1.1.2 Children

It is plausible that the presence of young children that are less than 5 years of age or between 6 and 11 years of age in the household may confound the association between neighbourhood walkability and physical activity, even though this has not been previously shown in the literature. It is theoretically plausible that the presence of young children in the household may influence neighbourhood walkability and be causally associated with physical activity. First, the presence of young children in the household may guide family choices for residential location; families with younger children may select highly walkable neighbourhoods nearby schools, public transportation, supermarkets or by neighbourhoods that offer family-specific conveniences preferable for raising younger children. In theory, the presence of children in the household may affect neighbourhood walkability by affecting the social composition of the neighbourhood. Some families with younger children may choose to raise children away from densely populated areas while others may select neighbourhoods proximate to several destinations (i.e. supermarkets, parks, and schools). The former is a characterization of higher neighbourhood walkability while the latter characterizes greater land-use mix.[80] A two-year prospective study shows support that the presence of children in the household determines physical activity. The study reported that having a child significantly decreases levels of physical activity in parents and other household members.[81] Recognizing this association, a number of other studies have also controlled for the presence of children in the household, albeit at different ages in the relationship between neighbourhood walkability and physical activity.[33,47,56] Second, research on early childhood development supports that the first five years are the most critical years for the development of healthy relationships, play, learning, nutrition, physical activity and health. To be able to offer a solid foundation for later years, children less than 5 years of age may require more focused attention from parents and/or other family members than older children, and this may affect time available for physical activity. For this reason, it is likely that a noticeable discrepancy in physical activity participation would be evident among people who have children who are either younger than five years or between the ages of 6 or 11 years. This rationalizes why a variable for the number of children less than 5 years of age in the household, and another variable for the number of children between 6 and 11 years of age in the household were included as confounders in Model 1.

3.1.1.3 Income

It is plausible that income is a confounding variable of the association between neighbourhood walkability and physical activity. Income is a measure of individual socioeconomic status (SES) and determines neighbourhood walkability by affecting the social composition of neighbourhoods.[32,82] Literature has also suggested independent associations between income and physical activity. One study classified neighbourhoods in order of low to high median household income to examine the association between median household income and individual physical activity. The study reported that adults from higher SES neighbourhoods perceived low SES neighbourhoods as unsafe, and felt that this impacted the usability of parks and physical activity levels in low-income neighbourhoods.[82] Other studies have also supported that income disparities in neighbourhoods affect families' physical activity levels. [83,84]

3.1.1.4 Race

Another measure of individual SES is race, and it is plausible that race is a causal determinant of both neighbourhood walkability and physical activity. Race may be independently associated with neighbourhood walkability by determining a neighbourhood's racial composition. One US study described that considerably more

Black residents (86%) resided in neighbourhoods of ‘medium’ walkability compared to neighbourhoods of ‘low’ walkability, where significantly more White residents lived (65%; $p<0.001$).[36] Furthermore, the study described that the greater population of White residents in neighbourhoods of low walkability had access to cars as a key mode of travel compared to Black residents living in neighbourhoods of medium walkability. As illustrated by the above example, the racial profiles of neighbourhoods of differing walkability status may impact physical activity participation of individual’s.

Another US study revealed that a host of cultural and social factors such as race were chiefly responsible for relationships between minority groups and their neighbourhood choices.[85] The study reported that affordability of housing and location to nearby social amenities such as barbershops and manicure salons were prominent factors that might explain associations between neighbourhood racial profile and neighbourhood choices.[85] Furthermore, relationships were reported between the level of walkability of different American States and the higher and lower concentration of Black residents; irrespective of walkability status (high or low) in a particular region, more Black residents were settled in regions where similar housing values were found. These associations between race and neighbourhood walkability were also evident even after adjusting for neighbourhood or housing features, proximity to public transit, and access to a vehicle.[85]

Race is also independently associated with physical activity.[86,87,88] Research has shown that racial/ethnic disparities exist for participation in physical activity.[86,87,88] There is also research recommending different minimums of minutes for physical activity that could lower the risk of cardiovascular risk factors such as hypertension, and diabetes.[88,89]For example, one review recommended that Black men partake in physical activity for at least 185 minutes and Black women spend 215 minutes to minimize the risk for diabetes.[88,89] Another study[90] compared the likelihood of meeting physical activity guidelines among ethnic groups across census neighbourhoods and found that Latinos were at least as moderately active as Whites, but Asian Pacific Islander’s were significantly less likely (by more than 50%) to engage in moderate physical activity compared to Whites. The study also reported that when they controlled for perceptions of neighbourhood safety and proportion of park space, the original associations were attenuated; this implicated that the relationship between neighbourhood characteristics and physical activity may be somewhat explained by racial/ethnic disparities and varying neighbourhood perceptions of individuals belonging to these groups.[90]

3.1.1.5 Immigration Status

Immigration status is another potential confounder of the association between neighbourhood walkability and physical activity because it is plausible that immigrant status is independently associated with each of these variables. In the literature, independent associations between immigrant status and neighbourhood walkability aren't explicitly shown, but as a measure of individual SES, it is plausible that immigrant status determines neighbourhood walkability by affecting the social composition of neighbourhoods.

Immigrant status may also determine physical activity participation as demonstrated by a recent Canadian study that assessed how ethnicity and time since immigration affected physical activity levels among Canadian youth.[91] The study reported increases in physical activity levels among immigrant youth with more time that had passed since their immigration. Interestingly the study found that despite the time spent in Canadian society, there was still a significant difference in physical activity levels between immigrant youth and Canadian-born youth, in that the latter group exhibited higher levels of physical activity.[91]

3.1.1.6 Marital Status

Marital status is another measure of individual SES because marriage or cohabitation suggests that two incomes improve the wellbeing and livelihood of both individuals.[92] The availability of additional resources for consumption in the form of wealth and savings generally implicate improvements in health.[92] Marital status was considered to be a potential confounding factor of the association between neighbourhood walkability and physical activity. In the literature, independent associations between marital status and neighbourhood walkability aren't explicitly discussed, but it is plausible that marital status may also determine neighbourhood walkability by affecting the social composition of neighbourhoods. Hypothetically, young adults (i.e. singles) may prefer to live in more densely populated urban areas compared to adults at other stages of the life span.[93] There is a sense of appeal attached to living within city centres because of the greater connectivity between residences, transportation hubs, workplaces, and restaurants.[93] More recently, the younger generation has expressed a desire to live in cities because of shorter commutes to work and home by bike, walking, or public transit.[93] This suggests that certain characteristics of growing urban areas (i.e. high connectivity, higher land-use mix) are more walkable and may be populated with a certain demographic than suburban areas. Current economic trends show that it is middle-aged adults (i.e. married or common-law adults) who are in a better position to make a first-time mortgage[93] and perhaps ready to raise families away from cities. Within this slightly older demographic, adults may select residential areas proximate to schools, parks, and supermarkets; these neighbourhoods are usually located outside major city centres, in more suburban areas. This idea supports that marital status is independently associated with neighbourhood walkability and this association could be explained by the location of the workplace and density of available destinations.

The literature shows some support for associations between marital status and physical activity.[81,94,95] One study investigated the influence of gender and marital status on perceptions of neighbourhood walkability and environmental factors. The study reported that a greater proportion of widowed individuals compared to single, divorced, or separated individuals reported that they perceived environmental factors played an important role in their participation of physical activity. A two-year prospective study hypothesized that being married with children reduced physical activity levels. However, when relationships between marriage and physical activity were analyzed, the study reported no statistically significant changes in physical activity levels among couples after marriage compared to single individuals, even after adjusting for sex, age, race, education and having a child.[81] The results of this study supported findings from an earlier prospective study that followed individuals for 10 years and found increased physical activity levels among single individuals who later married. This supported the hypothesis that marital status may be positively associated with physical activity. Interestingly, the latter study also found unchanged physical activity levels for individuals who transitioned from being married to being single.[94]

Hypothetically, married couples, or individuals in common-law relationships may be more physically active than those who are single, widowed, divorced or separated because of the added incentive and motivation to be physically active with having company or social support. On the contrary, it is possible that couples may be less physically active than singles because of ‘getting too comfortable’ in the relationship.

3.1.1.7 Education

Education is a potential confounder of the association between neighbourhood walkability and physical activity because it is plausible that education is a causal determinant of both the exposure and outcome. Furthermore, education is another measure of individual SES and while in the literature, independent associations between education and neighbourhood walkability aren’t explicitly discussed, it is plausible that an educated demographic affects the social composition of neighbourhoods. Individuals who are more educated may choose to live in more or less walkable residential environments for different reasons. Well-educated individuals generally belong to higher income groups and hypothetically they may select highly walkable neighbourhoods. Additionally, well-educated individuals may be more likely to value and maintain a higher level of social capital within their neighbourhoods.

Research also shows that higher education is associated with higher physical activity participation.[95,96,97] Well-educated individuals are likely to recognize benefits of physical activity and positive health outcomes associated with physical activity participation. It is also plausible that despite environmental supports for neighbourhood-based physical activity, highly educated individuals may seek opportunities for physical activity beyond their area of residence or find innovative ways to facilitate neighbourhood-based physical activity. Lower education is a characterization of low SES residents who may be limited by their perception of how well equipped they actually are within the confines of their residential location to engage in physically active behaviours. A number of studies have also controlled for the effects of socio-demographic characteristics such as education when looking at the association between neighbourhood walkability and physical activity.

3.2 The Association between Physical Activity and BMI (Model 2)

3.2.1 Model 2: Lifestyle Confounders

Model 2 controlled for plausible (lifestyle) confounders informed from a comprehensive literature review: nutrition (or diet), smoking and alcohol use.

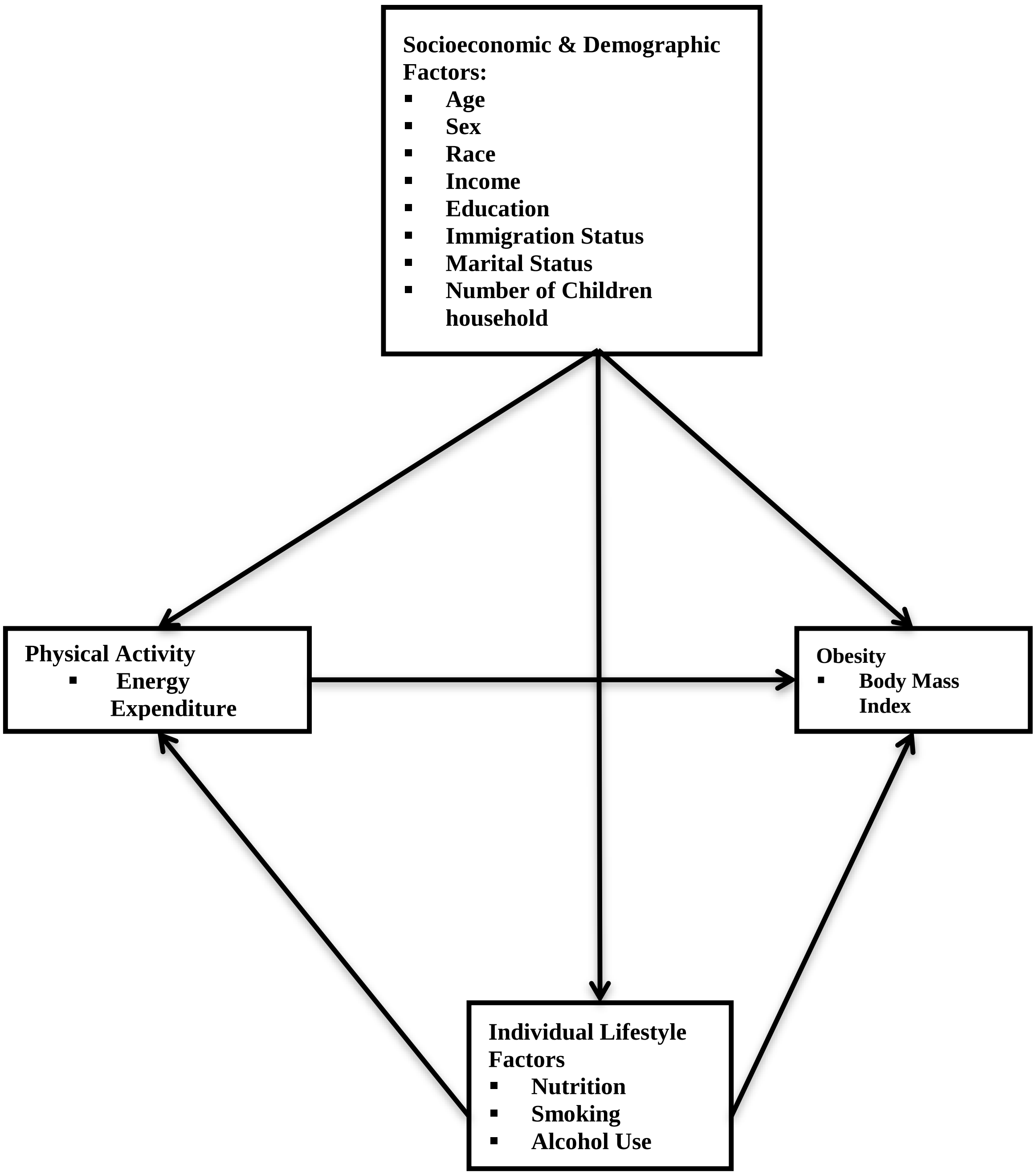

Figure 3-2: DAG for Model 2, the association between physical activity and BMI.

3.2.1.1 Nutrition

Nutrition or diet may confound the association between physical activity and obesity because it may be causally or non-causally associated with physical activity, and causally associated with obesity. It is plausible that individuals who are physically active are more likely to eat nutritious food to complement their active style. An individual's knowledge of and attitude toward either physical activity or nutrition may also inform their commitment to the other.[98] Diet is an important part of culture for some subgroups of the population and may shape the way members of the population address health behaviours such as physical activity. One US study suggested that diet was a modifiable social determinant of physical activity in an investigation of the relationship between cultural and lifestyle factors among Alaska Native and American Indian (AN/AI) peoples.[99] Specifically, the authors examined the relationship between traditional dietary patterns and traditional physical activities (i.e. harvesting physical activities such as fishing by hand, hunting, and trapping), and the prevalence of illness and chronic disease.[99] Even though men and women differed on certain aspects of food consumption and participation in traditional types of physical activities, the study reported statistically significant positive associations between consumption of traditional foods and traditional physical activities. In a literal sense, the AV/AI peoples often consumed the fruits of their labour. The study also reported that traditional physical activity practices related to traditional food consumption fulfilled several important functions within the AV/AI community, and replacement of the traditional diet with ready-made substitute foods was strongly associated with a decrease in energy expenditure and increase in consumption of foods that were high in carbohydrate and fat.[99]Other research suggests that nutrition or diet is independently associated with obesity, for example, that energy-dense eating patterns were independently, positively associated with MeTs.[100]

3.2.1.2 Smoking Status

Smoking is a confounding variable in the association between physical activity and obesity because of its uni-directional effects on each of these variables. Smoking has immediate and long-term negative effects on physical activity because it decreases endurance and impedes performance of physical activity.[101] Smoking also creates a higher risk of injury to the individual who is trying to be physically active because of its effects on the function of blood flow to blood vessels and muscle cells.[101] There are also general misperceptions about the relationships between smoking and obesity, that smoking is protective of weight gain. [102] A recent cross-sectional study from the UK reported an increasing likelihood of obesity from light to heavy smokers (adjusted OR 1.60, 95% 1.56 – 1.64, $p<0.001$) after quantifying current smokers' smoking behaviours. An earlier study from 2008 also supported that a cluster of risky behaviours such as poor diet, lack of physical activity and smoking together, predict weight gain.[103] The same study also evaluated relationships between smoking, weight status, distribution of body fat, and insulin resistance. The study reported that in the short-term, smokers may have lower body weights compared to non-smokers as a result of nicotine's effects on increased energy expenditure and appetite reduction. Nicotine has negative effects on insulin resistance, such that nicotine from heavy smoking increases insulin resistance, putting heavier smokers at a greater risk for central obesity compared to lighter smokers.[103]

3.2.1.3 Type of Drinker

Alcohol use was selected as a potential confounder in the pathway between physical activity and obesity since alcohol consumption may be independently associated with exercise and/or sports performance, and body weight. One cross-sectional study tried to investigate correlates of insufficient physical activity, but did not find any significant associations between alcohol consumption and insufficient physical activity even after considering a number of demographic factors.[104] Other research has investigated the relationship between alcohol consumption and obesity and recognized that regular alcohol consumption is an independent risk factor for obesity since it contributes to weight gain by the suppression of fat oxidation. [105]

3.3 The Association between Neighbourhood Walkability and BMI (Model 3)

A number of SES, demographic and behavioural characteristics has been identified as determinants of neighbourhood composition/walkability and obesity in literature and extensive literature continues to investigate these relationships. The following discussion is of Model 3 confounders examining the association between neighbourhood walkability and obesity.

3.3.1 Model 3: Confounders

Model 3 controlled for all of the plausible confounding variables in Models 1 and 2.

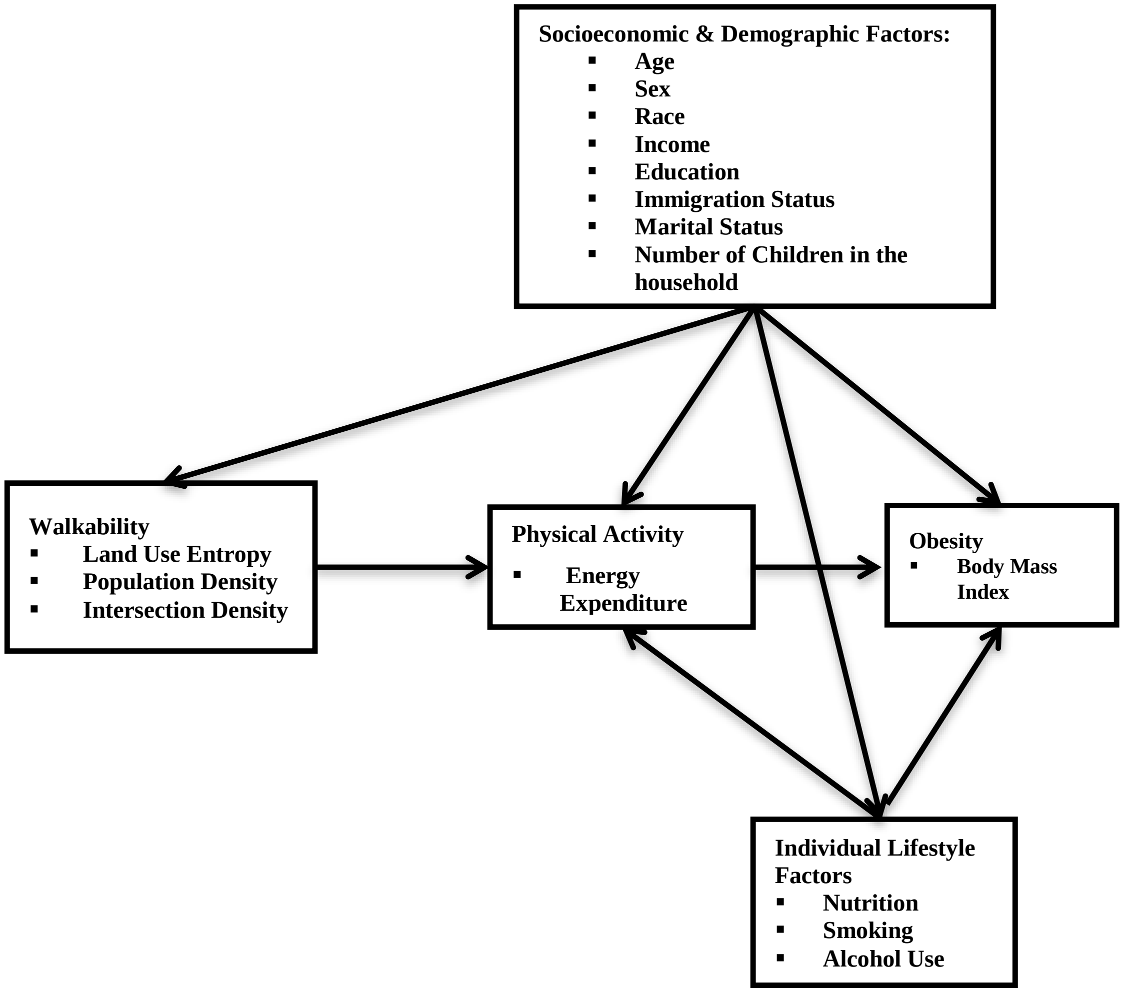

Figure 3-3: DAG for Model 3 the association between neighbourhood walkability and BMI.

3.3.1.1 Age and Sex

Age and sex are potential confounding variables in the association between neighbourhood walkability and obesity. For the same reasons discussed previously, age and sex determine neighbourhood walkability. It is also well known that age and sex are biological determinants of obesity.[3] Age is associated with obesity from a young age; overweight and/or obesity in childhood can predict overweight and/or obesity in adulthood. These patterns are also applicable to adults of different age groups.[106] Young adults may age well with regular exercise and good eating habits while others may exercise infrequently and eat poorly; the latter may lead to a higher risk for overweight and obesity. [107]Additionally, in older adults, body weight tends to decrease with age from the loss of muscle mass and bone density.[107]

Sex or gender is also associated with rates of overweight and obesity in adults; the odds differ between men and women of different races and socioeconomic backgrounds. One study found that compared to white males, those who were of ‘other’ ethnic/racial backgrounds had a lower adjusted odds of obesity.[108] In contrast, females from ‘other’ ethnic/racial backgrounds had higher adjusted odds of obesity (i.e. Hispanic or Black females), compared to white females.[108]

3.3.1.2 Race

Race is a confounding variable in the pathway between neighbourhood walkability and obesity. For reasons discussed previously, race determines neighbourhood walkability. There is research to show that race is also independently associated with obesity. One study examined which social factors of neighbourhoods were associated with obesity, and more specifically, whether the role of neighbourhood racial composition (i.e. Black compared to White residents) affected obesity prevalence. After controlling for factors such as poverty rate, the study found that previous statistically significant associations between neighbourhood racial composition and obesity were attenuated. The study also found that a greater proportion of black residents had a higher likelihood of being obese than their white counterparts. Other American studies have also found higher rates of obesity among non-Hispanic blacks compared to non-Hispanic whites and attributed these differences in body mass to race after controlling for other individual-level risk factors. [109,110,111,112]

3.3.1.3 Income

Income is a confounding variable in the association between neighbourhood walkability and obesity. For reasons discussed previously, income is a determinant of neighbourhood walkability. Further, it is plausible that income is causally associated with obesity. Both Canadian and US studies have found a higher prevalence of BMI among low-income neighbourhoods, irrespective of their neighbourhood walkability status.[82] In the US, income groups below the poverty line have been reported to have higher rates of obesity among other serious health conditions such as diabetes, other metabolic diseases and premature death.[113] Other research also shows that income is negatively associated with BMI and obesity because of its negative influence on other individual-level SES factors such as food affordability.[114] Economic factors such as income[115] may impact food consumption patterns of households, which can predict overweight and obesity. Research also shows that increasing wealth and is associated with higher rates of obesity.[113] The two are related based on reports that economic growth in higher income countries is associated with higher rates of obesity.[113]

3.3.1.4 Education

Education is a confounder of the pathway between neighbourhood walkability and obesity. For reasons discussed previously, education is a determinant of neighbourhood walkability. Further, education is also independently associated with obesity. It is plausible that education affects BMI or obesity positively by increasing an individual's knowledge and awareness of attitudes and behaviours towards eating and physical activity. Furthermore, it is plausible that varying levels of education will have more or less of an impact on BMI, for example, one study suggested the length of schooling may have a protective effect on weight status or BMI.[116]

3.3.1.5 Marital Status

Marital status is a confounding variable for the association between neighbourhood walkability and obesity. For reasons discussed previously, marital status is a determinant of neighbourhood walkability. Marital status is also independently associated with obesity. Cross-sectional research reports an association between marital status and overweight and obesity, and further, that these disparities exist by sex and race. [117] A couple of different hypotheses support this view: 1) the selection hypothesis states that the concept of marriage is elected by those with lower BMI's and 2) the marriage protection hypothesis supports that a marriage provides couples with additional social support and adds healthy pressure to attend social gatherings, all of which lead to better physical health outcomes than other relationships.[118] Other research supports the marriage protection hypothesis by suggesting that a marriage allows for food security in men and women. One study that compared women for whom food security was slightly an issue to women who had greater food security issues, found that the latter had a significantly greater likelihood of being obese, whereas those who were marginally food-secure were overweight.[119] In the same study, males who were married had a higher likelihood of being overweight compared to men of other relationship status categories, except for those who lived with their significant others. Characteristics of participants less likely to be overweight or obese in another study were those who were either single, more educated, female, younger or lived in high SES communities.[47]

3.3.1.6 Immigrant Status

Immigrant Status is another confounder of the pathway between neighbourhood walkability and obesity. For reasons discussed previously, immigrant status is a determinant of neighbourhood walkability. Immigrant status is also independently associated with obesity as demonstrated by research on Somali immigrants of Norway; those who had been residents of Norway for well over a decade had a greater likelihood of being overweight or obese compared to immigrants who had stayed in the country for a short period of time (i.e. less than 4 years) (adjusted OR 7.16, CI: 2.14-23.8).[120] It has also been reported that immigrants to the US tend to adopt less healthy lifestyle habits that negatively affect health. For example, Latino immigrants that have integrated into

American society have predisposed themselves to overweight and obesity as a result of poor lifestyle choices, such as conforming to sedentary routines and choosing to eat foods of poor nutritional quality in large portions.[121]

3.3.1.7 Children

The presence of young children in the household may confound the association between neighbourhood walkability and obesity. For reasons discussed previously, the presence of children in the household may determine neighbourhood walkability. It is also possible that household environmental or demographic factors such as the presence of young children, is positively associated with overweight or obesity. Individuals with younger children who are less than 5 years or between the ages of 6 and 11 years may not be getting adequate sleep resulting in weight gain from increased hunger and tiredness.[122] Additionally, household food consumption patterns and the availability of favourite foods, meal options and portion sizes may be altered with the presence of younger children in the household to satisfy children's taste preferences.[123]

3.3.1.8 Physical Activity

Physical activity may confound the association between neighbourhood walkability and obesity because it is plausible that it is causally or non-causally associated with neighbourhood walkability and for reasons discussed previously, may be causally associated with obesity. As has been described in the literature review chapter, a number of studies have reported positive associations between neighbourhood walkability and physical activity.

3.3.1.9 Lifestyle Factors

Nutrition (or diet), smoking, and alcohol use may be potential confounders of the relationship between neighbourhood walkability and obesity. For reasons discussed previously, each of these may causally determine obesity, but may be causally or non-causally associated with neighbourhood walkability. Firstly, research generally suggests that individuals who live in walk-friendly neighbourhoods and communities are more likely to be healthier overall.[124] More specifically, research has shown that highly walkable neighbourhoods are positively associated with healthy food availability among high SES or predominantly white neighbourhoods.[125]Another study also hypothesized that characteristics of walkable neighbourhoods may also offer suitable food environments (i.e. healthier, higher-quality and increased accessibility to foods), and found that among normal weight individuals, the neighbourhood environment was a protective factor.[126] In contrast, individuals living in neighbourhoods of lower walkability and low SES may have fewer opportunities to obtain foods high in nutrition as a result of decreased accessibility and variety of supermarkets. Several papers have also controlled for diet when examining associations between neighbourhood walkability and obesity. Presumably, individuals who self-select highly walkable neighbourhoods and are conscious of their health behaviours are less likely to be smokers or engage in unhealthy drinking. Interestingly, prior research has shown that higher land-use mix (i.e. higher density or presence of alcohol, liquour and tobacco-selling companies) is a measure of walkable environments and is positively associated with smoking and drinking behaviours due to ease of access to tobacco and alcohol products.[7] On the contrary, neighbourhoods that are less surrounded by stores selling or promoting unhealthy foods, and tobacco and alcohol products may explain negative associations between neighbourhood walkability and diet, smoking, and alcohol use.

Chapter 4

4 Methods

The Methods Chapter begins with a description of the study population used in this thesis, and illustrates how the sample inclusion/exclusion criteria were finalized. Thereafter, a description of the data sources, and construction of main outcome and exposure variables is provided. A section describing the method for constructing confounding variables and the main statistical methods that were applied follows this.

4.1 Study Population

The target population for the present study is household residents from all provinces of Canada except for members of Indian Reserves, Canadian Forces Bases and persons residing in some rural or remote areas. Specifically, the inclusion criteria were adult men and women from the National Population Health Survey (NPHS) respondents, between the ages of 18 and 64 in 2010/11, who reside in urban census metropolitan areas (CMA’s). These CMAs were identified by the appropriate variable in the Statistics Canada Postal Code Conversion Files (PCCF+) in 2011. NPHS postal codes corresponding to the 2006 Census geography were linked to their respective 2011 dissemination areas from the 2011 PCCF+. After NPHS and built environment data were merged, and population sampling weights were applied, a final sample of 3258 adults was included in this study.

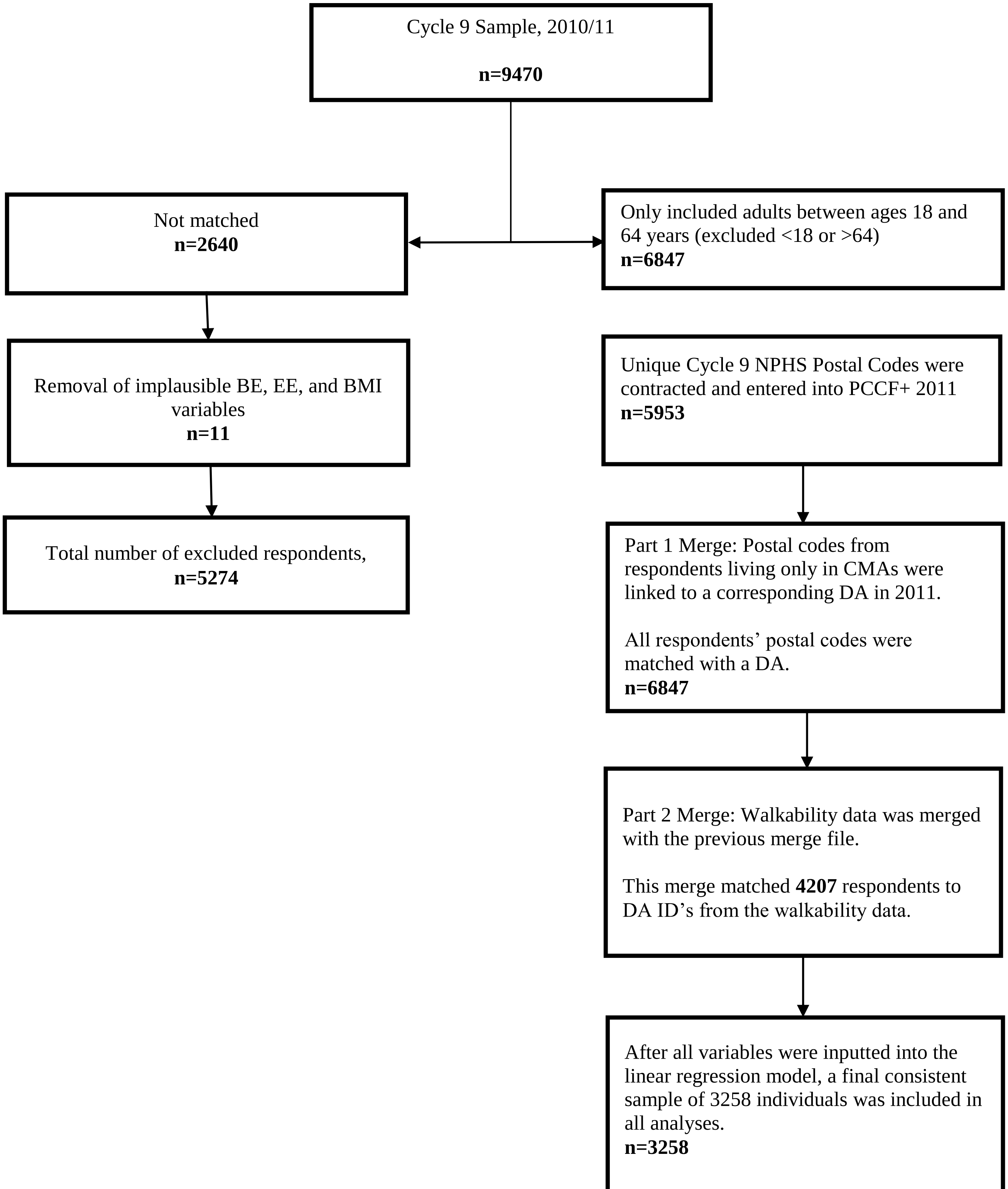

Figure 4-1: Sample size flowchart

4.2 Data

The two data sources used in the present study were the NPHS, and Census and DMTI built environment data constructed as part of the “Econometric analyses of adult obesity in Canada: Modifiable risk factors and policy implications” project funded by the Canadian Institutes of Health Services Research. These data files were compiled and validated at the Human Environments Analysis Lab in Geography at The University of Western Ontario. The NPHS was used to obtain individual-level demographic, socioeconomic and behavioral data while geographic variables were used to represent neighbourhood walkability at the census DA-level. Statistic’s Canada’s Postal Code Conversion Files (PCCF+ 2011) linked postal codes from Cycle 9 for the NPHS respondents to their corresponding DAs in 2011.

4.2.1 The National Population Health Survey

The NPHS has three major components: the household component, the institutional component, and the North component. The household longitudinal component was used in the present study and variables of interest were selected. In 1994/1995, the NPHS was introduced as two segments having both cross-sectional and longitudinal components. The longitudinal sample included a total of 17 276 persons who continued being interviewed every two years, allowing the opportunity to measure changes in the health of respondents over time. Every two years, at each subsequent cycle (4 to 9), data has been collected pertaining to household members’ health status demographic and socioeconomic characteristics, behavioural risk factors, and use of health services at each Cycle. To ensure representation of the Canadian population, the NPHS uses population-based sampling weights that are founded on two sets of estimated weights; one of these is to provide a weight for the selection of the household and panel member and the other is for weighting responses.

The longitudinal nature of the NPHS provided the opportunity to analyze the association between built environment variables and BMI in 2010/11 and in 2000/01. Analyzing cross-sectional associations between the built environment variables and adult BMI in the same sample at a different time points would provide insights into the possibility that these associations may have changed over time..

4.2.1.1 Sampling Design of the NPHS

The sampling design of the NPHS was based on the following primary considerations: a) integrating sample sizes from Canadian provinces; b) adopting the multistate stratified sampling method of the Labour Force Survey (LFS); and c) selecting one household resident to serve as the first point of contact to respond to survey questions for the longitudinal component.[127] By the LFS multistage stratified sampling method, each province was first classified according to major cities, urban towns, and rural areas.[127] Within each of these areas, the probability proportional to size (PPS) sampling strategy was implemented to select six clusters within Census Enumeration Areas (CEA) and from these geographic and/or socioeconomic strata, interviews proceeded within dwellings.[127] One household respondent was selected to provide household-level and individual data from each dwelling. Except for Quebec, which followed a different sampling strategy arranged by Sante Quebec, all provinces followed this procedure.[127]

Experienced interviewers from Statistics Canada obtained information from NPHS respondents using a computer-assistant interviewing (CAI) strategy and controlled for errors in the process.[127] With the CAI tool, NPHS survey administrators made efforts to collect and confirm responses from respondents by following procedures for invalid values and non-respondents.[127]

4.2.2 Walkability data

Walkability data at the dissemination area (DA) level was constructed; the land-use mix index was calculated with the help of Model Builder, an application that was integrated with ArcGIS for purposes of geoprocessing. “Census tract (CT) - and Dissemination area (DA) - level data were UNIONed with the land use layer, then each individual land use was isolated and its area/areal unit calculated out in square kilometers (sq. km.). Data were exported to Excel, where the land-use mix index was calculated.” The land-use mix score was derived from a formula consistent with that used in an earlier paper by Christian and colleagues (2011).[42]

4.3 Construction of Variables

4.3.1 Outcome Variables

4.3.1.1 Physical Activity

The first outcome variable of interest is physical activity, and in the present study it was measured by a derived variable for total energy expenditure in the NPHS, provided by Statistics Canada. Total energy expenditure is the sum of all energy expended among a list of leisure-time activities provided in the NPHS. More specifically, energy expenditure (EE) was calculated based on the formula below, in kcal/kg/day, and was originally assessed on a continuous scale, in kcal/kg/day for the purpose of constructing a physical activity index. In this study, energy expenditure is used as a continuous variable for all descriptive and multivariable regression analyses.[128] Implausible values for the total energy expenditure were removed (i.e. greater than or equal to 15 kcal/kg/day). This variable was also analyzed for its potential mediator role in the pathway between neighbourhood walkability and adult BMI.

EE (kcal/kg/day)= Sum of ((N_i* D_i* MET value)/ 365), where:

N= the number of times a respondent engaged in an activity $_i$ over a 12 month period;

D= the average duration in hours of the activity $_i$ ($AVEDUR_i$);

MET= metabolic equivalent value; the energy cost of the activity expressed as kilocalories expended per kilogram of body weight per hours of activity (kcal/kg per hour)/ 365 (for the conversion of yearly data into daily data).

In constructing the physical activity index from the derived energy expenditure variable from the NPHS, the formula for total energy expenditure captures the frequency and amount of time spent in a single physical activity session, along with the metabolic cost of energy for a particular leisure-time activity in each cycle. MET values capture the intensity level of an activity and are an important part of the formula because NPHS questions do not explicitly ask for an estimate of the intensity of their physical activities.

It is also generally acknowledged that individuals have a tendency to overestimate the intensity of their physical activity sessions.

4.3.1.2 Body Mass Index (BMI)

The second outcome of interest was the BMI, the measure for obesity in the present study. BMI is calculated from dividing the weight in kilograms by the height in meters squared. In the NPHS, the BMI is a derived variable that uses a respondent's self-reported weight and height values and where necessary, from imputed weight and height values. It should be noted that Statistics Canada used imputation methods only on respondent weight and height variables. The imputation method for height followed whether or not a respondent's height was likely to change, depending on their age. Consequently, the age of a respondent in Cycle 1 or the age determined from the latest birthday was used to determine height. Imputation for weight was adjusted for missing weight values. The BMI derived variable is inclusive of all respondents excluding pregnant women living in Canada's ten provinces, and in the present study it was retained in its original form, in kg/m^2, as a continuous variable for all analyses.

4.3.2 Exposure Measures

Three different constructs for neighbourhood walkability were used in the present study. These measures were not combined into a walkability index because they were not correlated with each other.

4.3.2.1 Land-use mix Index

The first exposure variable of interest in this study that provided a measure for neighbourhood walkability was the land-use mix index for dissemination areas. Shown below, the land-use mix index was calculated using a formula provided by Christian and colleagues (2011). DA proportions of dissemination area land uses such as commercial lands, resource and industrial lands, government and institutional lands, open space, park lands, and residential lands were entered into the formula below:

$$H = -1\left(\sum_{i=1}^{n} pi * \ln(pi)\right)/\ln(n))$$

where,

H = land use mix score

pi= proportion of the area covered by land use *i* against the summed area for land use classes of interest (including *i*)

n = the number of land use classes of interest.

Thus, this formula yielded land-use mix values within a range of (0, 1). Values closer to zero indicate that the land use 'mix' is more homogeneous and represents single land use, for example large water bodies or extensive road space; whereas values closer to 1 indicate that the land use is constituted of more 'mix' (i.e. the land use space is more heterogeneous) and represents several land uses, for example, 4 or 5 land uses. During data cleaning and checking processes, where land-use mix index values for single land use were equal to 0, the area in square km. was adjusted so that the value for the overall land area was still valid, and did not correspond to the sum of individual proportions of land uses by definition. This indicated that the given land area in square km. was homogeneous and indicated the presence of a large body of water or road space.

4.3.2.2 Population Density

The second exposure variable of interest in this study was the Population Density (in square km., based on 2011 census tract data). Population density is defined by Statistic's Canada's formal definition, the number of persons per sq. km. Census data tables were added in ArcMap 10.1, joined to their respective spatial layer, and calculated. The data were then exported to Excel where it was checked for any errors, and the land-use mix index formula was applied as well. The lowest population density value that can exist for a given observation is 0, indicating that individuals do not populate that particular land area. For such values, a corresponding land area (in square km.) still exists, but it means that a water body or extensive road space represents the corresponding land area. Thus, the corresponding land area still exists even if its area is not the sum of parts single proportions of land. The corresponding land-use mix index value for this type of land use is 0 (see definition for land-use mix index above).

4.3.2.3 Intersection Density

The third exposure variable of interest in this study used was Intersection Density. Intersection density was derived using street networks and was defined as the number of 3-or-4-way intersections per sq. km. Nodes at each intersection was created and INTERSECTed with census tract and DA boundaries to determine a count of intersection/areal unit. Based on 2011 census tract data, the corresponding count figure was divided by the area (in sq. km.) to return a density value.

4.3.2.4 Neighbourhood Walkability Measures

According to the literature, a common method for handling neighbourhood walkability measures is categorizing them into intervals (e.g. tertiles[72,129,130] or quartiles [42,55,66,69]). In this study, each neighbourhood walkability measure was categorized in ordinal fashion, as a three-level variable in ascending order of “low,” “medium,” and “high”; the reference group was “low”. Another common way of handling walkability measures is to retain a continuous form and standardize regression coefficients so that the quantity represents a change in the outcome variable for a one-unit increase in the standard deviation (1-SD) in the explanatory variable.[13, 33] This latter approach allows interpretability of the results based on standardized z-scores.[13] Categorization was the method selected for neighbourhood walkability measures for a practical interpretation of the results (i.e. comparing ‘medium and high walkable neighbourhoods to low walkable neighbourhoods) while capturing the entire distribution of observations.

4.3.3 Confounding Variables

This section provides a detailed description of the way in which confounding variables were constructed.

Age: Age was included as a continuous variable, and a quadratic term for age was created to represent a non-linear relationship between age and the outcome of interest; thus, a variable for age squared was also included in each model. This would be illustrative of a quadratic relationship suggesting that as individuals become older, the effect of age may change.

Sex: Sex is a dummy variable and indicates whether a respondent identifies him or herself as a male or female. ‘Males’ were the reference group in the analyses.

Race: Race indicates a respondent’s particular ethnic/racial group. In this study, race was dichotomized into those who were ‘White’ compared to ‘Other’ racial groups (Black, Korean, Filipino, Japanese, Chinese, Native/Aboriginal, South Asian, South East Asian, Arab or West Asian, Latin American, Multiple Race). ‘White’ was the reference group in our analyses.

Number of children in the household less than 5 years of age: A derived variable for the number of children living in the household who were less than 5 years of age was based on the number of persons living in the household and a record identifier for the household. For this measure, respondents were able to indicate a value between 0 and 40 to indicate the number of persons 5 years old or less in the household. In this study, this variable was dichotomized so that the information was grouped into ‘No children 5 years or less in the household’ and ‘Between 1 and 3 children in the household’ for analyses, with the former as the reference group for this variable.

Number of children in the household between 6 and 11 years of age: A derived variable for the number of children living in the household who were between 6 and 11 years of age was also formulated using the same criteria as the variable for the number of children in the household less than 5 years of age. In the study, this variable was dichotomized so that the information was grouped into ‘No children between 6 and 11 years of age in the household’ and ‘1 or more children in the household’ for analyses, with the former as the reference group for this variable.

Immigration Status: Immigration Status was a derived variable that indicated whether a respondent was an immigrant or not, and remained dichotomous in this study. For this variable, Canadian-born respondents were the reference group.

Marital Status: Respondents who were either ‘Single’ or ‘Never Married’ were combined into one group and were selected as the reference group for this variable. Those who were

‘Married’ or in a ‘Common-Law’ partnership were grouped together, and those who were either ‘Widowed,’ ‘Separated’ or ‘Divorced’ were grouped together.

Income Adequacy: A derived variable for income was represented by the income adequacy variable that classified information about income into ‘low’ and ‘high’ income groups based on the total household income and the number of people living in the household. The low income group included respondents who fit the description of earning between less than $15 000 with a household size of between 1-2 persons and less than $30 000 with a household size of 5 or more persons. The high income group included respondents who were of either middle or high income groups and fit the description of between $15 000 or more with a household size of 1-2 persons and $30 000 or more with a household size of 5 or more persons. For the analysis, this variable remained the same, as it already distinguished between ‘low’ and ‘high’ income groups.

Labour Market Activity: The Current Labour Force Status variable was used to provide a measure of employment in this study. This variable examined which respondents were ‘employed,’ ‘unemployed’ and ‘not in the labour force.’ The latter two groups were combined to represent the proportion of unemployed respondents and this was the reference group for all analyses.

Education: A derived variable for education that pertaining classified the highest level of educational attainment group respondents into four main categories: ‘less than secondary school graduation’, ‘secondary school graduation,’ ‘some post-secondary,’ and ‘post-secondary graduation.’ The reference group for this variable was those who had attained ‘less than secondary school graduation.’

Nutrition: Total daily consumption of fruits and vegetables was an NPHS derived variable used to represent nutrition in this study. It was based on several questions in the Fruit and Vegetable consumption module of the NPHS that sought to report information about the frequency of selected fruits and vegetables respondents consumed on either a daily, weekly, monthly, or yearly basis. Respondents were also asked about the annual frequency of consumption of a particular fruit or vegetable so that a measure for the frequency of daily consumption rather than a quantity of fruits and vegetables consumed could be provided. First, an annual total of fruits and vegetables consumed was summed to represent total consumption and afterwards divided by 365 days to attain the per day consumption of fruits and vegetables together. This variable was retained in its original continuous form for our analyses.

Smoking Status: The smoking status was derived from the smoking module and was based on questions that asked about the respondent's current smoking status, whether they had ever smoked cigarettes and whether they had ever smoked daily. Based on an assessment of their smoking habits (from this information), respondents were grouped into the following categories: 'daily smoker,' 'occasional smoker,' 'always an occasional smoker,' 'former daily smoker,' 'former occasional smoker,' and 'never smoked.' For use in this study, the above groups were used to categorize smoker status of respondents, however, 'occasional smoker' and 'always an occasional smoker' were collapsed into one group, with 'never smoked' as the reference group.

Alcohol Use: To represent alcohol use in this study, a derived variable for the 'type of drinker' from the alcohol module was used to distinguish been respondents who were classified as 'regular drinker,' 'occasional drinker,' 'former drinker,' and those who 'never drank.' This classification was derived based on respondents' frequency of drinking alcohol and if they mentioned ever having a drink. The same categories used to distinguish the 'type of drinker' were retained in our analyses, with those who 'never drank' as the reference group.

Postal Code: A six-digit alpha-numeric code was determined as the individual's residential postal code, originally created by the Canada Post Corporation for mail deliveries. This variable in the NPHS was used in accordance with Statistics Canada's Postal Code Conversion Files (PCCF+) to link respondents to a corresponding DA.

4.4 Statistical Analysis

This section describes the steps for the descriptive analysis, multivariable regression analysis, and finally, the mediation analysis.

4.4.1 Descriptive Analysis

Univariable analyses were performed for the main predictors and outcomes of interest. These analyses provided information on any outliers, implausible values, means, and standard deviations for continuous variables. For categorical variables, frequencies and percentages were examined for each group. Data distributions of continuous outcome variables were also examined Q-Q plots to obtain information about normality. A linear regression model was used for bivariate analyses of all variables for each of the predictor and outcome variables, by sex.

4.4.2 Multivariable Regression Analysis

Multivariable linear regression analyses were performed for each of the main associations of interest, and these were informed by each of the conceptual models (Figures 1 to 3). Analyses in this study were guided by the hypothesized causal frameworks of the association between neighbourhood walkability and obesity; this is illustrated by Figures 5 to 7 that correspond to mediation pathways described by Baron and Kenny[53] so that the association between neighbourhood walkability and physical activity represents path *a*, the association between physical activity and obesity represents path *b*, and the association between neighbourhood walkability and obesity, with physical activity as the mediator represents path *c'* or the direct effect of neighbourhood walkability on obesity. In this study, data were first analyzed within these pathways through univariable and multivariable linear modeling in STATA13. For all univariable analyses, NPHS sampling weights were applied. Figures 5 to 7 are found at the end of Chapter 4.

4.4.3 Mediation Analysis

The method we adopted for mediation analysis is the approach proposed by Schluchter (2008).[131] The essence of this approach is to directly estimate the indirect effect and its associated standard error using the generalized estimating equation (GEE) method. Specifically, the first step of the method was to duplicate data records as follows for subject *i*:

Subject *i*	*y*	*x*	G	M*

Record 1	y_i	x_i	i	0
Record 2	y_i	x_i	0	M_i

where:

y_i denotes outcome; x_i denotes factor of interest; G is the indicator of the record, & M* is indicator for mediators:

The second is to apply GEE to fit the following model:

$E(Y)= \beta_0 + \beta_1 X_1 + \theta G + \theta GX + \gamma M^*$ (1)

The estimate θ is the difference between the estimates of coefficients from the unadjusted and the model adjusting for the mediator. To see this, consider the model with the first record, where G=1, M*=0; the model reduces to:

$E(Y) = \beta_0 + \beta_1 X_1 + \theta_0 + \theta X$

$= (\beta_0 + \theta_0) + (\beta_1 + \theta)X$ (2)

But when G=0, $M^*=M_i$, (i.e. the second record), and model (1) becomes:

$E(Y)= \beta_0 + \beta_1 X_1 + \gamma M$

Thus, the inference regarding the indirect effect can be easily obtained with the estimate for θ and its associated standard error.

4.5 Other Considerations

Statistical software packages SAS and STATA software and NPHS data access was provided by Statistic's Canada's Research Data Centre at The University of Western Ontario.

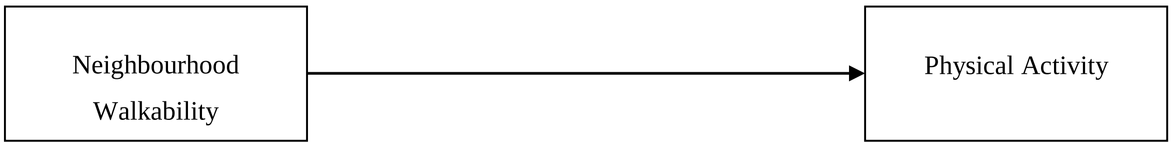

Figure 4-2: The association between neighbourhood walkability and physical activity (path *a*)

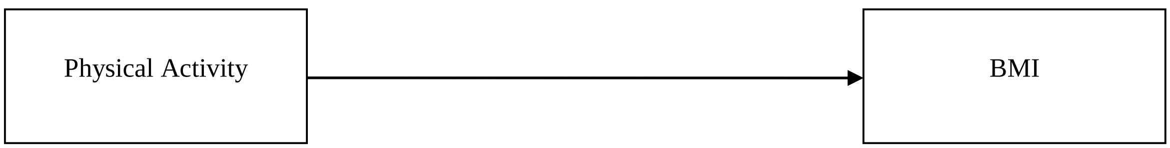

Figure 4-3: The association between physical activity and BMI (path *b*)

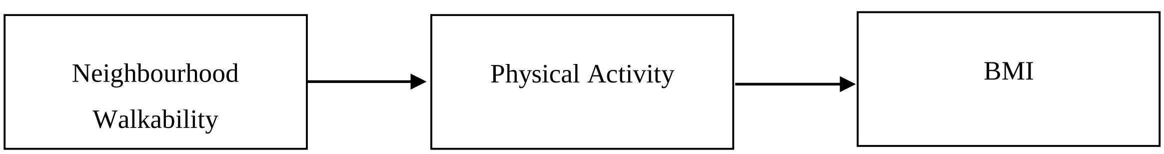

Figure 4-4: The association between neighbourhood walkability and BMI (path *c'*)

Chapter 5

5 Results

The Results Chapter begins with a presentation of the descriptive statistics of the outcomes and confounders by sex, followed by multivariable regression results and mediation analysis.

5.1 Descriptive Statistics

The total sample of NPHS respondents between ages 18 and 64 included in this study was 3258, from 2010/11. This exact sample remained consistent in each of the models for all regression analyses.

Table 1 at the end of this chapter gives an overview of the outcome variables by socioeconomic and demographic characteristics of the respondents and summary measures of neighbourhood walkability by sex. In general, the majority of the sample was Canadian-born (82% of males, 83% of females), white (88% of males, 89% of females), obtained a college or university-level education (51% of males 56% of females), and employed (93% of males, 96% of females). The majority of respondents in this sample indicated they did not have children less than 5 years of age or children (93% of males, 91% of females) or between 6 and 11 years of age (89% of males, 87% of females) living in the household. On average, the daily consumption of total fruits and vegetables was 4.16 servings among males and approximately 5.00 servings among females. The mean BMI of males was 26.91 kg/m^2, slightly higher than mean BMI for females, 25.66 kg/m^2. A larger percentage of females than males indicated they had never smoked before (approximately 39% of females versus 32% of males), however a larger percentage of males were daily smokers (18% of males versus 15% of females). The majority of respondents indicated they were regular drinkers (approximately 80% of males and 66% of females), although a much larger proportion of males compared to females were regular drinkers. The proportion of occasional male drinkers was half that of the proportion of occasional female drinkers (10% of males versus 20% of females). In general, the majority of respondents were married or in common-law relationships (56%

of males, 58% of females), however a larger percentage of females were widowed, separated or divorced, compared to males (12% of females, 6% of males) (Table 2).

Based on the conceptual framework for the hypothesized causal model, the three main associations of interest in this study were between neighbourhood walkability and physical activity, between physical activity and BMI, and between neighbourhood walkability and BMI. Univariable and multivariable associations were examined for these pathways in STATA 13. All three neighbourhood walkability measures were simultaneously entered in each of the multivariable models. See section 5.8 to view all results tables.

5.2 The Association between Neighbourhood Walkability and Physical Activity

Univariable analyses between intersection density and physical activity revealed no significant associations between any of medium, or high (compared to low) intersection density variables and energy expenditure. Population density was positively associated with energy expenditure, and the results showed that there was a significant association between ‘medium’ (compared to low) population density and energy expenditure (β=0.24; SE=0.11; p=0.025; 95% CI: 0.030, 0.457). No significant associations were found between high (compared to low) population density and energy expenditure, or between any of ‘high’ or ‘medium’ (compared to low) land-use mix and energy expenditure.

5.2.1 Model 1: Association between Neighbourhood Walkability and Physical Activity

Model 1 consisted of all three neighbourhood walkability measures and controlled for potential confounding effects of socioeconomic and demographic variables. For most neighbourhood walkability measures, no significant associations were found with energy expenditure.

In males, a significant inverse association was found between land-use mix and energy expenditure for respondents living in areas of ‘medium’ land-use mix compared to those living in areas of low mix (β= -0.39, *SE*=0.17, *p*=0.023; 95% CI:-0.724, -0.528). A similar pattern of association was also observed for 'high' (compared to low) land-use mix, although the magnitude of this relationship was much smaller and the finding was non-significant. This difference in magnitude of associations may illustrate non-linear associations between neighbourhood walkability and energy expenditure.

In females, no significant associations were found between any of the neighbourhood walkability measures and physical activity. A dose-response pattern for an increase in total energy expenditure, from areas of medium (compared to low) and high (compared to low) intersection density was observed. However, results revealed non-linear associations of population density and land-use mix on energy expenditure. The pattern of associations in females did not follow a direction similar to males, and the results were of a small magnitude and non-significant. Thus, the pattern of associations between neighbourhood walkability measures and physical activity in males and females was mixed. Based on the full multivariable linear model examining the association between neighbourhood walkability and physical activity, there is some evidence to suggest that population density and land-use mix may be associated with total energy expenditure in a non-linear fashion, but that intersection density may be associated with energy expenditure linearly.

5.2.2 Relationship between other confounders and physical activity (Model 1)

Multivariable findings of the association between neighbourhood walkability and physical activity by sex showed that among males, Age and Age^2 were significant, indicating that until the age of 45 years, the effect of age was negative and then positive thereafter. Having a higher education was significantly associated with higher total energy expenditure. Compared to males who completed less than a secondary school education, males who obtained an education beyond the high school level had the highest total energy expenditure by 0.60 kcal/kg/day and males who had fulfilled a college or university level education had higher total energy expenditure by 0.43/kcal/kg/day.

Multivariable findings for the association between neighbourhood walkability and physical activity by sex showed that among females, Age and Age^2 were significant indicating that until the age of 53 years, the effect of age as positive, and continued to have positive effects thereafter. The group of females who had fulfilled the highest level of educational attainment (college or university level education) was significantly associated with higher total energy expenditure of 0.40 kcal/kg/day compared to the group of females that acquired less than a secondary school education.

5.3 The Association between Physical Activity and BMI.

Univariable findings demonstrated a statistically significant inverse association between total energy expenditure and BMI (β= -0.37, *SE*=0.045, *p*=0.000; 95% CI: -0.459, -0.282). In other words, a one-unit increase in total energy expenditure was significantly associated with a lower BMI by 0.37 kg/m^2.

5.3.1 Model 2: Association between Physical Activity and BMI

In the multivariable model that examined the association between physical activity and obesity for the full sample, a significant inverse association was found between total energy expenditure and BMI. This finding was in the expected direction A one-unit increase in total energy expenditure was associated with a decrease in BMI by 0.26 kg/m^2.

5.4 The Association between Neighbourhood Walkability and BMI, adjusting for Physical Activity

Univariable findings for the relationship between intersection density and BMI showed that ‘high’ (compared to low) intersection density was significantly negatively associated with BMI and of a moderate magnitude (β= -0.54, *SE*=0.26, *p*=0.040; 95% CI: -1.051, -0.024). Medium (compared to low) compared to high (compared to low) intersection density was also positively associated with BMI, of small magnitude (0.23 kg/m^2 compared to 0.53 kg/m^2) though the former result was not significant. No significant univariable associations were found between ‘medium’ (compared to low) and ‘high’ (compared to low) population density and BMI, or for any levels of land-use mix and BMI.

5.4.1 Model 3: Relationship between Individual Neighbourhood Walkability Measures and BMI

None of the neighbourhood walkability measures were found to be significantly associated with BMI in the multivariable model when the full sample was considered. Among males, higher intersection density was negatively associated with BMI, of small magnitude for both medium (compared to low) and high (compared to low) intersection density (0.21 kg/m^{2}and 0.34 kg/m^2 respectively). ‘Medium’ (compared to low) population density was positively associated with BMI of moderate magnitude (β=0.30 kg/m^2) but ‘high’ (compared to low) population density was negatively associated BMI, of small magnitude (0.03 kg/m$^{2)}$. Similar associations were also found between land-use mix and BMI in that ‘medium’ land-use mix was positively associated with BMI, and of small magnitude (0.26 kg/m^2) but ‘high’ land-use mix was negatively associated with a BMI of 0.09 kg/m$^{2.}$

5.4.2 Relationship between other confounders and BMI (Models 2 and 3)

For males in Model 2, Age and Age^2 were statistically significant, indicating that the effect of age on BMI is positive until the age of 62.16 years. The high income group of males was significantly associated with a 2.35 kg/m^2 increase in BMI. Former daily male smokers were significantly associated with a 1.02 kg/m2 increase in BMI compared to males who had never smoked, which was nearly double the increase observed in the comparison of occasional male smokers to males who never smoked (0.48 kg/m^2). Furthermore, regular male drinkers were significantly associated with lower BMI’s compared to those who never drank (3.14 kg/m^2).

For females in Model 2, only Age was statistically significant.. Compared to females who had acquired less than a secondary school education, the group of females who had completed education beyond the high school level were significantly associated with a 1.87 kg/m^2 decrease in BMI; females who had achieved the highest level of educational attainment (college or university level education) were also significantly associated with a 2.11 kg/m^2 decrease in BMI. Compared to single or never married females, those who were married or in common-law relationships, and those who were classified as being widowed, separated or divorced were found to be significantly negatively associated with BMI, indicated by decreases of 1.32 kg/m^2 and 1.43 kg/m^2. Women who lived in households where there were children less than the age of 5 years had a significant positive association with BMI; this was indicated by a BMI increase of 1.32 kg/m^2.

For males in Model 3, statistically significant associations were found between physical activity, age, age^2, race, income, smoking, and alcohol type, and BMI. In males, Age and Age^2 were statistically significant, indicating that the effect of age on BMI is positive until the age of 49.25 years. Furthermore, a one-unit increase in total energy expenditure was significantly associated with a decrease in BMI of 0.16kg/m^2. Compared to white males, non-white males were found to have a significant decrease in BMI by 0.98 kg/m^2. The high income group of males was found to be significantly associated with a decrease in BMI of 2.14 kg/m^2 compared to the low income group of males. Former daily male smokers were statistically significantly associated with an increase in BMI of 1.05 kg/m^2, compared to males who had never smoked. A statistically significant inverse association was found between the group of males classified as regular drinkers and BMI (decrease by 3.35 kg/m^2).

For females in Model 3, statistically significant associations were found between physical activity, age, race, education, marital status, and number of children less than 5 years of age in the household and BMI. The group of non-white females had a BMI 1. 1.12 kg/m2 lower than white females. Compared to females who had only acquired less than a high school level of education, those who had acquired education beyond the high school level and a college or university level education were significantly negatively associated with BMI (1.81 kg/m^2 and 2.06 kg/m^2, respectively). Compared to single or never married females, those who were married or in common-law relationships, and those who were classified as being widowed, separated or divorced were found to be significantly negatively associated with BMI, indicated by decreases of 1.31 kg/m^2 and 1.44 kg/m^2, respectively. Women who lived in households where there were children less than the age of 5 years had a significant positive association with BMI; this was indicated by a BMI increase of 1.33 kg/m^2.

5.5 Mediation Analysis: The estimated indirect effect of physical activity in the pathway between neighbourhood walkability and BMI

Physical activity was tested as a mediator between population density and BMI. Results from the mediation analysis indicated no significant indirect effect of physical activity in the pathway between 'medium' population density and BMI. For this mediated relationship, the total, direct and indirect effects are shown in Table 4.

5.6 The Association between 2001 Neighbourhood Walkability Measures and Physical Activity and Adult BMI

An intent of this study was to explore whether there might be reason to pursue a longitudinal analysis of the association between neighbourhood walkability and BMI. Longitudinal NPHS data was used for this reason. This section presents the results of the association between neighbourhood walkability and physical activity and BMI using walkability data from 2001. It is likely that some respondents may have moved somewhere between 2000/01 and 2010/11. PCCF+ was used to link 2001 postal codes from respondents in our sample to 2001 built environment data at the DA-level. After NPHS data and 2001 built environment data were merged, I performed multivariable linear regression analyses similar to 2010/11. Indeed, there were different associations observed between certain neighbourhood walkability variables and physical activity and BMI.

There was a significant association between 'medium' land-use mix (in 2001) and total energy expenditure when 2001 walkability measures were used. No statistically significant associations were found between other neighbourhood walkability variables and total energy expenditure.

There was also a significant association between 'medium' land-use mix and BMI when 2001 walkability measures were used. No statistically significant associations were found between other neighbourhood walkability variables and BMI.

In comparing these associations to those found in 2010/11, it is evident that with changing geographical boundaries, associations that previously didn't exist may cease to exist or vice versa. Oliver and colleagues (2007) made this point clearly when they compared associations between land-use mix and walking outcomes.[41] A previous study tracked changes in residents' physical activities, social interactions and neighbourhood cohesion by observing pre-and-post move differences in outcomes.[132] More specifically, this study examined whether individual physical activity levels increased or decreased after moving to a walkable community. Amongst this subgroup, the majority expressed that their physical activity levels were higher and nearly half expressed that their health conditions were better or about the same as before. Respondents also expressed that the move to a more walkable community improved other dimensions of their well-being (i.e. outcomes, for example, increased social interactions and neighbourhood cohesion). However, a later analysis of insufficient and sufficiently active subgroups revealed significant increases in physical activity levels within the subgroup that was insufficiently active before, but not within the subgroup that was already sufficiently active ($p<0.01$). For example, residents from very low, low, and medium-walkability communities walked approximately 54.1, 55.3, and 49.8 minutes per week more in their respective communities after the move ($p<0.01$).[132]

5.7 Assessment of Linear Model Assumptions

Neighbourhood walkability variables were assumed to have a linear relationship with energy expenditure and BMI. In linear regression modeling, no assumptions have to be made about the distribution of predictor variables, under the assumption that they are measured without error. To ensure the validity of results from the models above, an assessment of linear model assumptions in the following aspects was conducted:

5.7.1 Linearity

5.7.1.1 Linearity of the relationship between neighbourhood walkability and physical activity.

At the start of the exploratory data analysis, a scatter plot was first examined to view preliminary relationships between continuous predictors and outcomes in STATA13. All variables, including predictor variables underwent data-checking steps for the removal of implausible values and extreme outliers.

Graphical inspection of a scatter plot for the relationship between intersection density and energy expenditure did not provide any obvious indication of a linear relationship. Rather, the scatter plot was suggestive of weak, non-linear relationships. Linear and quadratic terms for intersection density were regressed against energy expenditure to examine relationships between the variables; however, these relationships were weak and non-significant. A linear spline was further used to model the relationship between intersection density and energy expenditure because of earlier reservations about linear relationships between the predictor and outcome variable and from earlier graphical inspection that there may be curvature. A linear spline with 4 knots was fitted to the data, at 20^{th}, 40^{th}, 60^{th}, and 80^{th} percentiles but these associations were extremely small in magnitude and non-significant. The linear model was retained as a best fit for the data; a test of coefficients for the linear spline knots was non-significant.[133]

The linear test for the association between population density and energy expenditure was significant, which suggested that it was appropriate to assume the linear model would best fit the data. Linear testing for the association between land-use mix and energy expenditure began with graphical inspection of a scatter plot. The scatter plot did not provide any obvious indication of linearity but tests for linearity indicated that the linear term exploring the association between land-use mix and energy expenditure was significant. This suggested that it was appropriate to assume the data could be fit using a linear model.[133]

5.7.1.2 Linearity tests for the relationship between physical activity and BMI

The scatter plot illustrated a downhill linear relationship between energy expenditure and BMI. A simple linear regression was performed to support the assumption that a linear model would fit the data best. The linear regression revealed a significant inverse association between energy expenditure and BMI.

5.7.1.3 Linearity tests for the relationship between neighbourhood walkability and BMI

The same steps for linearity testing that were applied to examine relationships between neighbourhood walkability variables and physical activity, were also applied to examine relationships between neighbourhood walkability variables and BMI.

5.7.2 Residuals

As there was doubt about whether the effect of neighbourhood walkability variables was linear, residuals were plotted after main multivariable analyses were performed. Residuals were used because of their more powerful visual detection of deviation from linearity.[133] Since each statistical model was fitted to examine the adjusted effects of individual-level confounders on neighbourhood walkability variables, the residuals in this study refer to the adjusted effects for the sake of relevance, from residual-versus-fitted plots (RVFs).

For the adjusted effects of neighbourhood walkability on physical activity, and BMI, and for the adjusted effects of physical activity on BMI, the RVF plots displayed a pattern that was indicative of deviations from linearity. A more formal test for heteroscedasticity was executed using the Breusch-Pagan test. This is a test of the null hypothesis that residual are homoscedastic. The results of this test showed that the null hypothesis was rejected at the 95% confidence level, in favour of the alternative that the residuals were heteroscedastic. The same steps were repeated to obtain and analyze residuals for the effect of physical activity on BMI, and for the effect of neighbourhood walkability on BMI. The results of the Breusch-Pagan tests for all three models provided support for the presence of significant heteroscedasticity. To correct for heteroscedasticity in each regression model, the robust standard error option in STATA'13 was applied.

5.7.3 Collinearity (Variance inflation factor)

Multicollinearity among built environment measures is a matter of concern in the built environment literature and for this reason, many studies have justified the use of an index (e.g. the walkability index) that contains separate built environment measures or components. Such a composite measure of neighbourhood walkability is often used to examine relationships between walkability and physical activity or BMI. The collinearity of continuous neighbourhood walkability variables was examined in a correlation matrix. Correlation coefficients revealed a weak uphill linear relationship between intersection density and population density (r=0.3539) and a very weak linear relationship between intersection density and the land-use mix index (r=0.0502). The correlation matrix also revealed a weak negative relationship between population density and land-use mix (r=-0.1147). Contrary to the collinearity found between the built environment measures in previous studies, the neighbourhood walkability measures in this study were not correlated; hence, multicollinearity was not a concern. The variance inflation factor (VIF) for these neighbourhood walkability measures provided additional support for the lack of collinearity among them (*VIF*=1.01).[133] Weak relationships between the neighbourhood walkability measures in this study did not provide justification to develop a walkability index, even though other studies have done so[14,28]

Table 1: Descriptive Statistics for Neighbourhood Walkability Variables (Intersection Density, Population Density, and Land-Use Mix), Energy Expenditure, Body Mass Index and Other Individual-level Variables, By Sex

	Mean (SD) or Frequency (%)	
	Males	**Females**
Neighbourhood Walkability Variables (mean, SD)	-	-
Intersection Density	65.41 (49.25)	67.60 (53.88)
Population Density	4188.48 (6681.93)	3897.83 (5472.51)
Land Use Mix	0.34 (0.29)	0.365 (0.30)
Energy Expenditure (mean, SD)	2.65 (2.33)	2.37 (2.06)
BMI (mean, SD)	26.92 (5.07)	25.67 (5.59)
Other Individual-level Characteristics	-	-
Age (mean, SD)	41.74 (13.94)	41.64 (13.67)
Race (%)	-	-
Other	11.54	10.05
White	88.46	89.95
Income (%)	-	-
Low	3	3.48
High	97	96.52
Highest Level of Education Completed (%)	-	-
Less than Secondary School	8.72	5.83
Secondary School	11.29	11.07
Beyond High school	29.30	27.12
College or University	50.69	55.99
Marital Status (%)	-	-
Single/Never Married	37.39	30.53
Married or Common-Law	56.39	57.68
Widowed or Separated or Divorced	6.22	11.79
Immigrant Status (%)	-	-
No *(Ref)*	17.11	16.79
Yes	82.89	83.21
Labour Market Activity (%)	-	-
Unemployed or Not Looking	7.05	4.24
Employed	92.95	95.76

Number of persons less than 5 years old in household (%)	-	-
No Children less than 5 years old in household	92.64	90.86
1 or more children less than 5 years old in household	7.36	9.14
Number of persons between 6 and 11 years of age (%)	-	-
No Children between 6 and 11 years of age in household	88.52	87.41
1 or more children between 6 and 11 years of age in household	11.48	12.59
Total daily consumption of fruits and vegetables (Nutrition)	4.16 (2.13)	5.00 (2.43)
Smoking	-	-
Never Smoked *(Ref)*	31.84	39.89
Daily	17.79	15.06
Occasional or Always Occasional	5.84	4.64
Former Daily	31.06	26.19
Former Occasional	13.46	14.21
Alcohol Drinker/Use	-	-
Never Drank *(Ref)*	2.60	4.72
Regular Drinker	79.85	65.91
Occasional Drinker	10.50	20.00
Former Drinker	7.05	9.37

Table 2: Univariable and Multivariable Linear Regression Estimates for the Association between Neighbourhood Walkability and Energy Expenditure, by Sex, in 2010/11.

Males

Predictors	**Energy Expenditure Model 1a**			
	Univariable		**Multivariable**	
	β (S.E)	**95% CI**	**β (S.E)**	**95% CI**
Neighbourhood Walkability Variables	-	-	-	-
Low Intersection Density	*ref*	*ref*	*ref*	*ref*
Medium intersection density	-0.014 (0.156)	-0.320, 0.292	0.295 (0.181)	-0.060, 0.649
High intersection density	0.016 (0.172)	-0.322, 0.353	0.283 (0.213)	-0.135, 0.702
Low Population Density *(Ref)*	*ref*	*ref*	*ref*	*ref*
Medium population density	0.136 (0.171)	-0.199, 0.471	-0.141 (0.204)	-0.542, 0.258
High population density	-0.041 (0.156)	-0.346, 0.265	-0.236 (0.207)	-0.641, 0.171
Low Land Use Mix *(Ref)*	- *ref*	*ref*	*ref*	*ref*
Medium land use mix	-0.277 (0.161)	-0.593, 0.038	-0.388 (0.171)	*-0.724, -0.052
High land use mix	-0.031 (0.170)	-0.366, 0.303	-0.079 (0.191)	-0.455, 0.296
Other Individual-level Characteristics	-	-	-	-
Age	-0.027 (0.006)	*-0.038, -0.015	-0.227 (0.049)	*-0.324,-0.130
Age^2	-0.0002 (0.00006)	*-0.0004, -0.0001	0.002 (0.001)	*0.001,0.004
Race	-	-	-	-
White *(Ref)*	*ref*	*ref*	*ref*	*ref*
Other	-0.082 (0.249)	-0.570, 0.406	-0.282 (0.279)	-0.828, 0.264
Income				
Low *(Ref)*	*ref*	*ref*	*ref*	*ref*
High	0.571 (0.354)	-0.124,1.263	0.622 (0.411)	-0.184, 1.428
Highest Level of Education Completed	-	-	-	-
Less than Secondary School *(Ref)*	*ref*	*ref*	*ref*	*ref*
Secondary School	0.140 (0.313)	-0.474, 0.755	0.001 (0.308)	-0.603, 0.605
Beyond High school	0.249 (0.277)	-0.295, 0.792	0.600 (0.271)	0.068, 1.133
College or University	-0.018 (0.251)	-0.511, 0.475	0.431 (0.257)	-0.073, 0.936
Marital Status	-	-	-	-
Single/Never Married *(Ref)*	*ref*	*ref*	*ref*	*ref*
Married or Common-Law	-0.636 (0.156)	*-0.941, -0.330	-0.018 (0.217)	-0.443, 0.4075

Widowed or Separated or Divorced	-0.739 (0.258)	*-1.245, -0.233	0.028 (0.325)	-0.610, 0.665
Immigrant Status	-	-	-	-
No *(Ref)*	*ref*	*ref*	*ref*	*ref*
Yes	-0.336 (0.182)	-0.696, 0.022	0.020 (0.232)	-0.434, 0.475
Labour Market Activity	-	-	-	-
Unemployed or Not Looking	*ref*	*ref*	*ref*	*ref*
Employed	-0.846 (0.339)	- 1.512, -0.181	-0.437 (0.326)	-1.076, 0.203
No. persons <5 yrs of age in household	-	-	-	-
No persons <5 yrs in household	*ref*	*ref*	*ref*	*ref*
Between 1 to 3 children <5 yrs.	-0.350 (0.232)	-0.804, 0.104	-0.350 (0.256)	-0.852, 0.151
No. persons between 6 and 11 yrs in household	-	-	-	-
No persons between 6 and 11 yrs	*ref*	*ref*	*ref*	*ref*
Between 1 to 3 persons between 6 and 11 yrs.	-0.120 (0.224)	-0.559, 0.319	0.002 (0.217)	-0.423, 0.427

Females

Predictors	**Energy Expenditure Model 1a**			
		Univariable		**Multivariable**
	β (S.E)	**(95% CI)**	**β (S.E)**	**(95% CI)**
Neighbourhood Walkability Variables	-	-	-	-
Intersection Density	*ref*	*ref*	*ref*	*ref*
Medium intersection density	0.086 (0.135)	-0.179, 0.350	-0.018 (0.185)	-0.381, 0.343
High intersection density	-0.074 (0.145)	-0.359, 0.212	-0.121 (0.195)	-0.503, 0.261
Population Density *(Ref)*	*ref*	*ref*	*ref*	*ref*
Medium population density	0.339 (0.138)	*0.068, 0.611	0.250 (0.186)	-0.114, 0.614
High population density	-0.089 (0.145)	-0.373, 0.194	-0.072 (0.202)	-0.468, 0.324
Land Use Mix *(Ref)*	*ref*	*ref*	*ref*	*ref*
Medium land use mix	0.011 (0.144)	-0.271, 0.293	0.041 (0.156)	-0.265, 0.347
High land use mix	-0.283 (0.146)	-0.569, 0.004	-0.230 (0.162)	-0.548, 0.088
Other Individual-level Characteristics				
Age	-0.023 (0.005)	*-0.034, -0.014	-0.085 (0.043)	-0.170, 0.0001
Age^2	-0.0003 (0.0001)	*-0.0004, -0.0002	0.0008 (0.0005)	-0.0002, 0.0018
Race	-	-	-	-
White *(Ref)*	*ref*	*ref*	*ref*	*ref*

Other	0.154 (0.298)	-0.431, 0.740	0.252 (0.390)	-0.514, 1.018
Income	-	-	-	-
Low *(Ref)*	*ref*	*ref*	*ref*	*ref*
High	0.908 (0.201)	*0.514, 1.301	0.967 (0.250)	0.477, 1.456
Highest Level of Education Completed	-	-	-	-
Less than Secondary School *(Ref)*	*ref*	*ref*	*ref*	*ref*
Secondary School	0.565 (0.292)	-0.008, 1.139	0.326 (0.286)	-0.235, 0.887
Beyond High school	0.425 (0.241)	-0.047, 0.897	0.194 (0.248)	-0.293, 0.682
College or University	0.506 (0 .220)	0.075, 0.936	0.403 (0.236)	-0.060, 0.866
Marital Status	-	-	-	-
Single/Never Married *(Ref)*	*ref*	*ref*	*ref*	*ref*
Married or Common-Law	-0.587 (0.156)	*-0.894, -0.281	-0.063 (0.196)	-0.448, 0.032
Widowed or Separated or Divorced	-0.809 (0.189)	*-1.179, -0.439	-0.245 (0.226)	-0.689, 0.198
Immigrant Status	-	-	-	-
No *(Ref)*	*ref*	*ref*	*ref*	*ref*
Yes	0.068 (0.179)	-0.282, 0.419	0.111 (0.237)	-.0354, 0.577
Labour Market Activity	-	-	-	-
Unemployed or Not Looking *(Ref)*	*ref*	*ref*	*ref*	*ref*
Employed	-0.321 (0.345)	-0.998, 0.356	-0.521 (0.409)	-1.324, 0.281
No. persons <5 yrs of age in household	-	-	-	-
No persons <5 yrs in household	*ref*	*ref*	*ref*	*ref*
Between 1 to 3 children <5 yrs.	-0.028 (0.219)	-0.459, 0.403	-0.088 (0.258)	-0.595, 0.418
No. persons between 6 and 11 yrs in household	-	-	-	-
No persons between 6 and 11 yrs	*ref*	*ref*	*ref*	*ref*
Between 1 to 3 persons between 6 and 11 yrs.	0.052 (0.191)	-0.322, 0.428	-0.086 (0.214)	-0.504, 0.334

*= statistically significant univariable results p<0.05; **=statistically significant in the multivariable model, p<0.05

Table 3: Univariable and Multivariable Linear Regression Estimates for the Association between Energy Expenditure and BMI, adjusting for individual-level confounders, by Sex, in 2010/11.

Males				
Predictors	**BMI Model 1b**			
		Univariable		**Multivariable**
	β (S.E)	**95% CI**	**β (S.E)**	**95% CI**
Energy Expenditure	-0.301 (0.062)	*-0.424, -0.178	-0.169 (0.055)	**-0.278, -0.061
Other Individual-level Characteristics	-	-	-	-
Age	0.097 (0.0108)	*0.076, 0.119	0.373 (0.085)	**0.206, 0.540
Age^2	0.001 (0.0001)	*0.0008, 0.0014	-0.003 (0.001)	**-0.005, -0.001
Race	-	-	-	-
White *(Ref)*	*ref*	*ref*	*ref*	*ref*
Other	-1.130 (0.460)	*-2.033, -0.227	-1.026 (0.557)	-2.118, 0.066
Income	-	-	-	-
Low *(Ref)*	*ref*	*ref*	*ref*	*ref*
High	-0.543 (2.716)	-5.871, 4.785	2.351 (0.917)	**0.554, 4.149
Highest Level of Education Completed	-	-	-	-
Less than Secondary School *(Ref)*	*ref*	*ref*	*ref*	*ref*
Secondary School	-0.486 (0.640)	-1.738, 0.773	-0.913 (0.760)	-2.404, 0.577
Beyond High school	-0.233 (0.598)	-1.406, 0.939	-0.737 (0.697)	-2.104, 0.630
College or University	-0.019 (0.590)	-1.177, 1.139	-1.092 (0.701)	-2.466, 0.282
Marital Status	-	-	-	-
Single/Never Married *(Ref)*	*ref*	*ref*	*ref*	*ref*
Married or Common-Law	2.472 (0.309)	1.866, 3.079	0.060 (0.467)	-0.856, 0.977
Widowed or Separated or Divorced	1.484 (0.527)	*0.449, 2.519	-0.606 (0.639)	-1.860, 0.647
Immigrant Status	-	-	-	-
No *(Ref)*	*ref*	*ref*	*ref*	*ref*
Yes	0.380 (0.508)	-1.063, 0.612	-0.547 (0.480)	-1.488, 0.395
Labour Market Activity				
Unemployed or Not Looking *(Ref)*	-	-	-	-
Employed	1.004 (0.578)	-0.130, 2.138	-0.757 (0.569)	-1.874, 0.359
No. persons <5 yrs of age in household	-	-	-	-

No persons <5 yrs in household	*ref*	*ref*	*ref*	*ref*
Between 1 to 3 children <5 yrs.	0.594 (0.488)	-0.363, 1.550	0.222 (0.535)	-0.828, 1.271
No. persons between 6 and 11 yrs in household	-	-	-	-
No persons between 6 and 11 yrs	*ref*	*ref*	*ref*	*ref*
Between 1 to 3 persons between 6 and 11 yrs.	0.684 (0.497)	-0.291, 1.659	0.538 (0.584)	-0.608, 1.68
Total daily consumption of fruits and vegetables (Nutrition)	-0.071 (0.068)	-0.204, 0.062	0.011 (0.069)	-.013, 0.146
Smoking	-	-	-	-
Never Smoked *(Ref)*	*ref*	*ref*	*ref*	*ref*
Daily	0.181 (0.587)	-0.969, 1.331	-0.341 (0.461)	-1.245, 0.563
Occasional or Always Occasional	0.087 (0.503)	-0.901, 1.074	0.483 (0.553)	-0.602, 1.568
Former Daily	1.512 (0.369)	*0.787, 2.23	1.029 (0.432)	**0.181, 1.878
Former Occasional	0.061 (0.461)	-0.843, 0.965	0.514 (0.473)	-0.413, 1.441
Alcohol Drinker/Use	-	-	-	-
Never Drank *(Ref)*	*ref*	*ref*	*ref*	*ref*
Regular Drinker	-0.626 (0.922)	2.434, 1.182	-3.146 (1.567)	**-6.220, -0.071
Occasional Drinker	0.426 (1.095)	-1.721, 2.573	-1.589 (1.648)	-4.822, 1.644
Former Drinker	0.661 (1.067)	-1.433, 2.755	-2.151 (1.714)	-5.513, 1.210

Females	**BMI Model 1b**			
Predictors		**Univariable**		**Multivariable**
	β (S.E)	**(95% CI)**	**β (S.E)**	**(95% CI)**
Energy Expenditure	-0.490 (0.064)	*-0.615, -0.365	-0.360 (0.071)	**-0.499, -0.221
Other Individual-level Characteristics	-	-	-	-
Age	0.110 (0.010)	*0.089, 0.129	0.268 (0.088)	**0.095, 0.441
Age^2	0.001 (0.0001)	*0.001. 0.002	-0.002 (0.001)	-0.004, 0.003
Race	-	-	-	-
White	*ref*	*Ref*	*ref*	*ref*
Other	-1.756 (0.417)	*-2.574, -0.938	-1.130 (0.606)	-2.318 , 0.058
Income	-	-	-	-
Low	*ref*	*ref*	*ref*	*ref*

High	-7.17e-06 (0.739)	-1.449, 1.449	1.186 (0.770)	-0.325, 2.696
Highest Level of Education Completed	-	-	-	-
Less than Secondary School	*ref*	*ref*	*ref*	*ref*
Secondary School	-1.388 (0.834)	-3.023, 0.247	-1.878 (0.939)	**-3.721, -0.035
Beyond High school	-1.677 (0.769)	*-3.184, -0.169	-1.131 (0.883)	-2.863, 0.601
College or University	-2.006 (0.720)	*-3.418, -0.594	-2.114 (0.839)	**-3.759, -0.469
Marital Status	*ref*	*ref*	*ref*	*ref*
Single/Never Married	-	-	-	-
Married or Common-Law	1.763 (0.325)	*1.125, 2.399	-1.319 (0.475)	**-2.251, -0.388
Widowed or Separated or Divorced	2.543 (0.484)	*1.593, 3.492	-1.429 (0.575)	**-2.557,-0.301
Immigrant Status	-	-	-	-
No *(Ref)*	*ref*	*ref*	*ref*	*ref*
Yes	-0.226 (0.427)	-1.063, 0.612	-0.733 (0.580)	-1.871, 0.405
Labour Market Activity	-	-	-	-
Unemployed or Not Looking	*ref*	*ref*	*ref*	*ref*
Employed	-0.920 (0.738)	-2.368, 0.527	-0.986 (0.811)	-2.577, 0.604
No. persons <5 yrs of age in household	-	-	-	-
No persons <5 yrs in household	*ref*	*ref*	*ref*	*ref*
Between 1 to 3 children <5 yrs.	-0.215 (0.465)	-1.127, 0.696	1.324 (0.576)	0.195, 2.453
No. persons between 6 and 11 yrs in household	-	-	-	-
No persons between 6 and 11 yrs	*ref*	*ref*	*ref*	*ref*
Between 1 to 3 persons between 6 and 11 yrs.	0.060 (0.477)	-0.876, 0.996	0.065 (0.539)	-0.993, 1.122
Total daily consumption of fruits and vegetables (Nutrition)	-0.086 (0.064)	-0.212, 0.039	-0.035 (0.070)	-0.173, 0.103
Smoking	-	-	-	-
Never Smoked	*ref*	*ref*	*ref*	*ref*
Daily	-0.115 (0.452)	-1.002, 0.772	-0.685 (0.494)	-1.654, 0.285
Occasional or Always Occasional	-1.437 (0.58)9	**-2.592, -0.282	-0.142 (0.591)	-1.301, 1.016
Former Daily	1.266 (0.380)	**0.520, 2.012	0.421 (0.401)	-0.364, 1.207
Former Occasional	-0.562 (0.460)	-1.463, 0.339	-0.705 (0.497)	-1.681, 0.271
Alcohol Drinker/Use	-	-	-	-
Never Drank *(Ref)*	*ref*	*ref*	*ref*	*ref*
Regular Drinker	0.143 (0.676)	-1.182, 1.469	0.272 (0.775)	-1.247, 1.792
Occasional Drinker	1.528 (0.751)	*0.055, 3.002	1.288 (0.813)	-0.308, 2.883

Former Drinker	1.934 (0.837)	*0.291, 3.57	1.061 (0.925)	-0.752, 2.875

*= statistically significant univariable results p<0.05; **=statistically significant in the multivariable model, p<0.05

Table 4: Univariable and Multivariable Linear Regression Estimates for the Association between Neighbourhood Walkability and BMI, adjusting for energy expenditure and other individual-level confounders, by Sex, in 2010/11.

Males				
Predictors	**BMI Model 1c**			
		Univariable		**Multivariable**
	β (S.E)	**(95% CI)**	**β (S.E)**	**(95% CI)**
Neighbourhood Walkability Variables	-	-	-	-
Low Intersection Density	*ref*	*ref*	*ref*	*ref*
Medium intersection density	-0.473 (0.396)	-1.250, 0.304	-0.223 (0.415)	-1.037, 0.592
High intersection density	-1.062 0.386	*-1.819, -0.305	-0.726 (0.439)	-1.587, 0.135
Low Population Density *(Ref)*	*ref*	*ref*	*ref*	*ref*
Medium population density	-0.412 (0.401)	-1.199, 0.375	0.351 (0.438)	-0.508, 1.209
High population density	-0.819 (0.380)	*-1.564, -0.074	-0.235 (0.433)	-1.083, 0.614
Low Land Use Mix *(Ref)*	*ref*	*ref*	*ref*	*ref*
Medium land use mix	0.420 (0.355)	-0.276, 1.116	0.611 (0.406)	-0.185, 1.407
High land use mix	-0.229 (0.380)	-0.975, 0.517	-0.009 (0.380)	-0.756, 0.737
Energy Expenditure	-0.301 (0.062)	*-0.424, -0.178	-0.158 (0.054)	**-0.263, -0.053
Other Individual-level Characteristics	-	-	-	-
Age	0.097 (0.0108)	0.076, 0.119	0.394 (0.085)	0.228, 0.560
Age^2	0.001 (0.0001)	*0.0008, 0.0014	-0.004 (0.001)	**-0.006, -0.002
Race	-	-	-	-
White *(Ref)*	*ref*	*ref*	*ref*	*ref*
Other	-1.130 (0.460)	*-2.033, -0.227	-0.984 (0.566)	-2.095, 0.126
Income	-	-	-	-
Low *(Ref)*	*ref*	*ref*	*ref*	*ref*
High	-0.543 (2.716)	-5.871, 4.785	2.142 (0.878)	**0.419, 3.866

Highest Level of Education Completed	-	-		
Less than Secondary School	*ref*	*ref*	*ref*	*ref*
Secondary School	-0.486 (0.640)	-1.738, 0.773	-0.884 (0.746)	-2.346, 0.579
Beyond High school	-0.233 (0.598)	-1.406, 0.939	-0.713 (0.690)	-2.067, 0.641
College or University	-0.019 (0.590)	-1.177, 1.139	-1.028 (0.696)	-2.393, 0.337
Marital Status	-	-	-	-
Single/Never Married	*ref*	*ref*	*ref*	*ref*
Married or Common-Law	2.472 (0.309)	*1.866, 3.079	-0.111 (0.459)	-1.012, 0.789
Widowed or Separated or Divorced	1.484 (0.527)	*0.449, 2.519	-0.719 (0.635)	-1.963, 0.526
Immigrant Status	-	-	-	-
No	*ref*	*ref*	*ref*	*ref*
Yes	0.380 (0.508)	-1.063, 0.612	-0.420 (0.483)	-1.368, 0.527
Labour Market Activity	-	-	-	-
Unemployed or Not Looking *(Ref)*	*ref*	*ref*	*ref*	*ref*
Employed	1.004 (0.578)	-0.130, 2.138	-0.745 (0.558)	-1.841, 0.350
Number of persons less than 5 years old in household	-	-	-	-
No Children less than 5 years old in household *(Ref)*	*ref*	*ref*	*ref*	*ref*
1 to 3 children less than 5 years old in household	0.594 (0.488)	-0.363, 1.550	0.291 (0.521)	-0.732, 1.314
Number of persons between 6 and 11 years of age	-	-	-	-
No Children less than 5 years old in household *(Ref)*	*ref*	*ref*	*ref*	*ref*
1 to 3 between 6 and 11 years of age in household	0.684 (0.497)	-0.291, 1.659	0.501 (0.584)	-0.643, 1.646
Total daily consumption of fruits and vegetables (Nutrition)	-0.071 (0.068)	-0.204, 0.062	0.004 (0.070)	-0.133, 0.140
Smoking	-	-	-	-
Never Smoked *(Ref)*	*ref*	*ref*	*ref*	*ref*
Daily	0.181 (0.587)	-0.969, 1.331	-0.372 (0.463)	-1.280, 0.536
Occasional or Always Occasional	0.087 (0.503)	-0.901, 1.074	0.502 (0.556)	-0.589, 1.592
Former Daily	1.512 (0.369)	*0.787, 2.23	1.050 (0.433)	**0.202, 1.899
Former Occasional	0.061 (0.461)	-0.843, 0.965	0.506 (0.466)	-0.408, 1.419
Alcohol Drinker/Use	-	-	-	-

Never Drank *(Ref)*	*ref*	*ref*	*Ref*	*ref*
Regular Drinker	-0.626 (0.922)	-2.434, 1.182	-3.349 (1.600)	**-6.488, -0.210
Occasional Drinker	0.426 (1.095)	-1.721, 2.573	-1.835 (1.669)	-5.108, 1.439
Former Drinker	0.661 (1.067)	-1.433, 2.755	-2.505 (1.737)	-5.912, 0.902

Females

Predictors	**BMI Model 1c**			
		Univariable		**Multivariable**
	β (S.E)	**(95% CI)**	**β (S.E)**	**(95% CI)**
Neighbourhood Walkability Variables (mean, SD)	-	-	-	-
Intersection Density	*ref*	*ref*	*ref*	*ref*
Medium intersection density	-0.104 (0.367)	-0.823, 0.616	-0.188 (0.452)	-1.074, 0.699
High intersection density	-0.062 (0.350)	-0.748, 0.624	-0.027 (0.496)	-1.001, 0.946
Population Density	*ref*	*ref*	*ref*	*ref*
Medium population density	0.069 (0.364)	-0.645, 0.783	0.336 (0.471)	-0.588, 1.260
High population density	0.123 (0.360	-0.582, 0.829	0.159 (0.498)	-0.818, 1.135
Land Use Mix	*ref*	*ref*	*ref*	*ref*
Medium land use mix	-0.118 (0.365)	*-0.834, 0.598	-0.055 (0.382)	-0.803, 0.693
High land use mix	-0.161 (0.360)	*-0.865, 0.544	-0.125 (0.370)	-0.850, 0.601
Energy Expenditure	-0.490 (0.064)	*-0.615, -0.365	-0.364 (0.072)	**-0.506, -0.221
Other Individual-level Characteristics	-	-	-	-
Age	0.110 (0.010)	*0.089, 0.129	0.266 (0.089)	**0.091, 0.441
Age^2	0.001 (0.0001)	*0.001, 0.002	-0.002 (0.001)	-0.004, 0.0003
Race	-	-	-	-
White *(Ref)*	*ref*	*ref*	*ref*	*ref*
Other	-1.756 (0.417)	*-2.574, -0.938	-1.126 (0.605)	-2.312, 0.059
Income	-	-	-	-
Low *(Ref)*	*ref*	*ref*	*ref*	*ref*
High	-7.17e-06 (0.739)	-1.449, 1.449	1.170 (0.769)	-0.339, 2.678

Highest Level of Education Completed	-	-	-	-
Less than Secondary School *(Ref)*	*ref*	*ref*	*ref*	*ref*
Secondary School	-1.388 (0.834)	-3.023, 0.247	-1.807 (0.956)	-3.682, 0.067
Beyond High school	-1.677 (0.769)	*-3.184, -0.169	-1.092 (0.887)	-2.833, 0.649
College or University	-2.006 (0.720)	*-3.418, -0.594	-2.064 (0.845)	**-3.721, -0.407
Marital Status	*ref*	*ref*	-	-
Single/Never Married *(Ref)*	-	-	*ref*	*ref*
Married or Common-Law	1.763 (0.325)	*1.125, 2.399	-1.313 (0.479)	**-2.252, -0.373
Widowed or Separated or Divorced	2.543 (0.484)	*1.593, 3.492	-1.445 (0.574)	**-2.570, -0.320
Immigrant Status	-	-	-	-
No *(Ref)*	*ref*	*ref*	*ref*	*ref*
Yes	-0.226 (0.427)	-1.063, 0.612	-0.747 (0.581)	-1.885, 0.392
Labour Market Activity	-	-	-	-
Unemployed or Not Looking *(Ref)*	*ref*	*ref*	*ref*	*ref*
Employed	-0.920 (0.738)	-2.368, 0.527	-1.019 (0.818)	-2.623, 0.585
Number of persons less than 5 years old in household	-	-	-	-
No Children less than 5 years old in household *(Ref)*	*ref*	*ref*	*ref*	*ref*
1 to 3 children less than 5 years old in household	-0.215 (0.465)	-1.127, 0.696	1.328 (0.577)	**0.196, 2.460
Number of persons between 6 and 11 years of age	-	-	-	-
No children between 6 and 11 years of age in household	*ref*	*ref*	*ref*	*ref*
1 to 3 children less between 6 and 11 years of age in Household	0.060 (0.477)	-0.876, 0.996	0.051 (0.542)	-1.013, 1.115
Total daily consumption of fruits and vegetables (Nutrition)	-0.086 (0.064)	-0.212, 0.039	-0.034 (0.070)	-0.171, 0.104
Smoking	-	-	-	-
Never Smoked	*ref*	*ref*	*ref*	*ref*
Daily	-0.115 (0.452)	-1.002, 0.772	-0.644 (0.491)	-1.607, 0.318
Occasional or Always Occasional	-1.437 (0.58)9	*-2.592, -0.282	-0.146 (0.592)	-1.307, 1.014
Former Daily	1.266 (0.380)	*0.520, 2.012	0.443 (0.399)	-0.340, 1.226

Former Occasional	-0.562 (0.460)	-1.463, 0.339	-0.672 (0.498)	-1.649, 0.304
Alcohol Drinker/Use	-	-	-	-
Never Drank *(Ref)*	*ref*	*ref*	*ref*	*ref*
Regular Drinker	0.143 (0.676)	-1.182, 1.469	0.270 (0.773)	-1.246, 1.787
Occasional Drinker	1.528 (0.751)	*0.055, 3.002	1.300 (0.812)	-0.293, 2.893
Former Drinker	1.934 (0.837)	*0.291, 3.57	1.300 (0.812)	-0.754, 2.882

*= statistically significant univariable results p<0.05; **=statistically significant in the multivariable model, p<0.05

Table 5: Results for the Indirect Effect of Physical Activity in the Pathway between Neighbourhood Walkability and BMI.

Mediated Relationship	Total effect β (95% CI)	Direct effect β (95% CI)	Indirect effect β (95% CI)
Population Density (low=ref)	*ref*	*ref*	*ref*
Popdens2 (medium)	0.1206 (-0.4118, 0.6530)	0.1641 (-0.3644, 0.6925)	-0.0435 (0.0176, -0.1045)
Popdens3 (high)	-0.1802 (-0.6868, 0.3264)	-0.1838 (-0.6892, 0.3216)	0.0036 (0.0621, -0.0550)

[a]Indirect = total – direct effect; indirect effect is equal to *G variable interaction in GEE model assessing mediation.
[b]Controls for individual-level confounders: age, sex, marital status, education, income, employment, immigration status, nutrition, smoker type, alcohol use, number of children in the household less than 5 years of age, number of children in the household between 6 and 11 years of age.

Table 6: Multivariable Linear Regression Estimates for the Association between Neighbourhood Walkability in 2000/01 and BMI, adjusting for individual-level confounders in 2000/01.

Predictors	**BMI Multivariable** **β (S.E)**	**(95% CI)**
Neighbourhood Walkability Variables (mean, SD)	-	-
Low Intersection Density	*ref*	*ref*
Medium intersection density	0.064 (0.310)	-0.545, 0.673
High intersection density	0.334 (0.330)	-0.314, 0.982
Low Population Density	*ref*	*ref*
Medium population density	-0.166 (0.343)	-0.838, 0.507
High population density	0.013 (0.350)	-0.674, 0.699
Low Land Use Mix	*ref*	*ref*
Medium land use mix	0.646 (0.326)	**0.006, 1.286
High land use mix	0.194 (0.338)	-0.469, 0.856
Energy Expenditure	-0.236 (0.056)	**-0.346, -0.126
Other Individual-level Characteristics	-	-
Age	0.248 (0.076)	**0.098, 0.397
Age^2	-0.002 (0.0009)	**-0.004, -0.0007
Sex	-1.155 (0.270)	**-1.686, -0.625
Race	-	-
White *(Ref)*	*ref*	*ref*
Other	-1.073 (0.446)	**-1.948, -0.198
Income	-	-
Low *(Ref)*	*ref*	*ref*
High	1.900 (0.725)	**0.479, 3.322
Highest Level of Education Completed	-	-
Less than Secondary School *(Ref)*	*ref*	*ref*
Secondary School	-1.239 (0.782)	-2.772, 0.294
Beyond High school	-0.853 (0.723)	-2.272, 0.565
College or University	-1.667 (0.702)	**-3.044, -0.289
Marital Status	-	-
Single/Never Married *(Ref)*	*ref*	*ref*
Married or Common-Law	-0.339 (0.388)	-1.099, 0.421
Widowed or Separated or Divorced	-0.309 (0.529)	-1.347, 0.730

Immigrant Status	-	-
No	*ref*	*ref*
Yes	-0.599 (0.416)	-1.415, 0.218
Labour Market Activity	-	-
Unemployed or Not Looking	*ref*	*ref*
Employed	-0.987 (0.548)	-2.061, 0.087
Number of persons less than 5 years old in household	-	-
No Children less than 5 years old in household	*ref*	*ref*
1 to 3 children less than 5 years old in household	1.015 (0.522)	
Number of persons between 6 and 11 years of age	-	-
No children between 6 and 11 years of age in household	*ref*	*ref*
1 to 3 children less between 6 and 11 years of age in household	0.355 (0.482)	-0.589, 1.299
Total daily consumption of fruits and vegetables (Nutrition)	-0.099 (0.063)	-0.224, 0.025
Smoking	-	-
Never Smoked	*ref*	*ref*
Daily	-0.294 (0.426)	-1.130, 0.542
Occasional or Always Occasional	0.565 (0.466)	-0.349, 1.479
Former Daily	0.914 (0.329)	**0.267, 1.559
Former Occasional	-0.027(0.397)	-0.806, 0.752
Alcohol Drinker/Use	-	-
Never Drank *(Ref)*	*ref*	*ref*
Regular Drinker	-1.022 (0.993)	-2.969, 0.927
Occasional Drinker	0.007 (1.030)	-2.013, 2.027
Former Drinker	0.258 (1.108)	-1.916, 2.432

*= statistically significant univariable results p<0.05; **=statistically significant in the multivariable model, p<0.05

Chapter 6

6 Discussion

Findings from this study did not support *a priori* hypotheses that neighbourhood walkability was associated with adult BMI, or that physical activity mediated an associations between neighbourhood walkability and BMI. Using a conceptual causal model informed by a comprehensive literature review, the present study theorized and examined cross-sectional associations between neighbourhood walkability measures (intersection density, population density and land-use mix) and physical activity and BMI. It had been hypothesized that lower neighbourhood walkability will be associated with lower physical activity levels, and lower physical activity levels will be associated with a higher BMI, further clarifying the hypothesis that lower neighbourhood walkability will be associated with a higher BMI. It was also hypothesized that physical activity may mediate an association between neighbourhood walkability and adult BMI. Overall, a mix of associations was observed in this study for all three neighbourhood walkability measures, even though they were largely non-significant. This mix of associations corresponds to findings of several reviews of studies throughout the built environment literature. [22,134]

In regard to the hypothesized direction of associations found in Model 1, neighbourhood walkability was positively associated with physical activity for one measure. Further, there was no evidence of a dose-response relationship between neighbourhood walkability measures and physical activity in the analyses. Though non-significant associations were revealed, the results illustrated that physical activity levels were higher on average in those areas of 'medium compared to low' intersection density, population density and land use mix, but less of a difference in physical activity levels patterns was observed when comparing 'high' (compared to 'low') areas of neighbourhood walkability. Furthermore, the strength of the association between neighbourhood walkability and physical activity was small.

In the built environment literature, as well as in the present study, walkability measures are typically focused on walking or biking for transportation or errands (i.e. to work or to shop) rather than walking or biking for recreation or other leisure physical activities. In this study, the physical activity measure used was total energy expenditure, and it was based on a list of leisure-time activities available in the NPHS including walking and biking for leisure-time physical activity, however, it is likely that the walkability measures in the present study were less supportive of walking for physical recreation. This might explain why these findings support previous literature showing that the neighbourhood built environment is less influential on leisure-time physical activity than transport-related physical activity.[135, 50] An earlier Canadian study using CCHS data also failed to find associations between any of their GIS-derived built environment measures and walking and cycling for leisure-time activity.[40] Another shortcoming of this study was that sufficient data were unavailable to be able to examine associations between neighbourhood walkability and walking or walking behaviours, and transport-related physical activity. This was because the NPHS did not collect the intensity and duration of transportation-related physical activities similar to leisure-time energy expenditure. Previous literature has reported that residents of medium compared to low walkable neighbourhoods are more likely to walk for transportation.[50]

Findings from Model 2 revealed relationships between physical activity and BMI in the expected direction so that an increase in total energy expenditure was associated with a lower BMI. The present study did not find significant associations between neighbourhood walkability and BMI as indicated by results in Model 3. Findings for these associations were mixed because they occurred in both expected and unexpected directions. This finding also reflected the inconsistency of associations reported in the built environment literature at large. For instance, the association between intersection density and BMI occurred in the expected direction; increasing intersection density was positively associated with BMI in areas of medium and high intersection density compared to low intersection density. This supported the hypothesis that within highly connected areas (higher neighbourhood walkability), one would find a lower prevalence of BMI. Pedestrian-friendly road features may be more abundant in areas of higher connectivity, providing an enabling environment for outdoor activity. Other design features and benefits of an area with greater street connectivity are safe routes to destinations, accommodations for transit users (including vulnerable peoples) and convenient pathways to reach destinations.[136] In an earlier Canadian study using CCHS data,[20] participants living in highest versus lowest areas of residential density and intersection density (highest compared to lowest quartiles), had a greater likelihood of participating in walking or cycling for leisure-time physical activity if they resided in areas with a greater number of intersections. Another Canadian study also found no association between higher walkability scores and the odds of walking/cycling for leisure or transportation within 1000m buffer zones but a greater likelihood of participation in leisure-time physical activity within 500m buffer regions when comparing residents of high neighbourhood walkability to less walkable neighbourhoods.[40] Additionally, a comprehensive review previously reported a high number of relationships between route/network connectivity and walking for transportation across individual studies.[77]

Generally, the findings indicated that there were no significant associations between population density and BMI in a non-linear pattern. However, previous studies and reviews have reported a majority of positive associations between these measures. For example, Saelens and colleagues (2008) reported a number of positive associations between higher population density and walking for transportation. A systematic review of studies also found that population density and walking behaviours were associated.[10]A later review also found inconsistent associations between objective and perceived measures of the built environment and physical activity and BMI.[22]

In the present study, no significant associations were observed between land use mix and BMI. However, one systematic review reported a large number of positive associations between land use mix and transport-related walking across studies, and similar to many of those studies, ours also used an land-use mix index to measure land use mix.[134] Another review that controlled for neighbourhood self-selection found consistent associations between mixed land use and compositely measured walkability and higher physical activity levels[10] and reported the high frequency of mixed associations between greater land use mix and higher physical activity levels. A 2011 review[10] found consistent associations between mixed land use and physical activity levels after controlling for neighbourhood self-selection, but results from this study did not support that finding. In that review, population density was significantly associated with walking behaviours, and univariable findings of the association between population density and walking in the present study correspond to those findings.

The classification of neighbourhood walkability into “low”, “medium”, and “high” was based on a few different reasons. First, this method would be able to capture all of the data at both high and low ends of the data distribution for these measures. The data distribution for each neighbourhood walkability measure was highly skewed, validating the decision to refrain from using standardized coefficients in this study's analyses Standardization would be an inaccurate method of viewing the associations between non-normally distributed neighbourhood walkability measures on physical activity and BMI and would misrepresent the meaning of these relationships if associations were interpreted by a 1-SD change in the neighbourhood walkability measures. A number of studies have either classified neighbourhoods by tertile or quartiles using clustering methods or arbitrarily applied this kind of categorization due to the lack of a standard approach to classifying neighbourhood walkability measures. It may be that inconsistency of the mix of associations of the effect of the neighbourhood built environment on physical activity and BMI may be because of these varying methods to classify neighbourhood walkability.

Unlike previous studies (e.g. Frank et al., 2005), this study has refrained from using a composite measure such as the walkability index. Because there were only weak correlations among the three neighbourhood walkability measures, this study was able to use measures independently in univariable and multivariable analyses without risk of multicollinearity. As well, including all three neighbourhood walkability measures in the same model would account for potential confounding effects of predictor variables on each other. However, many studies have used composite indices that include intersection density, population density and land use mix to provide a composite measure for walkability.[22] These studies have reported numerous inconsistent associations between walkability indices and overweight or BMI.[22]

Similar to the result of a previous Canadian study[39] that assessed for mediatory effects of individual-level physical activity in the pathway between neighbourhood characteristics and BMI, results from this study's mediation analysis revealed there was no mediated effect of physical activity in the relationship between population density and BMI. Population density was the only neighbourhood walkability measure that was included in the mediation analysis of the association between population density and BMI since univariable analyses pointed to associations between 'medium' (compared to low) population density and total energy expenditure from a conceptual point of view, it is likely that individuals are more motivated and more likely to be physically active in neighbourhoods that are "medium" populated compared to areas that are very densely populated or less populated with people and hypothetically, this could affect weight status. Like the present study, Pouliou and colleagues had used dissemination-area level explanatory variables as measures for neighbourhood area-level variables, obtained built environment variables from a DMTI database (land use mix, street network connectivity, residential density, density of fast-food restaurants, convenience stores, grocery stores, and recreational centres), and also used individual-level explanatory variables to describe lifestyle, SES and other confounding factors. That study also looked to see if diet was a potential mediator in the pathway relating neighbourhood characteristics and BMI but did not find statistically significant indirect effects of diet either.

Alternatively, previous literature has suggested that individual perceptions and cognitions may mediate an association between the built environment and physical activity. The Social Cognitive Theory and The Theory of Planned Behaviour both support the proposition that cognitions mediate physical activity behaviours because of their influence on intentions for physical activity or intent to be active.[137] From the perspective of the Social Cognitive Theory, self-efficacy, perceived behavioural control, attitudes and underlying cognitions are thought to mediate relationships between the built environment and physical activity.[137]

The Theory of Planned Behaviour supports the notion that human behaviour is stimulated by the perceived availability (or unavailability) of opportunities to engage in healthy (or unhealthy) lifestyles, for example, physical activity participation. Available social supports to the individual are important to cognitive processes affecting behavioural change because they can either strengthen or dissuade individual self-efficacy. In turn, this may impact individual decision-making to pursue physical activity or refrain from it.[137] Other literature has also theorized that perceptions might mediate associations between the objectively-determined built environment and physical activity on the grounds that individual perceptions are manifested by underlying cognitions (e.g. attitude, beliefs, self-efficacy, and perceived behavioural control) and individual experiences with the built environment.[56] An alternative point of view follows that perceptions may interact with the built environment to affect walking or physical activity outcomes.[56]

Canadian research has shown support for the indirect effect of individual perceptions and cognitions for associations between the built environment and physical activity behaviours. For example, McCormack and colleagues[138] tested the mediation between neighbourhood walkability variables and moderate and vigorous physical activity in men and women and found that perceived behavioural control (PBC) mediated an association between accessible physical activity facilities and vigorous physical activity in both men and women, but that PBC only mediated the relationship between accessible physical activity facilities and moderate physical activity in women.

Additional support for the role of perceptions in the association between the neighbourhood environment and physical activity is found in research describing channels through which perceptions are nurtured: neighbourhood aesthetics and conditions. Examples of neighbourhood aesthetics and conditions are physical order or disorder, littering, graffiti, noise, air pollution, level of crime, traffic density, and noise. Some neighbourhoods may have more or less of these features. If neighbourhood aesthetics and conditions are perceived as attractive or supportive for outdoor activity, residents may feel motivated to venture outdoors more often, take walks, and enjoy the surrounding presence of green space, parks and order in the neighbourhood.[62] In contrast, neighbourhood conditions could be perceived as a socially stressful environment characterized by poor social capital and neglect, and dissuade neighbourhood-based physical activity or outdoor activity. Accordingly, the risks for obesity might differ for highly active residents compared to more sedentary residents.

A Korean study[139] also examined relationships between perceived environmental factors and leisure-time walking in Korean adults using TPB constructs such as attitude, PBC, subjective norms and intention in an effort to identify correlates of walking. The study found that intention, PBC and perceived safety were correlated with walking and reported that perceptions of environmental features between walkers and non-walkers only differed on neighbourhood aesthetics. Specifically, those who perceived environmental features more positively, participated in more leisure-time walking than those who did not.[139] What guided the development of the Korean study was the acknowledgment of the TPB in determining health behaviours and support from previous studies that found TPB mediated relationships between environmental factors and walking. [139]

An earlier study[58] hypothesized that perceived barriers to physical activity mediated the relationship between the built environment and BMI, such as the amount of time available to spend in light- and moderate-to-vigorous physical activity (MVPA)sessions. The study's structural equation modelling (SEM) results did not show support for this hypothesis; instead, the results indicated that barriers to physical activity partially mediated an association between overall health and BMI. Particularly among individuals who had poorer health in general tended to perceive less opportunities for physical activity, participate in less moderate levels of physical activity and fell into the upper tail of the BMI distribution.[58]

6.1 Strengths

A major strength of this study was linking DA-level built environment data using Census and DMTI Spatial Inc. with a national survey, thus allowing this study to be widely representative of the Canadian population at large, particularly for the respondents aged 18 to 64 years. While most Canadian studies have examined cross-sectional associations of the built environment on obesity using the Canadian Community Health Survey (CCHS), the longitudinal nature of the NPHS along with the availability of data from Cycle 4 (2000/01) and Cycle 9 (2010/11) enables the prospect of extending this study to examine further longitudinal analyses of this association. This study is also novel in that it is the first to use NPHS data to examine hypothesized associations of interest.

Another strength of this study was the use of a meaningful areal unit, the census DA, which provided a definition for 'neighbourhoods'. While there is significant variation in the built environment literature at large about the definition of 'neighbourhoods' and their boundaries, the DA is the smallest formal geographical unit that can be used within a Canadian context. A disadvantage of using the DA is that every 5 years, the boundaries are changed so that postal codes from previous years may belong to newer DA boundaries rather continuing to correspond to the same 'neighbourhoods' they may have been linked to for years before. Data pertaining to past residential exposures where residents may have lived before are essentially erased. At the same time, residents may encounter new exposures, and consequently new associations between exposure and outcome variables may be apparent. Thus, changes boundaries or buffer regions over time may make it difficult to infer whether an association was a 'true' association or spurious.[41] Additionally, DAs do not reflect respondents' activity space exposures, and perhaps a better measure of exposure would be individual activity space. However, the walkability data used in this study were measured at the DA-level and this formalized unit of analysis was helpful to link with postal codes to analyze individual-level NPHS data. Furthermore, the neighbourhood walkability measures included in the present study have been used by earlier studies, indicating the validity of these measures.[15,20,40]

An overall strength of the present study was responding to the call by earlier papers to conceptually map relationships and theorize the inclusion of potential confounders for the associations of interest. As one review cited, there is an absence of a conceptual framework of these relationships.[77] This study's use of a conceptual framework has facilitated an in-depth analysis of the indirect and direct analysis of these relationships. The measures that were selected to represent neighbourhood walkability were hypothesized as linked to physical activity and BMI from a theoretical/conceptual point of view. In reference to the conceptual models described earlier in the paper, this study examined the association between neighbourhood walkability and physical activity and BMI separately, to facilitate individual comparisons of the effect of these measures on physical activity and BMI. Though cross-sectional, this study has tried to provide some insight about the potential mediatory role of physical activity at the individual-level. Causal inferences are unable to be made because of the analysis of associations at one time point. Another recommendation by earlier studies was to view the associations of interest according to sex. This has been the style of analyses performed by previous analyses and the present study accounted for that by conducting sex-specific analyses.

For the present study, objectively-measured neighbourhood walkability data were used and this aspect of the study followed a recommendation of numerous papers to evaluate associations between neighbourhood walkability measures and physical activity and BMI.[16,77] Another strength was the use of an eloquent mediation approach, able to calculate a significant indirect effect of the mediator variable, with accurate standard errors corresponding to the parameter estimates.

6.2 Limitations

Existing research suggests that the social environment may moderate or confound associations between the built environment and physical activity and obesity. The social environment is defined and measured either by different socio-demographic factors or by social capital. Often in the literature, the perceived built environment is also a proxy for the social environment, and it is described by perceived neighbourhood aesthetics (e.g. perceived safety, crime rates) as mentioned briefly in the literature review chapter. These constructs of the social environment are used to assess socio-demographic influences on health outcomes. In the NPHS, only one variable was elected as a candidate to measure neighbourhood aesthetics and safety, but more than half the data was missing for this variable. Due to survey limitations, additional perceived neighbourhood walkability characteristics identified in the literature were unable to be included in this study and only objectively determine built environment metrics were used as neighbourhood walkability measures in this study.

In regard to social capital constructs, the NPHS does not adequately capture measures for social capital across all cycles and as such, the present study did not control for social capital measures or observe interaction effects between social capital and neighbourhood walkability measures. Social capital is thought to affect obesity prevalence in neighbourhoods by interacting with built environment factors. Social capital is defined as the level of social investment and trust freely shared between neighbours.[140] Furthermore, it represents the way neighbours work towards neighbourhood upkeep for mutual benefit.[140] In Canada, social capital definitions aren't straightforward and published Canadian reports have stated that measures for social capital aren't concretely defined. [141–143] Social capital as a topic is still a work in progress.[141–143] Broadly, social capital encompasses values such as trust, civic or community engagement, political participation, and social support.[142,144,145] Among multiple data sources for measuring social capital in Canada, available indicators in past cycles of the National Population Health Survey measure social capital using social support variables such as the perceived social support index, social involvement dimension, positive social interaction, participation in organizations, perceived safety and self-rated health status. Additionally, in the CCHS, self-esteem, social support, satisfaction of life, neighbourhood safety, participation in community activities, community affiliation variables are some available social capital measures.[141–144]

Three Canadian studies have examined the role of social capital, as social environment measures in their research.[46,144,57] A 2011 Canadian study used measures of social capital and sense of community belonging to determine whether these attributes altered physical activity and eating behaviours.[46] In focus group sessions, residents shared that characteristics such as safety, levels of neighbourhood crime, infrastructure maintenance, and community opportunity structures were valuable to their respective neighbourhoods because they felt it had strong positive influences on community interaction, establishing strong relationships, and at large creating space for healthy eating and physical activity behaviours. Most residents also expressed that their individual perceptions of neighbourhood safety generated social capital within the community from the point of view that individuals who felt safe in the neighbourhood were more inclined to venture and be engaged in outdoor activities compared to those who felt unsafe.[46]

In two different papers, Prince and colleagues (2011)[144] and Prince and colleagues (2012)[57] looked at associations between the social and built environment of neighbourhoods on physical activity and obesity outcomes. The interesting discrepancy between the two studies was the way in which the social environment was defined, and differences in associations reported between social environment measures and obesity in both studies. Prince and colleagues (2011) measured social capital using a combination of individual measures that included councillor voting rates and an aggregated variable "Sense of Community Belonging" from 4 cycles of the CCHS. Prince and colleagues (2012) did not measure social capital, however their study used the same measures of social capital as Prince et al. (2011) to create an aggregate variable for social cohesion/ participation. Prince and colleagues (2011) found an increased likelihood of overweight and obesity among males who lived in neighbourhoods with a lower SES and a decreased likelihood in overweight and obesity in males who experienced a stronger/greater sense of community belonging in their neighbourhood. Their study also reported an association between being physically active and living in neighbourhoods with a higher sense of belonging for males. Prince and colleagues (2012) adjusted for social environment factors in their analyses and did not find any significant associations between the social environment and LTPA or overweight and obesity. However, they did find that a higher crime rate was associated with lower odds of overweight and obesity. Even though crime rate was not a social environmental measure in their study, crime rates and perceived safety have been reported as other social capital and social environmental indicators.[35,144]

As in the present study, other research has accounted for the social environment using socioeconomic and demographic variables such as age, sex, or income have also been analyzed either for their moderating effects or confounding effects in the association between the built environment and obesity.[35,57,144,146] For example, Neckerman and colleagues[62] explored the effect modification of income on the prevalence of obesity in neighbourhoods despite whether or not neighbourhoods were objectively-determined to be walkable. Their study found that despite the implications of a neighbourhood's walkability status as grounds for favourable or unfavourable walking, poor and non-poor neighbourhoods varied considerably according to their social environmental attributes. Some of the differences between poor and non-poor neighbourhoods were in regards to the availability of pedestrian amenities and conveniences, sidewalk commercial activities (i.e. poorer neighbourhoods had less supports for walking and worse aesthetics features).[62] This finding not only signified the critical importance of neighbourhood aesthetics and safety, but it demonstrated socially important differences between subgroups (i.e. low compared to high income neighbourhoods). [62]

Findings from a study conducted by Pouliou and Elliott (2010) supported that gender might affect the relationship between environmental determinants and overweight and obesity outcomes. This was an example where differences in weight-related behaviours (physical activity and diet) by gender were recognized in absence of an interaction analysis.[14] Another study also reported no statistically significant differences with respect to sex, education, self-reported health and weight status between high, medium and low walkable neighbourhoods.[72] However, there were statistically significant differences between the three neighbourhood types with respect to neighbourhood-based physical activity levels, in that they higher physical activity levels were found in highly walkable neighbourhoods compared to medium and low walkable neighbourhoods. Differences in neighbourhood-based physical activity between neighbourhoods implicated that this distribution may have been attributed to inequalities in available resources for physical activity for certain subpopulations based on socio-demographic and health-related characteristics. This finding supported previous literature that reported positive associations between the neighbourhood built environment and walking frequency or physical activity between different racial groups. This finding also emphasized that future studies should consider performing subgroup analyses to expose socioeconomic differences.[72] A recent Australian study looked at the interaction of age and walkability variables to examine the relationship between neighbourhood walkability and walking.[42] After adjusting for a number of social and economic indicators, the study reported positive associations between neighbourhood walkability and walking across adult's current life stage and also reported that these findings were evident among smaller and larger neighbourhood buffers.[42]

The social environment has been further defined by neighbourhood social connectedness, as shown in recent Canadian study to examine the combined joint effects of neighbourhood walkability and social connectedness on physical activity (recreational and transportation-related) outcomes.[147] The study reported that participants who lived in areas of higher walkability and higher social connectedness had greater levels of recreational physical activity than participants who lived in areas of low walkability and low social connectedness.[147] Statistically significant differences in physical activity outcomes were also found between participants from areas of high walkability and low social connectedness versus areas of low walkability and low social connectedness, which supported previous literature positing that higher levels of physical activity occurred in areas of higher walkability or greater social connectedness. [147]

Another limitation of the present study was the use of a self-reported measure of physical activity was originally based on recall of physical activity participation in a number of physical activities, allowing for the presence of recall bias. The majority of studies have examined physical activity through self-reported measures but many have also incorporated objective measures (e.g. accelerometers and pedometers) or both objective and self- reported measures for physical activity. Additionally, some researchers have tested for the mismatch or discordance of built environment and physical activity measures when examining their effects on physical activity or obesity. I also did not assess specific types of walking or physical activities (due to limitations of the NPHS) but I captured energy expended from a list of leisure-time physical activities. I considered looking at more common types of neighbourhood physical activities such as biking, jogging and walking for which NPHS data were available, however, these measures were not strong and unable to capture important information about these activities such as intensity and duration, the way the energy expenditure variable in the present study does. Another limitation with respect to the use of self-reported measures was this study's use of the BMI as a measure for obesity based on NPHS respondents' self-reported weights and heights. Stronger alternative measures for the BMI were unavailable for use in this study.

Even with a fairly large sample size, the present study did not find statistical significance between the majority of neighbourhood walkability measures and physical activity, and none with BMI. This may indicate a lack of association or may be attributable to methodological factors, including our selection of neighbourhood walkability measures. The selection of DA-level intersection density, population density and the land-use mix index as measures for neighbourhood walkability was justified by consulting the literature and appropriately theorizing why, the use of walkability measures and definition provided for 'neighbourhood' vary significantly across the built environment literature. There is no classical definition of neighbourhood available and in fact such methodological discrepancies render findings of studies incomparable. Alternative metrics of the built environment may have served as stronger measures of neighbourhood walkability since it is widely accepted that 'walkability' as a concept has been shaped by geographers and multidisciplinary teams without a standardized definition or a strong underlying theoretical framework that explain why certain built environment metrics may be better proxy measures for walkability than others.

This study is cross-sectional, like the majority of studies that have examined associations between neighbourhood walkability and BMI, and therefore no temporal or causal inference can be made. However, this study contributes to the literature because it addresses a few gaps and draws upon the recommendations put forth by earlier studies and reviews. One area of novelty in this study is in assessing mediation, though at one time point. Particularly, this study examines whether physical activity mediates an association between neighbourhood walkability and BMI.

Because this study is cross-sectional, it is not possible to account for neighbourhood self-selection and this limits the ability to place causal inference on any findings. This has been noted as a major limitation of many studies in the current literature where positive findings have been reported between the built environment measures and physical activity or obesity. Often these positive relationships contain this bias.[148] However, we speculated that factors such as age and sex influenced residential self-selection and accordingly controlled for these factors in the data analysis. In adjusting for these factors, this study may have partially adjusted for residential self-selection. More recently, studies have tried to incorporate statistical methods to adjust for this; one systematic review that reported that the most popular method for minimizing bias of neighbourhood self-selection was using structural equation modeling approaches.[10] Longitudinal designs and natural experiments have been highly recommended as ways future studies can build on existing evidence, and the quality of evidence for causality on the association between the built environment and obesity.[149]

Additionally, the present study did not find an association between the majority of neighbourhood walkability measures and physical activity, and BMI, in multivariable analyses, which differed from the majority of previous cross-sectional findings. In one review,[17] an equivocal number of significant and non-significant associations were found from studies investigating the relationship between the built environment/ walkability and obesity. On the contrary, longitudinal analyses that have explored many of the same relationships have found no associations between the built environment and physical activity or obesity.

6.3 Conclusions and Future Research Directions

This study finds no association between neighbourhood walkability and BMI, and also does not find any indirect influence of physical activity in this pathway. To better understand the nature of these relationships, even further conceptualization of neighbourhood walkability measures is required for analyses as limited walkability measures were available at the DA level. Most walkability research to date is focused on single regions, for which other walkability variables are available for use in statistical modelling (e.g., the presence of sidewalks, streetlights, multi-use pathways, and trees).

Building on recommendations for research using walkability variables such as land-use mix, it may be worthwhile to observe relationships using individual components of the land-use mix index and health outcomes (i.e. rationalize and examine separate contributions of each land type on health outcomes, rather than combined in a single land-use mix index).

Future studies analyzing relationships between the built environment and obesity across Canada like this study does, should consider incorporating information on exposures at a particular time and place with consideration of the historical identity of particular places and related contextual and social factors, as discussed in Appendix 3. This would facilitate a more comprehensive analysis and provide information pertaining to activity spaces and related exposures can provide for a stronger and more comprehensive analysis. Any relationships observed could have implications for planning policies and implementation activities in various locations, for various subgroups, to reduce to obesity prevalence nationally.

This analysis adds to the body of literature on the built environment and obesity within a Canadian context and continues important public health conversations on the obesity epidemic in Canada. Overall, the present study did not find cross-sectional associations between neighbourhood walkability measures and adult BMI across Canada in 2010/11, and this may result from the limitations of captured walkability and physical activity measures.

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Appendices

Appendix 1: Summary Table

Author et al. (Year) [Country] [Region] [Study Design]	Study Objective and Sample Characteristics	Body Mass or Physical Activity [Outcome] Measure	Built Environmental/ Walkability [Exposure] Measures	Other Variables [Confounders or Covariates/ Moderators/ Mediators]	Statistical Method/ Analysis Type	Key Findings/ Relationships Observed	Additional Comments
Prince et al. (2011) Canada Urban Cross-sectional	To determine relationships between built and social environments and outcomes of physical activity and overweight/obesity. n = 3882 adults in 85 Ottawa neighborhoods, Adults aged 18 to 65+ years *Data Sources:* The Ottawa Neighbourhood Study (ONS), which used data from i) 2006 Canadian census household data; ii) GIS data from DMTI Spatial Inc. the City of Ottawa and the National Capital Commission; iii)Telephone contact with businesses; iv)Web-based research v)Team knowledge of local resources; vi)Field research and validation	*Outcomes:* Overweight and Obesity (self-reported; categorical by Health Canada guidelines); Analyzed as binomial (under-/normal weight compared to overweight/obese. Physical Activity (self-reported, IPAQ); binomial outcome with low and moderate reporting of PA (insufficiently active) compared to high levels of PA (active).	*Neighbourhood Definition:* Neighborhoods defined by 'natural barriers', areas of similar SES and demographics Environment variables at the neighbourhood-level: <u>Food Environment</u> (all per 1000 perople): >Grocery stores >Fast Food outlets >Convenience Stores >Restaurants >Speciality food stores <u>Social Environment:</u> councillor voting rates, founded offences of property and Violent crime rates, sense of community belonging, SES index (% of housholds below low-income cut-off, average household income, % of unemployed residents, % of residents w/ <highschool education, % of single-parent families)	*Covariates:* (Individual-level): Age, education, household income, smoking status, season of collection (all categorical). Physical Activity: self-reported, past-week PA captured from the International Physical Activity Questionnaire (IPAQ). BMI: self-reported height & weight used to compute; categorized into under, normal, over,obese, but used as bionomial (underweight compared to normal weight).	Multilevel, binomial regression, stratified by sex	Higher green space associated with reduced likelihood of PA (OR= 1.77, 95% CI: 0.86, 0.99) and higher odds of overweight and obesity among men (OR=1.10, 9% CI: 1.01, 1.19) and a reduced likelihood of overweight and obesity in women (OR=0.66, CI: 0.44, 0.89). Neighbourhood SES scores, voting rages, sense of community belonging all significantly associated with overweight/obesity.	Objective; GIS data; Food outlets and mixed land use were proxies for walkability; Support for increased risks of overweight/obesity resulting from higher social cohesion or sense of belonging; emphasizes importance of role of social factors, which can increase or decrease likelihoods of physical activity
Pouliou et al. (2010) Canada Urban	i) To explore determinants of overweight and	*Outcome:* BMI (overweight/obesity) (Continuous)	*Neighbourhood Definition:* Postal codes within CMAs	*Covariates:* Individual-level characteristics (health status,	Bivariate analyses and Multivariate linear regression based on a	Energy expenditure was a significant predictor of BMI and	Objective data; GIS data; Walkability Index -

Cross-sectional	obesity, and their prevalence using spatial analysis and GIS; ii) To identify relationships between individual and socio-environmental determinants and overweight and obesity at the individual and community levels. n = 115 548 study participants Adults aged 20 and older *Data Sources:* 2003 CCHS and CanMap Route Logistics (CMRL) database		(Toronto and Vancouver) <u>Built environment</u> (land-use mix,street network connectivity, residential density,density of opportunities).	socioeconomic, demographic, lifestyle factors). Health Status variables: chronic disease status (i.e. CVDs, etc), Socioeconomic variables: income adequacy (judged by level of income and household size), employment status, home ownership, education Demographics: age, gender, marital status, period of arrival in Canada, race/ethnicity; Lifestyle: smoking, drinking, physical activity, fruits and veg consumption Social: sense of belonging to community, member of voluntary organization (categorical)	stepwise variable selection procedure	negatively associated with BMI Street connectivity was significantly positively associated with BMI. Residential density was negatively associated with BMI.	from Frank et al. (2005) Addresses individual and socio-environmental determinants of overweight and obesity through the perspective of population health (i.e. going above individual level characteristics; Different indicators of SES chosen by different researchers, since it was first suggested that SES may be linked with obesity (i.e. widely used indicators are education, income, occupation); room for other indicators (i.e race/ethnicity and obesity); Other measures that can be considered from a social environmental standpoint are measures of collective efficacy and social capital; Recent studies have demonstrated that there might be indirect influences (due to social influences and social control); Role of GIS and spatial analysis to explore accessibility

							to various opportunities for eating and physical activity; Lack of theoretical framework that might underlie the broader individual as well as environmental (physical and social) determinants.
Prince et al. (2012) Canada Urban Cross-sectional	To infer potential built and social environmental characteristics, seasonal and individual associations of LTPA and overweight/obesity in Ottawa neighbourhoods. n=86 Ottawa neighborhoods n=4727 adults Adults aged 18 to 65+ years *Data Sources:* CCHS (4 cycles 2000/01, 2003, 2005, 2007). Ottawa Neighbourhood Study (ONS); derived their data from i) 2006 Canadian census household data; ii) GIS data from DMTI Spatial, the City of Ottawa; iii) telephone contact with businesses; iv) web-based research; v) team knowledge of local resources; vi) field research and	*Outcomes:* Overweight and Obesity (self-reported; categorical by Health Canada guidelines); Analyzed as binomial (under-/normal weight compared to overweight/obese Physical activity; via PA index: the sum of the average daily energy expenditures (kcal/kg/day) of all leisure time activities. Respondents were classified as follows: physically active (≥3.0 kcal/kg/day); moderately active (1.5–2.9 kcal/kg/day); and inactive (<1.5 kcal/kg/day). In analyses, LTPA was analyzed as a binomial outcome with	*Neighbourhood Definition:* Natural barriers, similarity in SES and demographics; within 1-km buffers of homes <u>Neighborhood-level environments:</u> Recreation, Social, Food. <u>Food environment</u> (objective): grocery stores, convenience stores, specialty food stores, fast food outlets, full service restaurants (continuous). <u>Social environment:</u> (via neighbourhood SES index): included % of households below the low-income cut-off (19), average household income, % of unemployed residents, % of residents with less than a high school education, and % of single-parent families. <u>Recreation environment</u>: total bike	*Covariates:* (Individual-level): Age, education, household income, smoking, season of data collection (all categorical variables); LTPA or BMI category controlled for - (as a confounder) when not the outcome of interest.	Multilevel modelling	LTPA sig associated with park area in females and crime rates in males In women, the odds of being overweight/obesity, positively associated with park area, convenience store, fast food outlet density; negatively associated with crime rates. In men, the odds of being overweight/obesity negatively associated with crime rates.	No Walkability index; Indirect sources of neighbourhood environments data; doesn't look at the objective measures that are more commonly assessed by other studies.

	validation (e.g., car, walking, bicycle).	inactive and moderately active respondents (inactive vs physically active).	and walking path length (km), counts per 1,000 people of indoor recreation facilities, winter outdoor facilities, summer outdoor facilities, park area (km2), and green space area (km2).				

Glazier et al. (2014) Canada Urban Cross-sectional	To examine associations between a walkability measure (Glazier et al., 2012) and transportation and health outcomes, specifically the individual and combined associations of residential density and walkable destinations. n= 10 182 dissemination blocks Adults, aged 30 to 64 years *Data Sources:* BE data came from the 2006 Canada census, City of Toronto, Ministry of Education and DMTI spatial data bases, the Transportation for Tomorrow Survey (a transportation survey). CCHS (a national health survey)and a validated administrative diabetes database (Ontario Diabetes Database, ODD)	*Outcomes:* BMI (overweight or obese) (dichotomous), active transportation (walking, bicycling, public transit, car use) (continuous)	*Neighbourhood Definition:* Dissemination Block was the level of analysis, the smallest geographical unit for which Canada census and dwelling data is available Built environment measures (Walkability index, and separate components of this index: Population density, Residential density, Availability of Walkable Destinations, Street Connectivity.	None (except examined separate BE components)	General linear modeling	Higher prevalence of obesity for those who lived in HW than LW Similar findings between all separate index components for walkability (street connectivity, population density, residential density, availability of walkable destinations) ad obesity, except for street connectivity.	Objective; GIS data; Walkability Index developed and validated for Toronto - NOT Frank; Walkability index - used by Glazier et al., (2012).

Sarkar et al. (2013) USA Urban & Rural Longitudinal	To examine independent longitudinal associations between built environmental factors and change in BMI (at three time points over 12 years). Prospective (longitudinal) study, using multi-level modelling framework n=684 individuals, over 35 LSOAs, and 2052 observations at three time points Cohort of men that initially made up the sample for the CaPS study were 45-59 years when study started and then their health was followed up in 4 phases over time; the latest follow-up period included 1225 men aged 65 - 84 years; by the end the study cohort included valid responses from 684 men distributed over the three time points; *Data Sources:* The Caerphilly Prospective Study, for the purpose of studying a number of parameters of health in older adults with progression of age	*Outcome:* BMI (objectively measured using a Holtain stadiometer and standard scales) (continuous)	*Neighbourhood Definition:* > UK census defined lower layer super output area (LSOAs) as being stable, compact zonal systems , appropriate compatibility wrt homogeneity in shape and social composition. >>>LSOAs were taken as areal units for studying potential area-level (contextual) variations in BMI Built environment morphometrics (which means that it uses metrics that consider size and shape of the built environment): Land-use mix (5-category LUM with rsidential dwellings, retail community services, business and offices, recreation and leisure; densities of walkable service destinationsl bus stops, retail, churches, community services, and recreation and leisure amenities).; Destination accesibility via street network distance; Topological accessibility of street network (Connectivity and betweenness)	*Covariates:*: Study controlled for 6 vascular risk factors >adjustments made at each measurement occasion (time) for socio-demographic and lifestyle factors;	Multilevel modeling framework that included 3 levels; Level 1 - measurement across time, Level 2 - individual participant, Level 3 - the lower layer super output area (LSOA)	Found that BMI was significantly associated with a number of BE factors including land use mix, density of retail, churces, rec and leisure services, street network accessibility and slope variability Several built environment morphometrics considered to be associated with walkability and physical activity were significantly related to individual level variations in BMI After adjusting for individual level lifestyle factors, socio-demographic confounders and morbidities, higher densities of retail land use, churches and recreation and leisure facilities in the vicinity were more likely to lower BMI Higher levels of land use mix associated with increased levels of BMI – contrary to general understanding that a heterogeneous neighbourhood act as a generator of physical activity leading to reduced BMI.	Objective; GIS data; No Walkability Index
Rutt et al. (2005) USA Urban, suburban, rural, agricultural Cross-sectional	To examine relationships among the built environment, physical activity, and body mass index in	*Outcomes:* BMI (self-reported) (continuous). Physical	*Neighbourhood Definition:* used different buffer zones for transportation variables, and other	*Covariates:* (Confounders:)more time spent watching TV, worse overall self-reported health, greater	Structural Equation Modeling (SEM) to model relationships so that confounding, mediating and	Increasing BMI related to less moderate intensity physical activity, higher SES, and worse overall	GIS data -geocoding techniques; Objective; No Walkability index

	mainly Hispanic border in El Paso. n= 943 adults with complete surveys for use in analysis >>doesn’t specify, but mean ages are 42, 44 and 39 *Data Sources:* Center for Disease Control and Prevention’s (CDC) Behavioral Risk Factor Surveillance Survey [BRFSS]; Center for Environmental Resource Management (CERM); San Diego Health and Exercise Survey; Los Angeles Epidemiologic Catchment Area (LESACA); Hollingshead Four-Factor Index of Social Status	Activity: divided into light, moderate, vigorous categories based on Metabolic Equivalent Value (MET); though there is nothing about intensity, but used the Compendium of Physical activities to categorize the different physical activities as light, moderate or vigorous; this is one of the most widely used instruments for assessment of intensity of self-reported physical activity.	variables thought to affect physical activity in an individual's neighborhood as well as for the number of physical activity facilities; >>>1/4 mile radius was used as the chosen distance because it is commonly used in transportation literature (but this was a problem because of the narrow distance that was not able to capture the number of physical activity facilities) >>>also used radius of 5 miles and 2.5 miles; finally chose 2.5 miles radius	number of children, older age, lower acculturation, lower SES, decreased fruit and veg consumption, and more self-reported morbidities	moderating variables can be possible	health, and living in areas with greater land-use mix (less residential) Higher numbers of barriers to physical activity in those with poor health partly mediated the relationship between overall health and BMI Found an unexpected positive relationship between BMI and the SES – could be because of the higher poverty rate No significant association found between density or sidewalk availability and BMI (though previous studies expect that increased density would be related to a lower BMI) A significant mediating relationship was found between self-reported overall health, perceived exercise barriers, moderate physical activity and BMI such that people with worse overall health self-reported more barriers to PA, less moderate PA and higher BMI.	

Zick et al. (2013) USA Urban Cross-sectional	To assess the causal effect of neighborhood characteristics on BMI by incorporating corrections for residential selection using an instrumental variables approach. n=953 uses 550 of 567 census block groups in Salt Lake County, Utah >Age 21 or older, white,non-Hispanic women	*Outcome:* BMI (continuous)	*Neighbourhood Definition:* Block group level. Land use; Population density; Intersection number and type; Sidewalk availability; Distance to physical activities; Number of physical activity facilities; slope	*Covariates* (Individual level): age, education, marital status, year of pre-pregnancy weight measurement Confounder: Residential self-selection	Using a theoretical framework known as the Household production theory to set the foundation for their methods Statistical analysis is a 2-step instrumental variables approach	Findings suggests that if statistical adjustments are not made for the endogeneity of BMI and neighborhood walkability then the relationship between neighborhood characteristics and BMI may be understated Assumption that people who have healthy body weights prefer to live in walkable neighborhoods or prefer to live in neighborhoods that have characteristics that are highly correlated with walkability Main finding: residential bias understates the relationship between neighborhood walkability features and BMI	Objective data; GIS data; No Walkability index

Stark et al. (2014) USA Urban Cross-sectional	To examine association between individuals' body mass index (BMI) and characteristics of parks (size and cleanliness) in urban environment n = 44 282 subjects for analysis; Cross-sectional study. Adults aged 18 - 65+ *Data Sources:* Community Health Survey in New York City (2002-2006) *Data Sources::* New York City Department of Parks and Recreation (NYCDP&R) provided data on park boundaries and park cleanliness; Community Health Survey of New York City (2002-2006),	*Outcome:* BMI units (measured via self-reported weight) (continuous)	Neighbourhood Definition: Zip code boundaries buffered by 400m <u>Characteristics of Parks:</u> Size and Cleanliness >Park Cleanliness measures: presence of litter, glass, weeds, and graffiti. <u>Built environment measures</u>: residential unit density, street intersection density, land use mix, retail floor space, and density of subway stations. >>together, these measures were incorporated into a walkability index.	*Covariates:*: (Individual –level) variables were adjusted for: sex, age, race/ethnicity, education, household income relative to US federal poverty line, nativity, marital status, self-reported health, employment, number of children under age of 18 in the household.	Hierarchical linear models	Greater neighborhood park access and greater park cleanliness associated with lower BMI amongNYC adults, adjusting for other neighborhood features such as homicides and walkabilities and other characteristics that might influence park usage. Similar to previous findings of other studies, there was a negative relationship between weight outcomes and physical activity environments including parks and sports facilities	Objective GIS data; Walkability Index used is the one from Neckerman et al. (2009) which is also from a Frank one, see where that is

Smith et al. (2008) USA Urban Cross-sectional	To examine the relationship between neighborhood walkability, density, pedestrian-friendly design and two novel measures of land-use diversity - to residents' excess weight. n= 564 block groups (total population of 898 387, each block group has about 1500 residents) Adults aged 25 - 64 years *Data Sources:* 2000 Census and GIS street-network information that was analyzed in 2007-2008 >Utah Population Database (UPDB), a health-related research database, contains driver license data from the Driver License Division of the Utah Department of Public Safety.	*Outcomes: BMI (*measured by healthy weight, overweight, obesity). (categorical)	*Neighbourhood Definition:* Block-group level <u>Walkable environment measures:</u> Higher density and pedestrian - friendly design, and also two new census-based land-use diversity measures: proportion of residents walking to work & median age of housing	*Covariates:* (Individual - level) age, and neighbourhood level - racial/ethnic composition, median age of residents and median family income	Linear regressions of BMI and logistic regressions of overweight and obesity >>> included controls for individual-level age and neighborhood level racial/ethnic composition, median age of residents, and median family income >>>Gender-specific models since research indicates that predictors of weight outcomes differ by gender	Increasing levels of walkability decreased the risks of excess weight Doubling the proportion of neighborhood residents walking to work decreases individual's risk of obesity by almost 10% Population density is unrelated to weight in 4/6 models and inconsistently related to weight measures in two models. Pedestrian-friendly street networks are unrelated to BMI, but related to lower risks of overweight and obesity in ¾ models Both land-use diversity measures were important predictors of overweight and obesity Regarding collinearity among walkability measures, there was some association), but did not find problematic multicollinearity; stated which were the weakest and strongest relationships amongst the walkability measures Stronger correlations between newer walkability measures and the outcome variable	Objective data; GIS Data; No Walkability index

						Higher density associated with reducing risk for overweight among men; other tests for	

Yamada et al. (2012) USA Urban Cross-sectional	To compare 4 types of diversity measures: entropy scores, distances to walkable destinations (via parks and transit stops), proxy measures of mixed use (walk to work measures and neighborhood housing ages), and land use categories used in entropy scores n=4960 adults; Adults aged 25 to 64 *Data Sources:* Driver licence database that contains all license holders in Salt Lake County, Utah, for individual-level BMI information; DIGIT lab at University of Utah provides street centerline dat and parcel-level land use data from Salt Lake County Assessor's office; Utah Transportation Authority - for data on county's light rail transit system; Dun and Bradstreet business data to identify large grocery stores; 2000 US Census	*Outcome:* BMI (from self-reported heights and weights) (continuous)	*Neighbourhood Definition:* Census block group, tract, and 1-km buffer; these are the 3 geographical scales. They were used to compose all measures of mixed land use, except destination-oriented distances. Used 1 km street network buffers around each driver's licence address to define an individual's neighborhood (just like Frank et al.), to measure entropy scores and street connectivity.; >>>Land use polygons were drawn around each address Walkability features in neighborhoods via 4 types of alternative measures of land use diversity	Built environment measures: Population density, intersection density, distance to the closest rail station, distance to CD, area of single family residential, multifamily residential, retail, office, education, entertainment buffers, for males and females both Examines relationship between BMI and four types of mixed land use measures obtained at three geographic scales that define neighborhoods:1 kilometer street-network buffer, census block group, census tract Focus is on land use diversity among the 3Ds is based upon its multifarious operationalization's mentioned above.	Used GEE to examine the association between individual's BMI and walkability features in their neighborhoods	Buffer measures are not necessarily consistent for males and females; Individual BMI was better predicted when alternative measures were used	Objective; No GIS; No Walkability; Index Has good buffer information.

Rundle et al. (2007) USA Urban Cross-sectional	To examine whether urban form (land use mix, bus and subway stop density, population density and intersection density) is associated with BMI (body size). n= 13102 participants (n=1989 census tracts) Adults aged 18 + (but min age of 30) *Data Sources*: Data was collected previously from the New York Cancer Project (NYCP)	*Outcomes:* BMI	*Neighbourhood Definition:* Census tracts Characteristics of urban form (land use mix, bus and subway stop density, population density and intersection density)	*Covariates:* (Individual-level measures; Demographic): age, race/ethnicity, gender, pre-tax income, educational attainment, address of residence, height and weight measures (i.e. sociodemographic and home address) Adjusted for individual and neighborhood level sociodemographic characteristics	Multilevel analysis	BMI is associated with BE characteristics in NYC significant association between urban form measures and BMI (when all 5 BE measures were put simultaneously into model, only ones that remained significant still, were land use mix, subway density and pop density (inversely) associated with BMI) LUM, public transit, population density separately, had statistically significantly associations with BMI, when adjusting for confounders and BE measures entered into model separately. Intersection density not sig associated with BMI.	Objective; GIS data; No Walkability Index

Brown et al. (2013) USA Urban Cross-sectional	i) To test whether walkability/bikeability is associated with BMI/obesity risk. ii) To determine whether this relationship no longer exists when MVPA is included in the analysis (if so, this would suggest a causal role for MVPA). n= 3528 adults; Cross-sectional study Adults aged 25 to 65 *Data Sources:* National Health and Nutrition Examination Study (NHANES) (2003/04 and 2005/06); 2000 Census walkability/bikeability data	*Outcomes:* BMI - measured in a clinical exams; Obesity was dichotomous (1 for 30<BMI<60 obese, and 0 for 18.5<BMI<25 healthy weight).	*Neighbourhood Definition:* Census block group Census block group walkability/bikeability measures included neighborhood housing age; population density; and proportions of employed residents who walk or bike to work.	*Covariates:* >>>Individual-level variables - age, marital status, education, race/ethnicity, smoker, average caloric intake from two 24-hour recalls, hours of accelerometer wear (all categorical)(continuous: age and recalls of caloric intake and hours of accelerometer wear); >>>Economic status variables: median family income, median age of residents in block group, proportions of ethnicity;	Linear and logistic regression of BMI; adjusted for geographic clustering; gender-specific models. Mediation tests using Freedman and Schatzkin test of differences in coefficients (Mackinnon et al.)	Walkability and bikeability features were predictors of lower BMI/higher obesity risk; The expected direction held for males (greater density and older housing associated with lower BMI) For males and females: (greater proportions of neighbourhood workers who walk to work and more MVPA associated with lower BMI/obesity MVPA partially mediated relationship between walkability/bikeability and BMI Concluded that if there were higher proportions of people walking/biking to work in the US, then this would mean that there would be more people with lower weights and higher MVPAs as a result in these neighborhoods >>When MVPA variable was added to final models, to examine whether it was related to BMI an whether these relationships attenuated (diminished or removed) the effect of walkability/bikeability on BMI, then they found that MVPA	Walkability - from Census measures. Indirect measures

						minutes/day was related to lower BMIs and risks of obesity >>>>their mediation tests showed that adding MBPA reduced the significant relationship between proportion walking to work and female BMI; similar findings in males but between biking to work and BMI, so these findings indicated that MVPA partially explains sex-specific walkability/bikeability relationships to BMI Neighbourhood walkability/bikeability and MVPA also have independent and significant relationships with BMI and obesity risk	

Wen et al. (2012) USA Urban & Sub-urban Cross-sectional	To explore whether neighbourhood built environment attributes are significant correlates of obesity risk and mediators of obesity disparities by race-ethnicity. n=9739 Adults aged 20-64. *Data Sources:* 2003 - 2008 waves of continuous National Health Nutrition Examination Survey, merged with 2000 census and GIS-based data,	*Outcome:* BMI;Obesity (BMI>30, based on objective height and weight).	*Neighbourhood definition*: Census tract. Population density, median age of neighbourhood buildings,percentage of residents walking to work (these three for walkability index) and the last two are: two GIS-based measures constructed = street connectivity and distance to parks.	*Covariates:* (Individual-level variables) race-ethnicity: self-reported, non Hispanic whites, non-Hispanic blacks, Hispanics and others, age, age-squared, gender (male/female), immigrant status, marital status, education, poverty income ratio, smoking status	Multilevel logistic model	Obesity disparities observed in this study are thought to be better explained by psychosocial and environmental realms, which are socially constructed; study confirms there is a pattern of racial-ethnic disparities. Whites at a lower risk of obesity than blacks and Hispanics and magnitude of disparity is greater in women than in men, and disparity is greater among women than men Similar findings for males and females: significantly negative associations between neighborhood street connectivity and percentage of residents walking to work and obesity risk, where as a positive relationship exists between distance to parks and obesity risks (all considering individual controls and neighborhood SES and ethnic composition); Population density (contrasting findings for men and women) - found to be in expected direction, negatively correlated to obesity risk for men but opposite for women (linked to greater obesity risk in	Objective data; GIS data (street connectivity and distance to parks) & Indirect measures of BE (population density, median age of neighborhoods, percentage of residents walking to work); No Walkability index Prevalence of walking to work should be more used and analyzed in future studies

						women); density-obesity link needs to be further explored >results showed that for men, BE plays a suppressing effect on racial-ethnic disparities in obesity, while for women, the mediating role of BE is minimal. >>>BE does not explain why racial-ethnic minorities are at higher risks of obesity than whites; especially because blacks and Hispanics according to this study have better neighborhood built environments for purposes of maintaining healthy weights compared to white people.	

Joshu et al. (2008) USA Urban Cross-sectional	To determine differences between levels of urbanization in terms of personal and neighborhood barriers and the importance of these and land-use development patterns. n=1642 Adults aged 18 to 65 + Sex: males=34%, females=67%. *Data Sources:*	*Outcome:* BMI (self-reported); categorized as underweight (BMI <18.5), normal weight (BMI 18.5-24.9), overweight (BMI 25.0-29.9), or obese (BMI ^30); however, in analyses, it was looked dichotomously (obse vs normal weight).	*Neighbourhood Definition:* zip codes (Respondent zip codes to match country of residence on basis of FIPS codes to classify geographically) <u>Neighbourhood Environment:</u> Sidewalks absent, trail absent, enjoyable scenery absent, heavy traffic, hills absent, streetlights absent, unattended dogs, foul air from cars/factories, number of neighbourhood barriers County sprawl index (Ewing et al.): gross population density, percentage of county population living at low suburban densities, percentage of county population living at moderate to high urban densities, net density in urban reas, average block size, percentage of blocks with areas less than 1/100 square miles	*Covariates:* Controlled for individual-level, neighbourhood, personal, demographic barriers Race/ethnicity, household income, education, level of urbanization (Categorical), age (continuous) Perceived neighbourhood barriers: hills, lack of sidewalks Personal barriers (that would influence PA levels): bad weather, feeling tired)	Logistic Regression Models; stratified by urbanization level.	Levels of urbanization differed by neighbourhood barriers; Heavy traffic & unattended dogs (specific neighbourhood barriers) correlated with obesity differentially (differed across each level of urbanization); Time & injury (personal barriers) correlated with obesity differentially (differed across each level of urbanization); Obese people more likely to report internal personal barriers (poor health, dislike of activity, lack of energy and motivation) Frequency of neighborhood barriers differed significantly across levels of urbanization Findings of study validated previous findings of relationship between sprawl and GMI Dose-response relationship showed significant findings: >>>Increase in number of perceived neighbourhood barriers increased odds of being obese <p<0.05)	Objective & Perceived data; Urban Sprawl index (has many of the same walkability components)

						>>>Increase in the number of personal barriers increased the odds of being obese (p<0.001) Level of urbanization found to be an effect modifier in relationship between personal barrriers <> obesity Significant interaction terms: self-conscious, no time for exercise and dislike of exercise	
Van Dyck et al. (2010) Belgium Sub-urban Cross-sectional	To determine whether Physical Activity and a sedentary lifestyle mediated the relationship between neighbourhood walkability and adiposity measures (via BMI and Waist to height ratio) n = 24 neighborhoods, 1200 adults >Mediation analysis, cross-sectional Adults aged 20 to 65 years *Data Sources:* Belgian Environmental Physical activity Study (BEPAS), which was based on Neighbourhood Quality of Life Study (NQLS) and the Australian Physical Activity in Localities and Community Environments (PLACE) study	*Outcomes:* Body mass index (BMI)(self-reported) and waist-to-height ratio (WHTR) (objectively measured by anthropometric tape). However, the BMI was used in analyses, even though they measured (continuous)	*Neighbourhood Definition:* Unspecified. Residential density, Intersection density (measure for connectivity) and Land use mix <u>Neighbourhood Walkability index:</u> Constructed from objectively assessed land use variables via GIS database, its index consisted of residential density, intersection density (measure for connectivity) and land use mix. Top and bottom quartiles represented high and low walkable neighborhoods.	*Covariates:* Adjusted for Individual SES, neighbourhood SES, other sociodemographic factors. *Mediator:* Physical activity: measured by IPAQ; assesses frequency, (# of days in the last 7 days) and duration (hours and minutes per day) of PA in different domains (work, transportation, recreation, household) and motorized transport; to also compute daily minutes of walking for recreation, cycling for transport, walking for transport, moderate-tovigorous PA; they define MVPA and VPA; >Accelerometers used to objectively measure PA	Product-of-coefficient test of mediation; Generalized Linear Models (GLM).	Associations of walkability with PA and SB variables: >Walkability positively associated with objective and self-reported daily minutes of SB; Walkability positively associated with objectively measured MVPA and weekly mins of self-reported walking for recreation >Walking for transport had a strong effect Mediators of relationship between walkability and adiposity: > objective and self-reported MVPA, walking and cycling for transport, walking for recreation and vigorous leisuretime PA were significantly negatively related with BMI after adjusting for neighborhood walkability >all correlates of BMI positively associated	Objective data; GIS data; Walkability index: residential density, intersection density, land use mix, based on (Frank et al., 2009; Leslie et al., 2007).

						with WHTR, except walking for transport and walking for recreation >only objectively measured MVPA and self-reported cycling for transport were significant mediators of cross-sectional associations of neighborhood walkability with BOTH adiposity measures >two walking variables (walking for transport and walking for recreation) mediated the relationship between walkability and BMI >total and direct effects of walkability on BMI and WHTR were not significant BUT the total indirect effects of walkability on BMI, through specific domains of PA were statistically significant. >Overall, findings show that PA behaviors can partly mediate relationships of neighborhood walkability with body fatness (BMI and WTHR),but SB was not a significant mediator.	

Hu et al. (2014) USA Urban Cross-sectional	To examine the relationship between neighbourhood characteristics and obesity among adults. n = 7200 adult respondents Adults aged 18 - 65 and over *Data Sources:* 2007 Los angeles County Health Survey (LACHS) >Southern California Association of Governments (SCAG), a metropolitan planning organization for six counties in Southern California	*Outcome:* BMI (Categorical); Obese (BMI≥30) (1) ;otherwise not (0)	*Neighbourhood Definition:* US Census tract. Neighbourhood land use and built environment variables.	*Covariates:* individual socioeconomic characteristics and individual health behaviors (i.e. age, gender, race, ethnicity, household income, education), neighbourhood quality and safety. *Health behaviors included were physical activity and diet. Vigorous activities and moderate activities were analyzed because they influence calories expended.	Binary logistic regression model to determine the probability of being obese.	Significant associations found between neighbourhood land use/ built environment characteristics and likelihood of being obese >>>People residing in higher residential density, rail services, frequent bus services are less likely to be obese (implicating a well-designed transit-oriented type of neighborhood) tend to use active transportation modes to access their daily activities and reach transit services	Neighbourhood Characteristics; No GIS; No Walkability Index; Indirect measures
Zhao et al. (2008) USA Urban and Suburban Cross-sectional	To examine the effect of changes in population density – urban sprawl – between 1970 and 2000 on BMI and obesity of residents in metropolitan areas in the US. n=53 large metropolitan areas Age=?	*Outcomes:* BMI (continuous)	*Neighbourhood Definition:* Unspecified. Urban sprawl measure is population density Therefore, included because population density is also a proxy for walkability which shows that these terms are just labels for the same thing.	*Covariates:* (Confounders) - Confounders are demographic and socioeconomic info; age, race, sex, education, income, marital status, metropolitan area of residence (individual level?) - MSA level – median family income, employment rates and education	Two-step instrumental variables approach		Urban Sprawl - but uses population density, think about including this or not

Garden et al. (2009) Australia Urban Cross-sectional	To determine whether urban sprawl in Sydney, Australia is associated with overweight/obesity and levels of physical activity. n= 7,290 'Adults' aged 16 years and older *Data Sources:* 2002 and 2003 NSW population health survey.	*Outcomes:* BMI *(*Overweight or obesity based on self-reported height and weight); physical activity. Physical activity (minutes walked in the last week); BMI was used to classify people as overweight or obese; all outcome measures were dichotomized.	*Neighbourhood Definition:* LGA (Local government areas), the smallest geographical area for which the study had area-level data). Population Density.	*Covariates*: (Confounders) age, gender, household income, highest level of education completed, current smoking status, adequate diet, number of years lived in local area, perceived safety	Multilevel logistic regression model	Controlling for individual and area level covariates, for an inter-quartile increase in sprawl, the odds of being overweight was 1.26, the odds of obese was 1.47, the odds of inadequate physical activity was 1.38 The odds of not spending any time walking during the past week was 1.58 Significant positive associations between urban sprawl and likelihood of being overweight, obese, inadequate physical activity and no time spent walking during past week after controlling for individual and area level covariates were demonstrated in this study.	Objective data; No GIS data; No Walkability index; measure of Walkability was population density
Freeman et al. (2013) USA Urban Cross-sectional	To examine associations between neighbourhood walkability and engagement in active travel. n=8064 respondents or n=164 zip codes Age=N/A	*Outcome:* Physical activity; reporting episodes of active travel	*Neighbourhood Definition:* zip codes. Neighbourhood walkability index (at the zip-code level): residential density; intersection density; land use mix for five types of land usel subway stop density;ratio of retail building floor area to retail land area	*Covariates:* (Individual-level) demographic characteristics, socioeconomic status, health characteristics. (race, age, educational attainment, marital status, income, self-rated health); (Categorical); adjusted for these individual-level variables	Zero-inflated negative binomial regression model; Odds ratio estimates were reported, adjusted for all variables in the table.	For a one unit increase in the walkability scale, the odds of reporting zero episodes of sustained activity decreased by 10%; this was a statistically significant association. Among those who reported greater than zero episodes of active travel, increasing neighbourhood walkability was significantly associated with a higher number of episodes of active travel.	Walkability Index - based on a scale from Neckerman et al. (2009) which is an extension of a measure developed by Frank et al. (2006): includes residential density, intersection; land use mix for 5 land use types; subway stop density; ratio of retail building floor area to retail land area

						When the 75th percentile of walkability (higher) was compared to the 25th percentile of walkability (lower), the results showed that the OR=1.13 (95%CI: 1.06, 1.21) for the number of episodes of active travel. Significant inverse associations between neighbourhood walkability and reporting zero episodes of sustained active travel was found among non-Hispanic White individuals compared to those who were non-Hispanic Black or Hispanic. This study reported associations by varying strata of sociodemographic variables. Analyzed associations between zip code level walkability and reports of zero episodes.	

Sallis et al. (2009) USA Sub-urban Cross-sectional	To examine associations between neighborhood built environment and median income, to multiple health outcomes and examine whether associations are similar for low-and high-income groups; particularly how low vs high walkability and low vs high income neighborhoods are related to adults' biological, behavioral, social and mental health outcomes. n=2199 participants, (32 neighbourhoods) Adults aged 20 – 65 years of age	*Outcomes:* Physical Activity; daily minutes of moderate-to vigorous physical activity (MVPA) from accelerometer monitoring, body mass index (BMI) based on self-report, and mental and physical quality of life (QoL); Measures: >Total physical activity - actigraph model used to objectively assess moderate-to-vigorous physical activity;Walking for transportation and leisure - via IPAQ BMI - self-reported, defined overweight and obesity	*Neighbourhood Definition:* Census block groups - study provides a rationale for why they chose this and how they selected them	*Covariates:* - (Demographic) e.g. gender, age, education, ethnicity, number of moto vehicles/adults in household, marital status, number of people in household, years at current address; Neighbourood self-section is the potential confounder, so they conducted analyses adjusting for and also not adjusting for people's reasons for moving to current neighborhoods Quality of life and psychosocial variables - to asses physical quality of life (QoL) and mental QoL; Neighborhood satisfaction defined as the mean of 17 ratings of satisfaction with aspects of walkability and transportation, social interaction, traffic and crime safety and school quality (each item rated on a 5 point scale)	Mixed effects regression models for all continuous variables; Geeneralized linear mixed models for dichotomous overweight/obesity outcomes; Repeated measures framework used for BMI and weight status (via two time points), analyses took neighborhood clustering into account, so that three-level multilevel models were fitted to account for repeated measures nested within subjects and subjected nested within neighborhoods	*List the 4 they discussed	>Objective & Subjective (perceived) >Walkability index from Frank et al. (2010); The development of a walkability index: application to the Neighborhood Quality of Life Study. >>>Frank et al. (2010)
Pouliou et al. (2014) Canada Urban Cross-sectional	To examine the relationship between individual- and neighbourhood-level correlates of obesity, and assess the heterogeneities of this relationship. n=12 836 > Adults aged >- 20 yaers	*Outcomes:* BMI (continuous)	*Neighbourhood Definition:* Conventional 1-km buffers and generated additional activity-space buffers, based on the model created by Morency et al. (2011).The buffers were created that resulted from the model, within a radius of between 1.2 to 6.5km.	*Covariates:* Controlled for chronic conditions (i.e. blood pressure, diabetes, arthritis/rheumatism and anxiety/mood disorder) and demographic characteristics (i.e. age, gender and ethnicity). (all categorical). *Individual-level and Dissemination-area	Multilevel analyses.	Findings generally indicated that individuals living in areas of more mixed land use have a lower BMI None of the hypothesized mediators that related neighbourhood variables to BMI were significant (physical activity and diet)	Objective data; GIS data: Enhanced Points of Interest (EPOI) database from the Desktop Mapping Technologies Inc. *activity-space buffers represent an improvement to conventional1 km-buffers

	Data Sources: i) the 2003 CCHS; ii) the 2001 Canadian Census; iii) the Enhanced Points of Interest (EPO) database from the Desktop Mapping Technologies Inc.		Built environment variables: Land-use mix, street network connectivity, residential density, density of fast food restaurants, convenience stroes, grocery stores and recreational centres.	level explanatory variables. (Sociocultural): proportion of home ownders versus those in rental homes (Economic): education, average and median household income, average dwelling value, proportion of households below the low-income cut off, unemployment rate		>Street connectivity was not found to be associated with BMI >Residential density was negatively associated with BMI in Vancouver, but not Toronto	
MacDonald et al. (2012) USA Urban Cross-sectional	To examine the effect of population density and block size on BMI. n=690 adult participant; n=36 neighbourhoods Adult age= N/A *Data Sources:* 2000 US Census; data from the Twin Cities Walking Study (TCWS) used a matched-sampling design where the selected study area was exhangeable (demographically homogeneous) across diversity of neighbourhood types.	*Outcome:* BMI determined by measuring heights and weights (continuous)	*Neighbourhood Definition:* Median block size of an area; small median blocks, less than 2 hectares (ha) and large median blocks greater than 3.2 ha Built environment: Residential population density; median block size, and the interaction of these two variables. Dependingon the median block size (i.e. small or big), this would imply higher or lower street connectivity. As a result of stratifying these variables, the following neighbourhood types were present: the resulting neighbourhood types are: (1) high density, large block (HDLB); (2) high density, small block (HDSB); (3) low density, large block	*Covariates:* (Demographic): sex, race, educational attainment, marital status, home ownership, age, household income, housing tenure, self-reported overall health >>Hypothesized that physical activity may confound or mediate this potential association, but did NOT test physical activity as a mediator.	Linear regression AND GEE models, multilevel model to account for clustering because of neighbourhoods.	No significant association between effect of block size by population density on BMI, even after adjusting for demographic covariates and/or physical activity	Objective data; No GIS data; No Walkability index;

			(LDLB); and (4) low				
Casagrande et al., (2011) USA Urban Cross-sectional	To investigate the association between walkability and obesity among adults in Baltimore, living in neighbourhoods with racial and socioeconomic disparities. n=3493 adults, from 12 neighbourhoods Adults aged 30 - 64 years. *Data Sources:* Census Measures: >Race and SES info from the 2000 US Census; originally from The Healthy Aging Neighborhoods ofDiversity across the Life Span (HANDLS)	*Outcomes:* Obesity (via measurements computing a BMI); categorized so that BMI of 30 or higher denotes obesity.	*Neighbourhood Definition:* Boundaries of 2 to 5 census tracts. Neighbourhood Walkability: from the Pedestrian Environment Data Scan (PEDS) (an environmental audit tool that collects microscale environmental features); walkability score was derived from PEDS audit. Connectivity via street segments (using GIS and street files).	*Covariates:* Confounders that were adjusted for: age, gender, race, education, poverty status, self-reported health Potential mediators that were investigated in the pathways were perception of crime, physical activity and main mode of transportation	Multilevel (random-effects) log-binomial models	Overall, no sig association between neighbourhood walkability and obesity after adjusting for demographic characteristics Significant effects by race, poverty threshold, use of a car were all found in the expected direction, for example, those in less walkable neighbourhoods used a car more; those who were above the poverty threshold were sig more likely to live in low walkable neighborhoods; For the subgroup pof SES, the association between walkability and obesity was attenuated when they controlled for physical activity	Objective - via Pedestrian Environment Data Scan (PEDS) audit; to construct a walkability score No GIS data No Walkability index
Sofkova et al. (2013) USA Urban Cross-sectional	To explore the association between walkability and health-related indicators of urban residents (via physical activity and body weight measures). n=167 women >Adults aged 20 to 60	*Outcomes:* Body composition measures: BMI, the amount of fat fraction (Body Fat Mass, kg, %), the amount of fat fraction in kg due to the square of the height (Body Fat Mass Index, BFMI), visceral (internal) fat (VFA-visceral fat area), and level of obesity.	*Neighbourhood Definition:* N/A. Neighbourhood environments measured via ANEWS questionnaire (Neighbourhood - Environment Walkability Scale - Abbreviated). Specific questions about residential density, diversity of land use (through characterization questions), street	N/A	Student's unpaired t-test to compare individual groups, the two-factor ANOVA to look at effects of age and walkability (these two factors), and Scheffe post-hoc test to compare the two groups.	Reported noticeable differences between the two age groups of women for their observed changes in fat-free mass, total body water, and intracellular and extracellular water when they investigated how conducive the residential areas were for engaging in active transportation Reported mostly non-significant findings.	Subjective measure of walkability: ANEWS questionnaire was used to determine the level of neighborhood walkability; No GIS data; no walkability index

			connectivity, cycling and walking facilities, neighborhood aesthetics, residential safety.			For the outcome of changes in average percentages of fat fraction in younger women compared to older women, they detected significant differences in the association between land use mix and obesity. For the outcome of changes in total body water (intracellular and extraceullar water),and fat-free mass, they reported significant associations between how conducive the residential environment was for active transportation and obesity. No significant associations between access to services within walking distance of a participant's residence Failed to find significant associations between street connectivity and fraction of body composition groups by walkability group	

Van Hulst et al. (2013) Canada Urban Cross-sectioal	n=512 children living in the Montreal Metropolitan Area with both parents also living at the same residential address >Child's age between 8-10 years at the start of the original study >Adult mean age (of mothers and fathers) was between 40 and 43. *Data Sources:* Land use information from CanMap (DMTI Spatial Inc.); 2006 Canadian Census data were used; in-person neighbourhood audits by independent observers using an observation checklist adapted from an existing neighbourhood assessment tool.	*Outcome*: Obesity (based on measured heights and weights of parents and children); for parents, the BMI was computed by weight/squared height; categorized as obese if BMI was ≥30 otherwise considered to be normal or overweight.	*Neighbourhood Definition:* 500m network buffer of the family's residential location. Neighbourhood Environment Indicators: Residential Density, Presence of at least one park, % of neighbourhood area covered by parks, number of 3 or more-way intersections, total length of streets with normal traffic at rush hour, % of streets that have high traffic at rush hour, total length of streets with high traffic at rush hour.	*Covariates:* (Confounders) Household-level sociodemographic variables.	Principal components analysis; Multilevel logistic regressions.	Socioeconomic factors such as education and affluence impacted the likelihood of families being obese. Level of traffic in neighborhoods was also found to be associated with obesity, for instance, less traffic was associated with a lower likelihood of being obese than higher traffic. >Main effects models did not failed to find associations between indicators of neighbourhood attractiveness/aesthetics such as neighbourhood poverty, physical disorder and deterioration. and pedestrian friendliness and obesity.	Objective data GIS data and in-person audits (checklist of items from an existing neighbourhood assessment tool - meant for direct observation; the Montreal Neighbourhood Asessment Tool) [Reliability of an instrument for direct observation of urban neighbourhoods] No Walkability Index
McCormack et al. (2012) Canada Urban Cross-sectional	i) To use cluster analysis to identify neighborhoods with homogeneous built environment attributes (cluster uniform neighborhoods) and ii) To determine whether or not these clusters were associated with participation in PA (they quantified local walking behaviors according to whether they were for	*Outcome:* Local Walking; 1) non-participation (< 10 min/ week) vs participation >10 mins/week; 2) duration (min/week) in those who walked; 3) insufficient (10 to <150 mins/week) vs sufficient (> or equal to 150 mins/week) neighborhood-	*Neighbourhood Definition:* Buffer size of 1.6 km (line-based network buffer or walkshed was estimated for each household's postal code - it represented the distance that could be walked in any direction within 15-mins). Neighborhood self-selection and length of neighborhood tenure >to capture importance	*Covariates*: adjusted for all other characteristics to be able to find an association between neighborhood walkability and local walking: attitude towards walking, sociodemographic characteristics, and physical activity; Attitude towards walking: Using likert scales, 6 items (strongly agree to disagree)	Multinomial logistic regression to examine the association between neighborhood cluster and ALL neighborhood self-selection, length of neighborhood tenure, attitude towards walking, sociodemographic and season variables >>did a balance check to determine whether or not statistically significantly different	Residents from HW neighbourhoods more likely to participate in local walking than those from LW neighbourhoods	Objective and subjective; Use of GIS data at the walkshed level or in aggregated level; postal code of household street address >No walkability index

	transportation or recreational purposes) n=4304 Adults aged 18 and over	based transportation and recreational walking, respectively	of physical and social characteristics considered; 19 items to assess this: items captured the importance of proximity of recreational facilities, trails, parks, services, school/job, family/ friends, transit, and downtown; the availability of places for physical activity, walking, cycling, attractive streets, and highways; ease of driving, and walking; safety from crime; sense of community, and; affordability	Sociodemographic characteristics: Home ownership status, gender, age, highest education achieved, #of dependents (all categorical variables), except age (continuous)			
Jack et al. (2014) Canada Urban Cross-sectional	i) To compare self-reported, objectively-determined measures of neighborhood BE (LW,MW,HW) to each other and ii) To estimate associations between self-reported characteristics and walking AND between objectively-determined neighborhood characteristics and walking n=1875 Adults aged 18 and over	*Outcome:* Walking; Neighborhood based walking: >>Walking items adapted from IPAQ, modified to capture minutes of "neighborhood-based" (i.e., everywhere within a 15-minute walk of home) transportation and recreational walking. Respondents who reported walking <10-minutes/wk were coded as "non-walkers" and those reporting ≥10 minutes/wk were coded as "walkers".	*Neighbourhood Definition*: "anywhere with a 15 min walk from home". Neighborhood walkability characteristics: decision to locate current neighborhood recreational facilities, sidewalk length in meters, total population, respondents' household and percentage of green space and path/cycle way in meters within neighborhood administrative boundary (Self-reported) Neighborhood walkability: Perceptions of neighborhood walkability captured	*Covariates:* Gender, age, home ownership status (home owner or renter), highest level of education completed (less than high school, high school, college/technical school, undergraduate, or graduate), number of children <18 years of age, and time (in years) spent living in the neighborhood. Attitude towards walking was a composite variable based on the average response across six items.	Multivariate binary logistic regression was used to regress neighborhood - based walking participation on neighborhood	Differences in findings due to measures used (i.e. perceived walkability and objectively - determined neighborhood types) Perceived access to services, pedestrian infrastructure, and recreation destination mix did not significantly differ between respondents residing in HW and MW neighborhoods, however for HW vs LW, they did differ significantly for these and also for street connectivity, and utilitarian destination mix. >LW and MW different significantly on all perceived walkability variables EXCEPT for traffic	Objective and subjective; non-GIS data, cluster analysis; No walkability index

			using Abbreviated Neighborhood Walkability Scale (NEWS-A)			safety Perceived neighborhood aesthetics higher in MW than LW and HW neighborhoods For objectively determined HW vs LW, HW positively perceived access to services, street connectivity, pedestrian infrastructure and utilitarian and recreation destination mix, but negatively perceived motor vehicle traffic and crime-related safety >HW also more liekly to participate and spend time per week in transportation walking; perceived access to services, street connectivity, MV safety, mix of rec dest were also sig associated with transportation walking.	
McCormack et al. (2014) Canada Urban Cross-sectional	To determine varying effects of the neighborhood built environment on neighborhood-based physical activity, by sociodemographic and health-related characteristics n=1798 Adults aged 18 and over (and above 61 years of age.	*Outcome:* Neighbourhood-based physical activity; Minutes of neighborhood-based transportation and recreational walking and moderate-intensity PA were multiplied by 3.0 Metabolic Equivalents (METs) and minutes of	*Neighbourhood Definition:* Environmental attributes measured within a 1.6km network radius (walk shed of participant's home,that would take 15-min to walk).	*Covariates:* sex, age, highest education achieved (high school or less compared to college or university and number of dependents <18 years of age residing at home (none compared to at least one child) [via telephone interview] The self-administered questionnaire captured motor vehicle access (always compared to sometimes or never),	GZLM - to estimate marginal means of total-MET minutes of neighborhood based PA in a typical week, adjusted for covariates; >a priori pairwise comparisons taken to identify statistically significant diffs in PA	For ALL subgroups, except for participants over at least 60 years of age, overweight, or owning dogs, neighborhood-based PA was significantly higher ($p<0.05$) in HW compared to MW or LW Largest difference in neighborhood-based PA (MET-minutes/week) was between participants	Objective and subjective >non GIS >cluster analysis model >No walkability index

		vigorous-intensity PA multiplied by 6.0 METs to obtain an estimate of weekly energy expenditure (Ainsworth et al., 2000). > Energy expenditure for the four physical activities was summed to provide a measure of total neighborhood-based PA (i.e., MET-minutes/week).		annual household income (<\$80,000/year compared to ≥\$80,000/year compared to don′t know or refused), dog ownership (not an owner compared to own at least one dog), self-rated health (poor, fair or good compared to very good or excellent), and self-reported height and weight for BMI.		reporting "sometimes or never" having access to a motor vehicle who resided in a HW compared to LW(72% higher in the HW), $p<0.05$ Lowest difference in neighborhood-based PA was between those overweight and residing HW compared to MW(32.8% higher in HW, $p<0.05$) Mainly, that the benefits of interventions should be reasonably equally distributed across the population of interest In HW neighbourhoods, higher levels of neighbourhood – based PA was found among low and high income and education subgroups Suggests that even those who are low-educated could gain from living in a HW neighbourhood – supports previous finding that availability of local PA resources is reported to have a greater influence on socio-economically disadvantaged compared with more affluent individuals…*though in general, low SES = ill health	

McCormack et al. (2013) Canada Urban Cross-sectional	To explore associations between indicators of neighborhood walkability and social support and the TPB, and participation in and to what levels of neighborhood-based recreational and transportation walking. n=4422 Adult women aged 41-60	*Outcome:* Walking; >Neighborhood-Based Walking (for recreation and transportation): via IPAQ, including frequency and duration of all recreational exercise or leisure and transportation walking inside neighborhood during last 7 days; both were dichotomized to align with the Canadian recommendation of minimum of 150 mins per week of MVPA	*Neighbourhood Definition:* Unspecified; Neighborhood Walkability Scale (NEWS-A) Questionnaire that captures info about perceived walkability, social support (friends, family, dog ownership) and neighborhood-based transportation (NTW) and recreational walking (NRW); >>>>Walkability factors (7) included safety from crime, neighborhood aesthetics, access to services, street connectivity, pedestrian infrastructure, motor vehicle traffic and barriers >Additionally, measured residential density = dichotomous (high/low).	*Covariates:* Perceived behavioral control: via 5-point scales for transportation and recreational walking measured with 2 items; Attitudes (instrumental and experimental) toward walking - via 6 items Subjective norm related to walking (via 2 items); Social Support for walking: answered self-administered questionnaire (dichotomous); Home ownership (categorical);Demographics: Gender, age, education, number of dependents, self-rated health (categorical); Number of dogs (dichotomous) Mediator: >TPB variables: >Perceived behavioral control (PBC), attitudes, subjective norm, intention;	Mediation Analysis using Baron and Kenny Method	Perceptions of neighborhood walkability, social support and motivation-related cognitions were associated with NRW and NTW; associations among their indicators was also found; >>>when accounting for TPB variables, there was attenuation of associations between measures of neighborhood walkability and walking which suggested partial mediation Association between access to services, street connectivity, residential density with participation in sufficient levels of NTW (agreeing with previous literature) >Neighborhood aesthetics association with participation in NRW, but did not achieve sufficient levels of participation Among those with higher access to services, street connectivity, intention of NTW was more likely whereas it was less likely among dog-owners and those with higher neighborhood aesthetics Intention of NRW was less likely among dog owners and those with higher neighborhood	Subjective; Non-GIS; Mediation; No Walkability index

						aesthetics; turned out that those who were more active were less likely to intend to do MORE walking (could be due to the way question was asked) Perceived behavioral control positively associated with sufficient NTW but not with sufficient NRW Association between access to services and participation in NTW and achievement of sufficient NTW partially mediated by perceived behavioral control.	
Montemurro et al. (2011) Canada Urban Cross-sectional	To examine neighborhood residents' definition of walkability, understand what their perceptions are about the neighbourhoods they reside in for walking, physical activity, food choice, and find out which of these factors influence their neighborhood choice n=63adults Median age is 60.	*Outcomes:* Neighbourhood-based physical activity.	*Neighbourhood definition:* N/A Main environmental 'exposures' that participants were asked about were Walkability, neighbourhood selection, perception.	N/A	*Qualitative methods, since little of it exists in research about walkability, physical activity, food choice and neighborhood selection Focus groups were used and participants were asked questions re: 1) did they feel their neighborhood environment impacted physical activity participation (personally and others);2) what factors influenced neighborhood choices;3)suggestions about how to improve neighborhood related to physical activity and food choice; Guided questions used, probed when needed	Participants able to define walkability with little difficulty; most cited neighborhood features included proximity to amenities and services, safety, path availability (including sidewalks and crosswalks), natural or green spaces, visibility, aesthetics, seasonal factors, universal walkability; Most felt neighborhoods were walkable Mention of leisure, exercise, destination, dog walking among those who perceived walking as mainly a leisure or exercise type of activity;	Subjective; Non-GIS; No Walkability Index

						Most with no intention of going to a particular destination; Recognition of others' involvement in physical activities, presence of health facilities, cost = major barrier for use of certain venues (i.e. YMCA); Other influential factors: connectivity (i.e. busy roadways), quality (e.g. of sidewalks), seasonal conditions (e.g. winter), safety; Social interaction - repeatedly cited as being important, to meet people, perceptions that this engages people and strengthens community; Valuation of older neighborhoods and the features/infrastructure of those relative to 'newer' developments Larger influences of physical activity thought to be community leagues, local playing fields, courts, rinks, valuation of diverse venues; Outlook on joining community league programs affected by lack of specific info about program and	

						community support	
de Sa et al. (2011) Canada Urban Cross-sectional	>*Data Ssources* were CCHS and GIS maps for the Regional Municipality of York in Ontario	See de Sa findings below (from this original thesis paper, that's why)	See de Sa findings below (from this original thesis paper, that's why)	See de Sa findings below (from this original thesis paper, that's why)	See de Sa findings below (from this original thesis paper, that's why)	See de Sa findings below (from this original thesis paper, that's why)	Walkability Index (NOT Frank); GIS
de Sa et al. (2014) Canada Rural & Suburban Cross-sectional	To create a walkability index and explore its associations with PA participation from CCHS 2007/2008 data. n=1158 Study was NOT restricted to adults, but the representation rom CCHS (aged 12 and over)	*Outcomes:* Physical activity (Leisure time and transport-related); measured it dichotomously	*Neighbourhood Definition:* buffer zones of 500m and 1000m around each respondents' 6-digit postal code address	*Covariates:* Age, sex, BMI, education, income, ethnicity, smoking status.	Logistic Regression	Association between neighborhood walkability and physical activity in a 500m and 1000m buffer region for walking/cycling for leisure-time purposes and within a 1000m buffer region for walking/cycling for total physical activity, when they controlled for demographic and health behaviors. This was a moderate-to-strong association With a 500m buffer, comparing lowest to highest quartiles for walkability, found that higher ended was significantly more likely to walk or cycle for leisure purpose (55% more likely) Same effect apparent within a 1000m buffer zone, particularly evident among those who lived in 2nd, 3rd, 4th quartiles but this finding did not apply to these quartiles of respondents within the 500m buffer zone. For those who were in the 4th quartile, they were more likely to engage in	GIS data; Walkability Index (NOT Frank)

						walking/cycling for leisure and transportation purposes.	
de Sa et al. (2014) Canada Urban Cross-sectional	To measure association between different BE aspects and leisure time and transport-related PA. n=158 Not restricted to adults, considered eligibility of CCHS sampling methods (i.e.aged 12 and older)	*Outcomes:* Physical activity; street intersections >Outcome: PA – specifically leisure time physical activity and transport physical activity o Continuous outcomes: daily minutes engaged in walking or cycling for leisure (based on frequency and average daily duration);(Leisure time daily energy expenditure – LTDEE – a derived variable by Stats Can) >Dichotomous outcomes: engaged in walking or cycling for leisure time purposes (any or none) and walking or cycling for transport-purposes (any/none) >>General measures of PA – a leisure-time PA transport- related PA combined in one index, and a separate LTPA index	*Neighbourhood Definition:* Centroid of postal codes, buffer zone of 500m - so BE characteristics quantified within this space, is this best represents a walking distance of 5 minutes and meets daily recommended physical activity levels if you walked two and from somewhere (i.e. 10 mins total) >>>Building area, Parks/green space area – public and private parks, >>>Residential density >>>Intersections – number of street intersections	*Covariates:* BMI via self-reported height and weight, education, income, ethnicity, smoking status, age, sex.	Multilevel HLM: Model 1 was a univariate association between BE and PA outcome; Model 2 was adjusted for all other covariates; the advantage of	For this association: BE (all) on PA No single measure of the BE associated with walking or cycling for LTPA For this association: Residential Density > PA Higher residential density associated with decrease in LTDEE – but found to be non-significant when considering other factors (in fully adjusted model) For this association: Intersections > PA Those living with fewest intersections compared to highest, the highest were more likely to be engaging in walking or cycling fo leisure, considering covariates	Walkability Index (NOT Frank)

Zhu et al. (2014) USA Urban Cross-sectional	To make a pre/post comparison of residents who moved to a more walkable community and see if there were changes in their physical activity levels, social interactions, and neighbourhood cohesion. n=449 Adults aged 18 years and older.	*Outcomes*: Physical activity levels, Social Interactions, Neighbourhood cohesion; selected based on social ecological theory. Physical activities were captured by the number of days per week with ≥30 daily min of moderate physical activities and by frequencies (days/ week and min/day) of specific activities. Positive social interactions were measured by the frequency of specific interactions; neighborhood cohesion was measured using a 5-point Likert scale, by asking the respondent how much he/she agreed or disagreed with relevant statements. Residential self-selection (neighborhood preference in	*Neighbourhood Definition:* 711-acre Mueller community Walkability: based on publicly available Walk Score (WalkScore.com, 2014); this included density of retail destinations, street intersections, residential land uses; valid measured, linked with walking quantitatively in previous studies.	No Covariates were controlled for.	Conducted a paired t-test to view pre-post move differences for the entire sample	Found that percentage of already active residents increased from (34.4% to 45.8%) on a regular basis, i.e. they did at least 30 mins or more of PA per day for at least 5 days or more per week, increased their PA after the move PA increases in biking, total walking and walking in the community, reduction of car use (all significant) After the move, there was close to the recommended 150 min of moderate physical activity Sig increases in all variables related to social interactions and neighborhood cohesion for entire sample, but similar patterns for pre/post in 284 sub-sample of respondents Sub group analyses showed that there were differences between groups in terms of their physical activity changes; for instance, those who moved from less to more walkable communities increased their PA significantly, but high to high did not People who were insufficiently active	Non-GIS; Subjective - used a Walk Score

		relation to walkability) was captured by asking the respondent how important the “ease of walking” was in their relocation to Mueller).				sig increased PA while the previously significantly active subgroup did not. All subgroups for their pre-move social interactions and neighborhood cohesion, showed increases in their physical activities, except for few variables Sub-groups with diff levels of neighborhood preferences all showed increases in some PA measures but the impact was strongest for peeps who had the strongest preference for walkable neighborhoods	
Villanueva et al. (2014) Australia Urban or Rural Cross-sectional	To examine variation in the association between walkability and walking across life stages within a single study. n=21 347 Adults aged 18 to 65 + years *Data Source:* Stratified random sample of the Perth metropolitan area who completed the Western Australian Health and Wellbeing Surveillance System (HWSS) survey from 2003 to 2009 (n=21,347).	*Outcomes:* Walking/No walking (reference group = no walking); Any Walking (outcome variable) - via self-reported total minutes of walking continuously for min. 10 mins, for recreation, for exercise or for utilitarian purpose (i.e. to get somewhere)--> this variable was dichotomized into walking/no walking.	*Neighbourhood Definition:* Compared different cross-tabulations for respective increases in buffer sizes:200m by 400m, 400m by 800m, 800m by 1600m and 200m by 1600,) - based on previous lit review that had indicated these distances were commonly used to represent size of 'neighbourhod' (i.e. they represent 'walkable' distances to local destinations). Walkability Index: (continuous, measured by index, included 1) land-use mix; 2)street connectivity;	*Covariates:* Sex (male/female); age (continuous); education (categorical); socioeconomic index (based on a range of social and economic indicators) Assessed for interactions between age group and walkability	Binary logistic regressions were used to estimate the effect of neighborhood walkability for each adult life stage at each neighborhood buffer, for all adults.	For all ages, the adjusted odds ratio of walking across different neighbourhood buffers showed few differences in associations across all neighborhood buffer sizes. Overall, neighborhood walkability supports more walking, regardless of adult life stage; relevant for small and larger neighborhood buffers. Speculation that neighborhood buffer size may have an impact on walking purpose.	Objective data; GIS data; Walkability Index - from Frank et al. 2005

			3) residential density				
Saelens et al. (2012) USA Urban Cross-sectional	To examine whether objective built (e.g. residential density) and perceived (e.g. aesthetics) environment factors surrounding adults residences are correlates of physical activity and reported walking behavior, when adjusting for psychosocial (e.g. self-efficacy) barriers to physical activity and demographic correlates of physical activity. n=32 neighbourhoods or 219 census block groups Adults 20-65 years old	*Outcome*: Physical Activity (Walking) Physical activity: via accelerometers, counts per minute converted into MVPA minutes; average MVPA minutes per valid day included in analysis >>Self-reported minutes spent in transportation-relation walking (i.e. walking to store), and leisure walking, from IPAQ	*Neighbourhood definition*: Census block groups; but also neighborhoods were classified based on sharing same walkability classifications and median household incomes Neighbourhood environment: regional land use at parcel level and street networks integrated into GIS for creation of participant-specific BE measures for 1-km street network buffer around each participant's residence; It included net residential density, land use mix, intersection density, Retail FAR >>>>Parcel level land use daata to determine total number of parks within 1-km buffer around each participant; >>>street network distance calculated >>>count of private rec facilities also calculated within 1 km of each participant (Subjective) >Self-reported neighborhood environment: >>4 subscales used to characterize perceived attributes of neighbourhood (since objective measures were unavailable):	*Covariates:* >Demographics (collected by survey form): Age, gender, ethnicity, education, number of adults and children in the household, length of time at current address, number of motor vehicles per adults in household, marital status, household income, job status Other demographic data (collected at census block group level)= median resident age, percent nonwhite, median household income Psychosocial factors – reasons for selecting neighborhoods, psychosocial factors related to physical activity , such as reasons for moving to that neighborhood and reasons that may be relevant to participating in physical activity	Mixed-effect regression models to account for a multilevel data structure. Stepwise model building techniques were used.	Most objectively measured environmental factors associated with MVPA Specifically, higher residential density, retail FAR, land use mix, number of proximal private rec facilities and parks sig. related to MVPA; Retail FAR around individual's residence mostly explained objectively measured MVPA among all environmental factors; it was also a significant correlate of self-reported transportation walking; Lack of associations between perceived environment and objectively measured physical activity and transportation walking after controlling for demographic and psychosocial factors	Objective and subjective; GIS data for disaggregated measures; No Walkability index

			perceived neighborhood walking/cycling facilities, aesthetics, pedestrian/traffic safety, safety from crime; proximity of 18 recreation facilities.				
Giles-Corti et al. (2013) Australia Urban Longitudinal	To determine changes in perceived and objective neighborhood characteristics associated with walking after relocation, and approximately 12 months later. n= 388 (at T1 only) n=1420 (completion of T1 and T2) Adults aged 18 and over; Mean age of adults = 37.2 years at T1 only; after T1 and T2, mean age is 40.7 years Data sources include RESIDE questionnaires and GIS data	*Outcome:* Self-reported walking for recreation and transport in a usual week within the neighborhood; > Self-reported walking - measured via NPAQ	*Neighbourhood definition:* Unspecified. Households within new housing developments? (Built environment Change Variables: >>>7 transport-related destinations and 3 recreation-related destinations, that increased from T1 to T2 (Perceived) Built environment change variables: based on 5-point scale (Recreational walking had 14 perceptions and transport walking models had 4 perceptions) and the score was based on the number of changes in perceptions that occured from T1 to T2 >>>for objective and perceived variables they are included as continuous variables >>interpreted as the estimated additional minutes of walking for a unit increase in continuous variable and for categorical it is the estimated mean change in minutes of	*Covariates:* Age, gender, marital status, having children <18 years at home, level of education; Table 2 - exhaustive list of variables that were used to adjust for self-selection *the tables also indicate how these variables were handled in the analyses. Social environmental change variables; Intrapersonal change variables; Socio-demographic change variables - categorical	Statistical Analysis: Generalized linear mixed models that included a random cluster effect to account for clustering by new developments;	After relocation, transport-related walking declined, and recreational walking increased (because the access to these destinations increased by nearly 6 mins per week for each type of transport related destination that increased Association between BE and recreational walking was partially mediated by changes in perceived neighborhood attractiveness: when changes in "enjoyment" and "attitude" towards local walking were removed from the multivariate model, recreational walking Provides longitudinal evidence that transport and recreational walking behaviors respond to changes in the availability and diversity of local transport-and recreational destinations Consistent with previous cross-sectional evidence, if residents gained access	No Walkability index; Objective and subjective; GIS data

			walking for each level of the categorical change variable			to a mix of neighborhood destinations, then this was positively associated with changes in minutes of local walking Similar to those whose perceptions of their local neighborhood improved following relocation, minutes of transportation, and recreational local walking increased Positive changes in perceived and objective neighborhood attributes are independently related to changes in walking and suggests that the impact of an enhance be on walking will be greater if residents also perceive these to be favorable	

McCormack et al. (2012) Australia Urban Cross-sectional	To examine whether sidewalk availability was associated with participation in, and minutes of neighbourhood-based walking for transportation (NWT) and recreation (NWR), after controlling for neighbourhood self-selection n=1813 Adults 18 years and older	*Outcomes:* Participation (none. Vs any walking) as a binary outcome, and walking in minutes (continuous)	*Neighbourhood definition*: 1.6km service area within the road network buffer of respondent's residential location Walkability index (but don't specify what they put into it). Sidewalk length (per 10km).	*Covariates:* (Attitude and neighborhood preferences) Attitude towards walking, access to recreation, access to schools, access to services, street pedestrian/cycle friendly; housing affordability/variety	Heckman two-stage modelling approach (multivariate Probit regression for walking participation, followed by a sample selection-bias corrected OLS regression for walking minutes)	After adjustment, neighborhood sidewalk length and walkability were positively associated with a 2.97 and 2.16 percentage point increase in the probability of NWT participation, respectively. For each 10 km increase in sidewalk length, NWT increased by 5.38 min/wk and overall neighborhood-based walking increased by 5.26 min/ wk. Neighborhood walkability was not associated with NWT or NWR minutes. Moreover, sidewalk length was not associated with NWR minutes.	No Walkability index; Objective GIS;

Oliver et al. (2007) Canada Suburban Cross-sectional	To examine the influence of land use type (residential, commercial, recreational and park land and institutional land) on 'walking for leisure' and 'walking for errands' using 1 km circular and line-based network buffers. n=1311, but 8 neighbourhood clusters Mean age=42.52 (SD=10.12)	*Outcomes:*the amount of time respondents spend walking for errands (e.g. commercial land) (categorical); the amount of time respondents spend walking for leisure (e.g. park land).	*Neighbourhood definition:* Circular and network buffers of 1-km, but around this area, a 50m buffer was selected to include parcels from selected roads, ensures that everything along roads are included and prevent overrepresentation of extended parcels Land use type: Commercial land, institutional land, recreational and park lands, residential land, other land uses.	*Confounders:* Age, Gender, household income, Marital status, BMI.	Logistic regression	Increasing proportion of institutional land significantly reduced the odds of "walking for leisure 15 minutes or less per day" when using line-based road network buffers A greater proportion of residential land significantly increased the odds of "walking for errands less than 1 hour per week" – but no sig results for circular buffers An increased proportion of commercial land significantly decreased the odds of "walking for errands less than 1 hour per week" for both the circular and line-based road network buffers Greater association between land use and walking was found using the line-based road network buffers than the circular buffers suggesting that they may be better suited to examine relations between the built environment and walking Results are important because they show that relations between the built environment and walking are sensitive to the choice of measurement. For studies prior to this	No Walkability index; Objective; GIS data

						one, if they change their measure, they may find associations with physical activity, using line-based road network buffers. Concluded thatthat the selection of a network or circular buffer has a considerable influence on the results of the analysis	
McAlexander et al. (2011) USA Urban Longitudinal	To associate the degree of concordance between directly and indirectly measured built environment attributes with changes in PA over time among African American and Hispanic Latina women participating in a PA intervention. n=410 (all women) Age= between ages 25 to 60 years of age	*Outcomes:* BMI, body fat percentage, (both measures of body composition); self-reported PA and accelerometry analyzed at T1 and T2; for the self-reported, they were converted into continuous scores in MET-minutes and the accelerometer-MVPA were put into a daily average	*Neighbourhood Definition*: 800m radius circle	N/A	Repeated measures analyses were used. Interactions were tested in all models	No significant associations were found between BE attribute concordance values and change in self-reported or objectively measured PA. No sig interaction effects (by ethnicity).	Objective and subjective; GIS data; No Walkability index
Badland et al. (2010) New Zealand Sub-urban Cross-sectional	To identify associations between neighbourhood selection, neighbourhood preference, work-related travel behaviors, transport infrastructure. n=1616 adults >Age 20 to 65 Sex: males=42.8%, demales= 57.2%	*Outcomes:*Work-related travel modes, commute distance and public transport access	*Neighbourhood Definition:* 10-15 min drive away from home, and place of work within a 20-min comute on a motorway (freeway). Neighbourhood preference: (suburban style or urban style), participants rated strength of preference on a five-point Likert scale (ranging from 1 = very slight	*Confounders:* sex, age, ethnicity, education, household income, housing tenure, and residential neighbourhood clustering (using robust standard errors)	Linear Regression to look at associations between neighbourhood residence, neighbourhood preference and workplace commute distance, neighbourhood public transport density and PMB access; Logistic Regression to examine associations between	Found that people who lived in less walkable neighbourhoods had significantly longer commutes to make to work than those who lived in highly walkable neighbourhoods; Those who preferred suburban neighborhoods had longer commute that those who preferred urban neighborhoods	All self-reported Walkability Index based on measures used by Badland et al. (2009) and Owen et al. (2007)

			preference to 5 = very strong preference, later collapsed to ‘no strong preference’ (1, 2) and ‘strong preference’ (3, 4, 5)) Neighbourhood Residence: dichotomized into low/high walkability, using 2006 census data. Walkability index measure included street connectivity, dwelling density, land use mix and retail floor area ratio.		neighbourhood residence and neighbourhood preference and work travel modes.	But among the combined option: suburban style preference and selected for suburban experienced much longer commute time to place of work than preference of urban environment, but also had greater access to cars Finding from combined measure of these, which was neighbourhood residence, preference and combined was significantly associated with proportion of work trips made by car, public transport, active travel,: neighbourhood residence was significantly related to public transport and active transport work related trips, with associations in expected directions; Those who lived in less walkable neighbourhoods with no preference, tended to use cars for commute more than those who lived in high walkable neighbourhoods with an urban style preference; those who prefered suburban style neighbourhoods, were less likely to take public or active transport to/from work compared to those	

						with urban style preference - similar findings for those who preferred low walkable and suburban style settings, and stronger relationships than when preference was considered Findings revealed a consistency with residential self-selection hypothesis where 57% strong preferences matched with neighbourhood they lived in; mismatch could be due to lack of availability of neighborhoods - but levels of physical activity due to work related travel behaviors could be inferred using info about neighbourhood residence and preference	
Witten et al. (2012) New Zealand Urban Cross-sectional	To examine association between BE and PA; looks at impact of 5 objective measures of the BE and 3 self-reported and 1 objective measures of PA. n=2033 Adults aged >20 to 65 years of age	*Outcomes:* Physical activity; 3 self-reported measures of Physical activity (transport, leisure and walking), and 1 objective measure of PA (Accelerometer-measured); any minutes versus no minutes of self-reported PA as outcome categories	*Neighbourhood Definition*: Meshblock level Destination access, Street connectivity, Dwelling density, Land-use mix and Streetscape quality (4 derived by GIS (3/4 were the walkability index components and the 4th was the Neighbourhood Desintinations Accessibility Index) ;and 1 was a systematic street audit); (the 3 components of the walkability index	*Covariates:* Age, sex, ethnicity, marital status, household income, education, occupation, household car access, neighbourhood preference for living in higher or lower walkable neighbourhood (participants were asked their preference using 5-point preferability scale by Levine et al., 2005). >Controlled for Neighbourhood preference >BE variables - were rescaled to represent a 1-SD change;	Multi-level logistic regression analyses; regression coefficients from models of different built environment exposures are more easily comparable, as they all refer to a 1-SD change.	Walkability Index based on Lesli et al. (2007); Neighbourhood Selection Strategy: Used a walkability index (based on Lesli et al.2007) to classify neighbourhoods - so that neighbourhoods were scored into 6 high and 6 low from walkability scores; the walkability index in this study was a way to classify neighbourhoods but not used as one of the 5 objective BE measures, rather, 3 of the walkability index	No Walkability Index; GIS data; Objective

			were: street connectivity, dwelling density, and land-use mix)	Specifically, Model 1 was adjusted for sex, age, and ethnicity; model 2 was additionally adjusted for marital status, education, income, employment and car access (all individual or household-level covariates); model 3 was additionally adjusted for neighborhood-level deprivation; and model 4 was additionally adjusted for neighborhood preference.		components were used as BE measures	
Hou et al. (2010) USA Longitudinal	To investigate differential association between neighbourhood-level street network with walking, biking, and jogging by urbanicity and gender n=5015 at the start of the study. Mean age at start of study=24.8 ±3.7 yrs.	*Outcomes:* Physical activity; Frequency of participation in 13 different activity categories (eight vigorous and five moderate) of recreational sports, exercise, leisure, and occupational activities over the previous 12 months.	*Neighbourhood Definition:* 1-km Euclidean Buffer Intersection density, as a basic structural property; Link-node ratio as a derived structural property; Road type/ classification,	First Effect measure modifier is Urbanicity - 3 levels, so that census tract-level population density was in tertiles - participants living in urbanized area: low (including rural)m middle and high urbanicity Second Effect measure modifier is gender Individual-level covariates Census-level covariates	Two-part marginal effect model	Street density positively associated with walking, biking, jogging in low urbanicity areas, but these associations were not found in men for middle and high areas, and were inversed in women.	GIS data; Objective; No Walkability Index

Wilson et al. (2011) USA Urban Cross-sectional	To explore the role of the neighbourhood environment in supporting walking n=10286 residents of 200 neighborhoods Age= Adults aged 40 to 65 years	*Outcomes:* Walking Measures; minutes walked in the previous week: < 30 minutes, ≥ 30 to < 90 minutes, ≥ 90 to < 150 minutes, ≥ 150 to < 300 minutes, and ≥ 300 minutes.	*Neighbourhood Definition:* 1-km circular buffer from each resident's home Street connectivity, Residential density, hilliness, tree coverage, bikeways, and streetlights within a 1-km circular buffer from each resident's home; and network distance to nearest river or coast, public transport, shop, and park.	Census-level covariates	Multilevel multinomial logistic regression; Markov chain Monte Carlo simulation	Likelihood of walking for >300 mins (compared to <30 mins) was highest in areas wit most connectivity, greatest residential density, least tree coverage, most bikeways, most streetlights Likelihood of walking >300 mins also higher among those living closest to river or the cost	No Walkability index
Papas et al. (2007) Epidemiologic Review	20 studies; to summarize existing empirical research relating built environment to obesity Systematic Review; majority of studies were cross-sectional, two longitudinal	*Outcomes*: Body weight (direct measure)	*Exposures*: Objective measure of the built environment	N/A	N/A	Most studies reported a statistically significant association between an aspect of the built environment and BMI Recommend future studies to incorporate multi-level analytical tools, longitudinal designs, focus on physical activity and diet, investigate mechanisms through which the built environment influences obesity, investigate aspects of the social environment (e.g. age and life course states) and contextual influences, and within racial/ethnic groups.	A summary of existing empirical research relating the BE to obesity, included articles between 1990 and 2011
Feng et al. (2010) Systematic Review	Systematic Review	Outcomes: Obesity	*Exposures:* Built environment	N/A	N/A	Significant heterogeneity across studies, limits ability to pool effects of studies; very little between-study similarity in methods	Systematic review of epidemiologic evidence on built environment and obesity; purpose was to perform an evaluation for the

						Studies should report data collection methods and spatial units chosen Absence of agreement on how the built environment should be measured – this is important when deciding which metric will be used to measure walkability, land-use mix, urban sprawl (there is no consensus on which metrics should be used): more evaluation of longitudinal associations, multidisciplinary collaboration, better understanding of place.	quality of between-study evidence

McCormack et al. (2011) Systematic Review	Systematic Review Included 13 quasi-experiments and 20 cross-sectional studies between 1996 and 2010, English-language studies	*Outcome:* Physical Activity levels	*Exposures:* Objectively-measured built environment aspects	N/A	N/A	Land-use mix, walkability (composite indices) and neighborhood type consistently associated with higher physical activity levels, with controlling for neighborhood self-selection. Lack of studies examining changes in physical activity among same respondents in same neighborhood after changes are made wrt pedestrian connectivity, population density, land uses (there are consistent correlates with walking)	To review empirical evidence examining the association between the built environment and physical activity

Ding et al. (2012) Epidemiologic Review	Comprehensive Review 36 reviews met inclusion criteria (26 focused on physical activity as the outcome, 5 on obesity, 5 on both)	*Outcomes*: Physical activity or obesity	*Exposure:* Built environment characteristics	N/A	N/A	Several recommendations: develop complex conceptual and statistical models (examine moderators of the association between built environment and physical activity); examine mediators to understand mechanisms; consider multi-level conceptual and statistical models; objective & perceived measures should be included; account for neighborhood self-selection bias; definition of "place" is inconsistent > address this issue.	To investigate potential for causal relationships between the built environment and physical activity/obesity and evaluate peer-reviewed studies examining this association

Grasser et al. (2013) Systematic Review	34 publications based (33 cross-sectional, 1 prospective) Cross-sectional and longitudinal studies included in Systematic Review	*Outcomes:* Classified into 4 categories: walking and cycling for transport, overall active transportation, weight-related measures	*Exposure:* Built environment factors that might promote walking	N/A	N/A	Results of this review have also been supported by a a meta-analysis from the transport field Questionable/ mixed evidence for connectivity measures Weak evidence to support walkability as a strong correlate of physical activity for transport and weight-related outcomes; limitations of review thought to be due to cross-sectional design, poor or fair quality of studies, lack of prospective studies.	To find out which GIS-based measures of walkability (density, land-use mix, connectivity and walkability indexes) in urban and suburban neighborhoods, are used in research and consistently associated with walking, cycling for transport, overall active transportation, and weight-related measures in adults
Andrews et al. (2012) Summary/ Review	>Summary	N/A	Walkability-focused.	N/A	N/A	Summary of existing state of walkability research	*This is a review/summary/recommendations for future studies: The paper argues that there has been substantive research focusing on the walkability of the built environment, but little research on walkability. Walkability research could benefit from incorporating perspectives of health geographers and other disciplines, and would be beneficial to incorporate other concepts such as places, locations, distances, movements. >This paper argues

							that there is a complex relationship between humans, walking and environments; demographic and social variables related to the social composition of places should be considered.
Mackenbach et al. (2014) Systematic Review	Systematic Review Included 92 studies in the review; majority from North America, then Europe, Australasia 83 Cross-sectional and 9 longitudinal	*Outcome: A*dult weight status	*Exposure*: Physical environmental and transport – related factors	N/A	N/A	Authors of this review were primarily trying to test the hypothesis that inconsistent findings in the literature was were due to the heterogeneity in measures and methods used in primary studies >>>But they found they were unable to reveal consistent differences, even when they stratified by mode of measurement >>>Suggestion to use quality assessment tools when performing a SR and to be able to differentiate between objective and perceived measures	To provide an updated review on associations of physical environmental factors with adult weight status, stratified by continent and mode of measurement, along with a risk-of-bias assessment between 1995 and 2013
Saelens et al. (2008) A Review	To look at work from both the transportation and public health fields and summarize what the literature has to say regarding characteristics of the BE in relation to walking and what are the questions and policy implications that have come out of this. Included 13 reviews between years 2002	*Outcome:* Correlates of Walking (transportation-based and recreational).	*Exposure:* BE characteristics	N/A	N/A	Positive relations between transportation-based walking with density, distance to non-residential destinations, and land-use mix. Ambiguous (mostly null or unexpected) findings for relationship between transportation-based walking and route/network	Purpose of this review is to look at work from both the transportation and public health fields and summarize what the literature has to say regarding characteristics of the BE in relation to walking and what are the questions and policy implications that have come out of this.

	and 2006; also includes 29 studies published in 2005, until and including May 2006					connectivity, parks and open space, and personal safety Findings for recreational walking and these aspects was less clearer. Little or no evidence to support relationships between transportation-based walking and pedestrian infrastructure, conditions, traffic related issues, aesthetics, or accessibility of physical activity facilities BUT there was some evidence of relationships between recreation walking and pedestrian infrastructure and aesthetics, and personal safety and land use mix (but last two also had equal numbers of null/unexpected results). Similar frequency in findings, for null/unexpected results for relationships between environmental factors and general or total walking; slightly more expected than null/unexpected findings (2 more) for route/network connectivity and traffic; little evidence that general or total walking was related to	

						distance to non-residential destinations Consistent associations overall between transportation-based walking and density, land use mix and proximity of non-residential destinations but does not suggest that the same relationships hold between these BE factors and recreational walking or to the total amount or frequency of walking >>>Less evidence was consistently found between transportation walking and pedestrian infrastructure, (i.e. sidewalk presence and condition), though pedestrian infrastructure is more consistently related to recreational walking Conclusion of this review is that there is enough evidence to inform policy changes, however, future/newer studies should continue to build upon and address limitations of earlier studies, and prospective studies are also needed **this review contained articles from 2005 to early 2006 and also improved upon previous reviews by addressing the following things: More studies using	

						objective measures of walking, especially those that are micro-scale measures Greater diversity in environmental factors studies from all levels (i.e. street to neighborhood to regional levels) Examination of demographic variables as moderators. According to this review, least progress has been made in terms of examining causal relationships between environment and walking - need more prospective studies than cross-sectional Need to consider measurement and control for potential confounding factors in these relationships as well as demographic and self-selection factors and also look at potential confounding factors at both individual and neighborhood environment level esp because of multilevel data. Look at criticisms of transportation based walking and also self-selection criticism made at cross-sectional studies.	

Ferdinand et al. (2012) Systematic Review	To systematically review literature examining relationship between BE and PA or obesity rates; included any article that focused on the following: > any aspect of the BE and any form of PA or direct measures of obesity. >narrow reviews of body weight only, disadvantaged groups, how to best measure BEs Systematic review that included a total of 169 abstracts after inclusion/exclusion criteria was applied	*Outcome:* PA or obesity rates/risks	*Exposure:* any aspect of the BE	N/A	N/A		Purpose of review was to systematically review literature examining relationship between BE and PA or obesity rates; included any article that focused on the following: any aspect of the BE and any form of PA or direct measures of obesity. >narrow reviews of body weight only, disadvantaged groups, how to best measure BEs Also interested in studies focusing on children, other vulnerable populations, Southern states or benefits of BE gaps in literature Any articles that showed improvements in PA or obesity rates wrt to BE characteristics
Renalds et al. (2010) Systematic Review	>Systematic Review that included 23 articles	*Outcome* (or themes examined): physical activity, obesity and overweight, social capital, mental health	*Exposure*: any BE aspect in title, from 2003 to 2009	N/A	N/A	Generally they found that neighborhoods characterized as more 'walkable', either leisure-oriented or destination-driven, are associated with increased PA, increased social capital, lower overweight, lower reports of depression, and less reported alcohol abuse.	Need for longitudinal studies, and studies concentrated on rural settings rather than urban-only settings (or majority). 2/3 of articles looked at physical activity and obesity.

Brownson et al. (2009) USA Review	>*Three broad types of measures used to measure the built environment and physical activity – objective, perceived and observational (audit) measures *Depending on environmental attributes, you can use different measures (that pertain to age, culture, physical abilities, has to be relevant to populations!*)	NA	*Exposure*: any GIS-derived BE studies, perceived and archival data	NA	NA	NA	Research on improving technical quality of measures is needed; Refers to population density, land-use mix etc, as first-generation BE measures
Lopez et al. (2006) USA Summary	Summary of differences between inner city and suburban populations	Focus is on design and form of suburbs, compared to inner city populations (Suburban compared to Urban)	N/A	N/A	N/A	N/A	N/A

Appendix 2: Activity Space

Individuals travel within and between microenvironments daily, and spend unequal bouts of time in each. One straightforward example is travelling from home to the workplace. Different travel routes between destinations may go across non-residential areas and neighbourhood boundaries, allowing for greater exposure to broader community, organizational and policy-level influences. As such, individual movement between places and through spaces describe an individual's *activity space* or '*local exposure area'*.[150,151]Activity space exposures are largely shaped by land configuration, distribution, design, and structure of the built environment within which daily movements happen.[13] Travel within and between microenvironments confirms that an individual's activity space is not confined to one space. Individual activity space does not have fixed boundaries and therefore, is not limited to only one local exposure area.[1,151] Except for one Canadian study[152] that estimated "activity space foodscape", by observing individual mobility patterns, no other papers in the literature review have assessed for individual activity space or local exposure area.

Appendix 3: Context and Place

Reflecting on the history of human geography helps to understand that society continues to transform the way various geographical spaces are viewed and given meaning to, and the also provides a way to understand how social relationships are built in these spaces. [153,154] Key concepts of place, space, composition, and context must be introduced to understand how the neighbourhood environment can act as a catalyst or hindrance for social interactions between people and their place of residence.

First, concepts of identity, and place and space should be acquainted with. Briefly, identity is related to that which gives meaning to oneself, and in keeping with this idea, places are particular spaces that individuals identify with if they have attached meaning to it. [153,154] For this reason, each space is "intersubjective", that is, it accounts for "material circumstances, social identities, and subjective experiences." [153,154] The next most important terms to understand are composition and context. Composition refers to the number of people in a given place sharing a common societal position (i.e. SES) and context refers to the existing conditions within a place that can affect health.[153,154]

Some contextual drivers of obesity and other health inequalities are specific social aspects of neighbourhood environments (e.g. socio-demographic and cultural factors), which create a distribution of available community resources. Consequently, the availability of community resources can affect human behavioural patterns and predict the likelihood of community health outcomes. This is why it is important to acknowledge social environmental conditions in a given setting. One Canadian study found that Albertans relied heavily on cars for transportation, however a closer look at the context of their transportation behaviours showed that Alberta had a poorly developed transit system. The results of this study well demonstrated the critical role of context on walking behaviours and use of public transportation.[46]

Another Canadian study[152] recognized the absence of the role of contextual factors in the built environment literature and lack of consensus for measuring them spatially within local areas. To address these gaps and demonstrate the importance of context, the study used multilevel modelling to assess whether risks of overweight and obesity varied as a "function of composition (characteristics of individuals within areas) and context (characteristics of the areas themselves)", and found statistically significant differences between built and social environmental indicators on overweight in both major cities, by sex.[152] In Montreal, centrality and social diversity were significantly associated with overweight in men, with stronger relationships between social diversity and overweight (i.e. a 1-SD increase in social diversity was associated with a 35% decrease in the odds of being overweight). In contrast, financial insecurity was the only indicator significantly associated with overweight in women from Quebec City.[152] Individual-level SES factors explained most of the variance in overweight men and women in Montreal but not for men and women in Quebec City. [152] These regional differences suggested that the latter population might be more homogeneous with respect to SES and that contextual factors on overweight were found to significantly differ between Montreal and Quebec City. [152] The greater proportion of regional distributions of overweight could have also been explained by residential-area characteristics. [152]

Appendix 4: Lack of Consideration of Context

The discussion on context and place brings forward the "uncertain geographic context problem", which is the lack of consideration of spatial and temporal uncertainty when relationships between contextual influences and health outcomes are studied.[155,156] The former refers to the uncertainty of spatial configuration that the area under study can be mapped out precisely in geographic space and perfectly distributed in reality, which no spatial data are, while the latter refers to the uncertainty about the time and duration of the exposure to contextual influences.[155,156] There are strategies available that address issues of uncertainty for spatial data sets, however their application is less feasible.[155,156]

The issue of uncertainty in addition to a partial understanding of geographical boundaries and spatial configuration restricts health researchers in their ability to identify the "true causally relevant" geographic context.[155,156,41,157,158] To deal with the uncertainty problem in studies, health researchers use areal units such as census tracts, postal codes, and other buffer zones as artificial boundaries to provide a somewhat meaningfully defined area within which demographic, socioeconomic and health data can be measured, since they cannot be measured at a particular point.[41,157,158]This relates to the modifiable areal unit problem (MAUP), which is when the areal unit of analysis changes, relationships between the exposure and outcome variables change; this is concerning for the reliability of results.[41,157,158]

Appendix 5: Boundaries for Geographical Spaces

As implicated in the section above, neighbourhoods are contextual areas defined by different geographical scales or boundaries that envelope social, spatial, statistical, and perceptual dimensions.[54] This section is going to discuss commonly used operational definitions for 'neighbourhoods' in the built environment literature.

First, neighbourhoods are commonly defined by *buffer zones*, which are pre-specified regions, measured in units of distance, surrounding an individual's household address or location of residence.[159] Often, measures of urban forms are calculated under the same given scale of measurement for the target area. There are different methods to construct buffer zones, but essentially, their wider purpose is to track individual movement in the selected space nearby the individual's place of residence.

Circular buffers are geographical spaces whose radii begin at a particular point or centroid (usually from a postal code or street address) and extend outward to represent a circular space; the extent of the radii represents the distance to the outward-most limit within which an individuals' movement can be observed. [41] Polygon-based road network buffers are the different 1-km paths that can be used as routes by individuals to travel from home to their destination. [41] Similarly, line-based network buffers represent the space accessible to individual's surrounding their homes.[41] For all of these, relationships between the built environment and human behaviour can be analyzed within varying distances (e.g. 400m, 500m, 800m, 1000m, 1600m). Other geographical boundaries that are widely used include airline (or Euclidean) buffers, transportation zones, local areas, administrative or pre-defined areas (i.e. census tracts, census block, measured objectively (directly) and indirectly (perceived or subjective).[10,41]

It is useful to use circular or network buffers if individuals are residing closer by to central business and commercial urban areas than individuals who live further away since there are more destinations located within urban regions than beyond. Often in existing research, the challenge with buffer selection has to do with adequate representation of neighbourhood spaces and environmental exposures, so that they can reflect an individual's activity space. The issue is that individual's activity spaces may actually exist beyond the neighbourhood. Elipse-shaped buffers may be advantageous for tracking individuals' activity space; like circular buffers, they begin at a centroid point or residential address, and are long-drawn-out; their shape can makes it possible to capture a greater concentration surrounding environmental exposures and individual's in-motion.[160] Within ellipse-shaped buffer regions, neighbourhood exposures within these spaces would be more relevant to individuals than to a cluster of households in a pre-defined residential area.[160]

Appendix 6: Social Capital

In the context of a neighbourhood environment, the literature explains that adult residents particularly value social capital because it affects their perceptions of the neighbourhood environment.[161] Often, higher social capital improves social interactions within neighbourhood settings. Social interaction is viewed as a motivating factor for adults because it pushes them to participate in neighbourhood-based physical activities such as walking. One activity that subscribes to greater social capital in a neighbourhood is for example, the development of a community program to increase awareness of healthy lifestyles, and benefits of healthy eating and physical activity.[140] Such a program would facilitate the sharing of resources between neighbours through social bonding. In this regard, social capital becomes a community resource that is fostered by levels of interpersonal trust and cooperation between neighbours. Social capital belongs uniquely to a given neighbourhood due to its social composition, which suggests that social capital may be a contextual influence of the neighbourhood environment on health outcomes.[140] A number of papers have hypothesized moderating effects of social capital on obesity prevalence in neighbourhoods without formal hypothesis testing. For future studies, social capital is an area requiring further investigation.

Appendix 7: RDC Proposal

1. **Project title:**
   Longitudinal associations between Neighborhood Walkability, Physical Activity and Obesity in Urban Canada

2. **Rationale and objectives of the study:**
   A number of studies have investigated the risk factors for obesity in Canada. These studies conclude that obesity is influenced by individual, behavioral, social, and built environment factors (PHAC, 2011). A growing body of cross-sectional literature suggests association between walkability and obesity even after controlling for physical activity, diet and socioeconomic variables. The majority of Canadian studies have examined relationships between a number of built environment metrics and physical activity and/or overweight/obesity using cross-sectional data from the Canadian Community Health Survey (CCHS) (Pouliou et al., 2010; Glazier et al., 2014; Kitchen et al., 2011; Chen et al., 2006; Bryan et al., 2011), along with multi-level modeling or logistic or mixed methods (Prince et al., 2011; Seliske et al.,2012; Lebel et al., 2011; Mansfield et al., 2012). Only one Canadian study used Statistics Canada's National Population Health Survey (NPHS) data to explore the longitudinal relationship between physical activity and BMI among Canadian adults (Sarma et al., 2014), and another study considered the role of social environmental factors (e.g.

Pouliou et al., (2010)). However, none have studied the association between the walkability and obesity using longitudinal data.

One systematic review suggested that the built environment may channel its effects on obesity through physical activity (Papas et al., 2007). Another recommended identifying mediators in the causal pathways linking the built environment features and obesity (Feng et al., 2010). One prospective study suggested that certain risk factors of obesity, such as physical inactivity, may mediate rather than confound effects of the built environment (Sarkar et al., 2013).

This project will address a number of gaps identified in the existing literature. It will investigate the relationship between walkability and physical activity as a first step in analyzing the potential causal association between walkability and obesity, and subsequently examine the relationship between physical activity and obesity. Drawing insights from the previous literature (e.g., Glazier et al., (2014)), this project will also analyze the longitudinal effect of each of the individual components of walkability (such as intersection density, population density, street connectivity and land use entropy index) on physical activity as well as the combined effect of multiple measures through the walkability index. The effect of social environmental factors available in the NPHS data set will also be considered since little is known about the role of these factors in Canadian populations (Prince et al., 2012). In summary, this study aims to examine the association between walkability and obesity longitudinally and determine the potential mediatory role of physical activity in the causal relationship while adjusting for known confounders.

Research Objectives

The purpose of this project is to examine the association between neighborhood walkability and adult BMI in Urban Canada. <u>The study will address the following objectives:</u>

Objective 1: To examine the association between neighborhood walkability and adult BMI in Urban Canada.

- ***Hypothesis 1:*** Less walkable neighborhoods may be associated with a decrease in physical activity among adults.
- ***Hypothesis 2:*** Decreased physical activity may be associated with an increase in adult BMI.
- ***Hypothesis 3:*** Less walkable neighbourhoods is associated with an increase in adult BMI.
- ***Hypothesis 4:*** Physical activity may mediate the relationship between neighborhood walkability and adult BMI.

- ***Hypothesis:*** The effect of neighborhood walkability on adult obesity will vary by neighborhood social capital.

3. Proposed data analysis and software requirements:

Objective 2: To determine the interaction of the social environment and neighborhood walkability that influence obesity risks

The data analysis will be conducted using Stata and walkability measures constructed from the DMTI built environment data for years 2001, 2006, and 2011. NPHS longitudinal data from 2000/01 to 2010/2011 will be linked with the DMTI built environment data sets to be able to carry out longitudinal analyses. The linkage will be performed at the Dissemination area (DA) level for the NPHS respondents aged 18 to 53 years of age in 2000/01 across urban jurisdictions in ten provinces. Longitudinal weights will be applied to all descriptive and regression analyses and only aggregate statistical results of the analysis will be requested for release.

The data analysis will involve three steps. The first step will be a univariate analysis of the built environment exposure variables, and demographics and socioeconomic characteristics of the respondents (e.g. household income levels, education status, etc.). Bivariate analyses will also be carried out to determine associations between exposure variables and outcomes. For continuous variables, descriptive data will be presented using means and standard deviations and for categorical variables, descriptive data will be presented using proportions and percentages. Results submitted will be subjected to appropriate sample size restrictions.

Following descriptive analyses, the second step of the data analysis will be carried out by examining changes in physical activity among the same respondents due to changes in walkability index and of intersection density, population density, and entropy index separately. This part of the analysis will use longitudinal methods, such as random-effects and fixed-effects modeling approaches. As well, changes in BMI will be examined among the same respondents due to changes in physical activity levels, using similar longitudinal methods. Alternative longitudinal statistical methods may be considered following the suggestion of my thesis committee. The third part of the analysis will examine the main effect of walkability on obesity using longitudinal methods.

3. Data Requirements:

I am requesting access to the confidential Master Data File for years 2000/2001 to 2010/2011 of the NPHS household component. Note that NPHS longitudinal data is not available as a Public Use Microdata File and can only be accessed at the RDC. The NPHS contains questions on the same individuals in the respective years on obesity, general health, and work-related and leisure time physical activities, as well as socio-demographic information.

Population of Interest

The population of interest in the study includes NPHS respondents aged 18 to 53 years in Canada in 2000/2001. They will be followed until 2010/2011.

Variables

Exposure: Walkability (measured by an index consisting of Intersection density, Population density, and Land use entropy index), and by each of these components separately.

Briefly, walkability is defined as “the extent to which the built environment facilitates or hinders walking for purposes of daily living” (Andrews et al., 2012). Commonly used metrics in the built environment literature used to construct walkability indices include intersection density, street connectivity, population density, and land use mix. The land use entropy index is a measure of mixed or diverse land uses are characterized as being supportive for walking or pedestrian friendly (Brownson et al., 2009). Operationalization of this measure in our project will be that used by Frank, Andresen and Schmid (2004), ranging from zero, indicative of single-land use, to one, indicative of an equal distribution, of square footage across all four land uses (residential, commercial, office, and institutional) with a number of destinations within walking distance (Frank et al., 2004).

Outcomes: Physical Activity, Body Mass Index (BMI) and Obesity

A number of variables have been identified from the respective years of the DMTI built environment data, at the DA level to meet the objectives of the study. Table 1 below lists the main built environment variables of interest (i.e. exposure variables). These components of the built environment will be examined separately and in a combined walkability index. A number of variables have been identified from the respective years of the NPHS data to meet the objectives of the study. Table 2 below lists dependent and explanatory variables of interest. NPHS respondents will be linked to the DMTI built environment data at the DA level.

Table 7: DMTI Variables

Variable Name	Description
DA_Entropy	Land use entropy index for dissemination areas
DA_P_Comm	Dissemination area portion of Commercial lands (in sq km)
DA_P_Indy	Dissemination area portion of Resource and Industrial lands (in sq km)
DA_P_Instit	Dissemination area portion of Gov't and Institutional lands (in sq km)
DA_P_Open	Dissemination area portion of Open space (in sq km)
DA_P_Park	Dissemination area portion of Park lands (in sq km)
DA_P_Res	Dissemination area portion of Residential lands (in sq km)
Int_Count	Intersection count
Int_Densit	Intersection density (in sq km)
Pop_Densit	Population density (in sq km, based on census data)
Z_Val_Comm	Entropy z-value for Commercial land use
Z-Val_Indy	Entropy z-value for Industrial land use
Z_Val_Open	Entropy z-value for Open Space land use
Z_Val_Park	Entropy z-value for Park land use
Z_Val_Res	Entropy z-value for Residential land use

Table 8: NPHS Variables

Theme	Derived Variable Description	Variable Name
Constant Longitudinal Variables	Age	DHCD_AGE
	Sex	SEX
	Immigration Status	IMM
Alcohol Consumption	Type of Drinker	ALCnDTYP
	Weekly Alcohol Consumption	ALCnDWKY
	Average Daily Alcohol Consumption	ALCnDDLY
Chronic Conditions	Number of Chronic Conditions	CCCnDNUM
	Has a Chronic Condition	CCCnDANY
Household Demographics	Kind of Pet	DH_nDP2
	Household Size	DHCnDHSZ
	Number of Persons Less than 25 Years Old in Household	DHCnDL25
	Number of Persons Less than 12 Years Old in Household	DHCnDL12
	Number of Persons 12 Years Old in Household	DHCnDE12
	Number of Persons 5 Years Old or Less	DHCnDLE5
	Number of Persons 6 to 11 Years Old in Household	DHCnD611
	Age - Grouped	DHCnGAGE
	Household Type	DHCnDECF
	Living Arrangement of the Selected Respondent	DHCnDLVG
Labor Status	Current Working Status	LSCnDCWS
	Working Status in the last 12 months	LSCnDYWS
	Work status - full time or part time (for total usual hours)	LSCnDPFT
	Multiple job status	LSCnDMJS
Nutrition	Total Daily Consumption of Fruits and Vegetables	FV_nDTOT
Physical Activities	Energy Expenditure	PACnDEE
	Participant in Leisure Physical Activity	PACnDLEI
	Monthly Frequency of Physical Activity Lasting More than 15 Minutes	PACnDFM
	Frequency of All Physical Activities LastingMore than 15 Minutes	PACnDFR
	Participation inDaily Physical Activities Lasting MoreThan 15 Minutes	PACnDFD
	Physical Activity Index	PACnDPAI
Sociodemographic	Cultural or Racial Origin	SDCnDRAC

Smoking	Type of Smoker	SMCnDTYP
	Number of Years Smoked	SMCnDYRS
Social Support	Perceived Social Support Index	SSCnD1
	Social Involvement Dimension	SSCnD2
	Positive Social Interaction – MOS Subscale	SSCnDSOC
Income	Distribution of Household Income - Provincial Level	INCnDRPR
Height and Weight	Body Mass Index	HWCnDBMI
Education	Highest Level of Education – Respondent, 4 Levels	EDCnD3
Health Status	Health Utility Index 3 – HUI3	HSCnDHSI
Theme	**Data Dictionary or Household Questionnaire**	**Variable Name**
Physical Activity	Number of hours walking to work or to school	PACD_4A
	Number of hours biking to work or to school	PACD_4B
	Best description of usual daily activities or work habits (work-related physical activity)	PACD_6
Household Record Variables	Marital Status	DHCD_MAR
	Age (age is calculated and confirmed with the respondent)	DHCD_AGE
Neighborhood Aesthetics/Physical disorder	Stress (ongoing) – neighbourhood too noisy or polluted	STCD_C15
Walking	Activity in last 3 months - walking for exercise (Have you done any of the following in the past 3 months? - Walking for exercise)	PAC4_1A
	No. of times participated - walking for exercise	PAC4_2A
	Time spent – walking for exercise	PAC4_3A
Pet	Is there a pet in this household?	DH_4_P1
	Kind of pet (to ask about dog ownership)	DH_4DP2
Number of licensed drivers	Has a valid driver's license for a motor vehicle (Do you have a valid driver's license for a motor vehicle? Includes cars, vans, trucks, motorcycles)?	RSS6_4
Perceived Safety	Frequency of feeling safe in community	VSP6_1
	Frequency of feeling safe at home	VSP6_2

Participation in organizations	Member of organization or association	SSC4_1
	Frequency of participation in organizations	SSC4_2
Health Status	Health Description Index – Self-rated health	GHC4DHDI
Period of arrival in Canada	Year of immigration to Canada	SOCIO-Q3

4. **Expected project start and end dates:**
   This project is expected to start in September following approval and continue until August 31st, 2015.

5. **Expected Projects:**
   The final expected products are as follows:
   1. 1-2 journal articles
   2. Poster and Oral Presentations at academic conferences

Table 9: Leisure-time Physical Activities from the NPHS, Cycle 9

Activity	**MET Value**
Walking for exercise	3
Gardening or yard work	3
Swimming	3
Bicycling	4
Popular or social dance	3
Home exercises	3
Ice hockey	6
Ice skating	4
In-line skating or rollerblading	5
Jogging or running	9.5
Golfing	4
Exercise class or aerobics	4
Downhill skiing or snowboard	4
Bowling	2
Baseball or softball	3
Tennis	4
Weight-training	3
Fishing	3
Volleyball	5
Basketball	6
Any Other	4
No Physical Activity	0

Curriculum Vitae

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EDUCATION

The University of Western Ontario, London ON, Canada 2013 – 2015

Masters of Science (Epidemiology & Biostatistics)

University of Waterloo, Waterloo, ON, Canada 2007 - 2013

Bachelor of Science (Health Studies),
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RELEVANT WORK EXPERIENCE

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Clinical Research Assistant, Aging Rehabilitation & Geriatric Care

HONOURS AND AWARDS

Province of Ontario Graduate Scholarship 2014 - 2015

Western Graduate Research Scholarship 2013 - 2015

PUBLICATIONS

Shavadia, J., Yonga, G., Mwanzi, S., Jinah, A., Moriasi A., Otieno H.. Clinical characteristics and outcomes of atrial fibrillation and flutter at the Aga Khan University Hospital, Nairobi. *Cardiovascular Journal of Africa*. **24,** 6–9 (2013).

PRESENTATIONS

Ashna Jinah, Dr. Karen Campbell, Dr. Jason Gilliland, Dr. Sisira Sarma. *Does Physical Activity Mediate an Association between Neighbourhood Walkability and Adult Obesity in Canada? An Analysis from the National Population Health Survey in 2010/11.*

- Canadian Society of Epidemiology & Biostatistics. Poster Presentation.
- Association for Public Health Epidemiologist Conference, Delta London Armouries, London, Ontario, June 14 – 16, 2015 Poster Presentation.
- Canadian Conference on Global Health, Hotel Bonaventure, Montreal, Quebec, November 5 – 7, 2015. Poster Presentation.