

The Influence of the Urban Built Environment on Utilitarian Walking
and Body Mass Index: Trip Diary and Longitudinal Studies of
Canadians

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ABSTRACT

There is growing interest in developing livable cities with neighbourhoods that encourage active living. The urban built environment including land use, amenities and transportation systems is increasingly expected to provide a variety of benefits including neighborhood walking-friendliness. To date, there have been few long term studies with large population samples that have assessed the relationships between walking-friendliness of places and the level of utilitarian walking (i.e., walking for a specific purpose such as to go to work or to school) in people. Most research to date has relied on cross-sectional study designs and the conclusions of many existing studies are invariably limited owing to problems of self-selection of motivated walkers into walking-friendly neighbourhoods. This dissertation addresses some of the methodological limitations in this research area by measuring utilitarian walking using geographic information system-based estimates in a cross-sectional approach, and by geocoding respondents of a population-based longitudinal survey for quasi-experimental designs to assess the role of urban built environments on utilitarian walking and body weight. My dissertation has produced three key findings:

1. Montreal residents were able to achieve the recommended 30 minutes of physical activity each working day by commuting to work using public transportation. This benefit was greatest for suburban residents who walked approximately 35 to 50 minutes per day to and from commuter train stations, the majority of whom were affluent. Transportation system characteristics had greater influences on walking to public transport than did neighbourhood physical characteristics.
2. Canadians who were exposed over time to highly walkable urban neighbourhoods were more likely to engage in moderate and high utilitarian walking than Canadians with less exposure to highly walkable neighbourhoods. A unit increase in the probability of

spending more time in the fourth Walk Score® quartile neighborhoods increased the probability of moderate (increase of 4.0%, 95% C.I. 2.9%, 5.1%) and high utilitarian walking (increase of 7.7%, 95% C.I. 5.8%, 9.7%) compared to those spending the same time in low walkable neighbourhoods (first Walk Score® quartile neighbourhoods). Canadians who moved from neighbourhoods that were less walking-friendly to neighbourhoods of a higher walkability, were 59% (95% CI 3 %-146%) more likely to increase their utilitarian walking than those who moved to neighbourhoods with a similar walkability level.

3. Trajectories of body mass index (BMI - a measure of body weight adjusted for height) of Canadian men varied according to the friendliness of the urban built environment for walking, even after controlling for individual characteristics that influence body weight. Moving to more walkable neighbourhoods (2 Walk Score® quartiles higher), was associated with approximately a one unit (kg/m^2) decrease in BMI for men (95% C.I. - 1.7,-0.3). There was no detectable influence of neighbourhood walkability on body weight for women.

Improving public transport service reliability and neighbourhood walkability have potential to increase utilitarian walking and decrease body mass index in populations, even for those who are otherwise inactive in their leisure time. Planning to construct walkable communities supported by reliable public transport should be considered among public health policies to promote utilitarian walking and reduce overweight and obesity.

RÉSUMÉ

L'intérêt pour le développement de quartiers urbains viables encourageant une vie active va grandissant. On s'attend de plus en plus à ce que l'environnement bâti urbain, qui inclut l'utilisation du terrain, les services et les systèmes de transport, offre une variété d'avantages incluant la marche conviviale du quartier. À ce jour, peu d'études à long terme sur de vastes échantillons de population ont évalué le lien entre la possibilité de marche conviviale des lieux et le niveau de marche à des fins utilitaires (c.-à-d. marcher pour une raison particulière comme aller au travail ou à l'école). La plupart des recherches menées à ce jour reposent sur des études transversales. Les conclusions de plusieurs études existantes sont quant à elles invariablement limitées en raison de l'auto sélection de marcheurs motivés dans des quartiers propices à la marche. Cette thèse aborde certaines des limites méthodologiques dans ce domaine de recherche, en mesurant la marche à des fins utilitaires en utilisant des estimations basées sur l'information géographique dans une technique transversale, et par géocodage des répondants d'une étude longitudinale représentative de la population pour un modèle quasi-expérimental afin d'évaluer le rôle de l'environnement bâti urbain sur la marche à des fins utilitaires et le poids corporel. Ma thèse a tiré trois conclusions principales:

1. Les Montréalais ont réussi à atteindre les 30 minutes recommandées d'activité physique chaque jour de travail en utilisant les transports en commun pour s'y rendre. Ceux qui en ont tiré le plus d'avantages sont les résidents de banlieue qui marchaient de 35 à 50 minutes par jour à destination et en provenance des stations de train. Les caractéristiques du système de transport ont eu plus d'influence sur le fait de marcher vers le transport en commun que les caractéristiques physiques du quartier.
2. Sur la durée, les Canadiens vivant dans des quartiers urbains très propices à la marche étaient plus susceptibles de marcher à des fins utilitaires à intensité modérée à élevée que les Canadiens vivant dans des quartiers moins propices à la marche. Une

augmentation d'unité dans la probabilité de passer plus de temps dans les quartiers du quatrième quartile Walk Score® augmentait la probabilité de marche à des fins utilitaires modérée (augmentation de 4 %, 95 % I.C. 2,9 %, 5,1 %) et élevée (augmentation de 7,7 %, 95 % I.C. 5,8 %, 9,7 %) par rapport à ceux qui ont passé le même temps dans des quartiers peu propices à la marche (quartiers du premier quartile Walk Score®). Les Canadiens ayant déménagé de quartiers moins propices à des quartiers plus propices ont été plus susceptibles à 59 % (95 % I.C. 3 %-146 %) d'augmenter leur marche à des fins utilitaires par rapport à ceux qui ont déménagé dans des quartiers ayant un potentiel piétonnier similaire.

3. Les trajectoires de l'indice de masse corporelle (mesure du poids corporel ajusté à la taille) des hommes canadiens ont varié selon la convivialité de l'environnement urbain bâti pour la marche, même en tenant compte des caractéristiques individuelles ayant une influence sur le poids corporel. Le fait de déménager dans un quartier propice à la marche (2 quartiles Walk Score® plus haut), était approximativement associé à une unité (kg/m^2) de baisse de l'IMC chez les hommes (95 % I.C. -1,7, -0,3). Le potentiel piétonnier d'un quartier n'avait pas d'influence décelable sur le poids corporel chez les femmes.

L'amélioration de la fiabilité du transport en commun et le potentiel piétonnier d'un quartier peuvent faire augmenter la marche à des fins utilitaires et diminuer l'IMC des populations, même chez ceux qui sont inactifs dans leur temps de loisirs. Prévoir la construction de communautés propices à la marche en combinaison avec à un transport en commun fiable devrait être pris en considération dans les politiques de santé publique afin de promouvoir la marche à des fins utilitaires et de réduire l'embonpoint et l'obésité.

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AUTHOR CONTRIBUTIONS

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Chapter Three “Achieving Recommended Physical Activity Levels through Public Transportation Use: Unpacking Individual and Contextual Effects” by Rania Wasfi, Nancy Ross and Ahmed El-Geneidy. Rania Wasfi was the primary author of the manuscript. She performed all of the statistical analysis, interpretation of the results, and writing. Prof. Ross and Prof. El-Geneidy contributed intellectually and provided comments and edits on the manuscript. Access of the Origin Destination survey used in the analysis, came through a special agreement between Agence métropolitaine de transport (AMT) and Prof. El-Geneidy.

Chapter Four “Exposure to Walkable Neighbourhoods in Urban Areas Increases Utilitarian Walking: Longitudinal Study of Canadians” by Rania Wasfi, Kaberi Dasgupta, Naveen Eluru and Nancy Ross. Rania Wasfi was the primary author of the manuscript. She performed all of the spatial and statistical analysis, interpretation of the results, and writing. Prof. Dasgupta, Prof. Eluru, and Prof. Ross contributed intellectually and provided comments and edits on the manuscript.

Chapter Five “BMI Trajectories and Neighbourhoods Walkability: Longitudinal Study of Canadians” by Rania Wasfi, Kaberi Dasgupta, Heather Orpana and Nancy Ross. Rania Wasfi was the primary author of the manuscript. She performed all of the spatial and

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PUBLICATION DETAILS AND PERMISSIONS

Chapter Three “Achieving Recommended Physical Activity Levels through Public Transportation Use: Unpacking Individual and Contextual Effects” is reprinted from *Health and Place*, with permission from Elsevier. Wasfi, R, Ross, NA, and El-Geneidy, A (2013). “Achieving recommended daily physical activity levels through commuting by public transportation: Unpacking individual and contextual influences”. *Health and Place* 23: 18-25. doi:10.1016/j.healthplace.2013.04.006.

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Chapter Five “Body Mass Index Trajectories and Neighbourhood Walkability: Longitudinal Study of Canadians” is under review in the *American Journal of Public Health*.

DISCLAIMER

While the research and analysis of the second and third manuscripts of this dissertation are based on data from Statistics Canada, the opinions expressed in them do not represent the views of Statistics Canada.

TERMS THAT WILL BE USED INTERCHANGEABLY

- Active transport, active transportation, utilitarian walking, walking for transport and travel behaviour.
- Neighbourhood walking-friendliness and neighbourhood walkability
- Urban planning, and land use and transportation planning
- Cohort studies and longitudinal studies
- Trajectory analysis, growth curve models, and random coefficient regression models
- Low walkable neighbourhood, totally car dependent neighbourhood and first Walk Score® quartile neighbourhood (WSQ1).
- Low-medium walkable neighbourhoods, some-what car dependent neighbourhood, and second Walk Score® quartile neighbourhood (WSQ2).
- Medium-high walkable neighbourhoods, some-what walkable neighbourhood and third Walk Score® quartile neighbourhood (WSQ3).
- Highly walkable neighbourhoods and fourth Walk Score® quartile neighbourhood (WSQ4).

1 CHAPTER ONE: DISSERTATION INTRODUCTION AND OBJECTIVES

1.1 OVERVIEW

The purpose of this dissertation is to contribute to our understanding of the influence of urban built environments on utilitarian walking (i.e., walking for a specific purpose like to go to work or school or to run an errand) and body weight (measured by the body mass index (BMI)). Urban built environment is understood in this thesis to mean physical features of urban neighbourhoods such as diversity of land use, access to amenities like public transportation and, principally, how walking-friendly or ‘walkable’ an urban neighbourhood is as measured by summary scores of these features. There is growing interest from many academic fields in the ways in which cities might be planned in order to improve the health of populations.

Previous studies do signal associations between the built environment and the likelihood of walking for utilitarian purposes; however, research in this area has been plagued by problems of causal attribution from an almost exclusive reliance on cross-sectional study designs and on self-reported outcome measures. These limitations often mean that studies suffer from over/under estimations of the true influence of the built environment on behavioural outcomes. This thesis attempts to overcome some of these methodological deficits by capturing utilitarian walking using Geographic Information System (GIS)-based estimates in a cross-sectional approach (Chapter 3) and by geocoding respondents of a population-based longitudinal survey for quasi-experiments of the roles of urban built environments on utilitarian walking (Chapter 4) and body weight (Chapter 5).

This thesis has three objectives, all of which are informed by an over-arching hypothesis that urban environments that are more supportive of walking are associated with higher levels of utilitarian walking and lower body mass index.

1) To estimate the levels and determinants of utilitarian walking involved in commuting by public transportation in Montreal, Quebec, Canada. This objective was achieved by an approach that geocoded home addresses of 6,913 respondents from a trip diary (the Origin-Destination Survey) conducted by the Agence métropolitaine de transport in Montreal. Geocoded home addresses and measured distances to nearest public transportation stops allowed for a measured (objective) estimate of walked distances. These measured distances then served as outcome variables in multilevel regression analyses of individual and urban neighbourhood determinants of utilitarian walking.

2. To determine the influence of exposure to walkable neighbourhoods on utilitarian walking. This objective was achieved through geocoding postal codes of 2,976 working-age urban respondents from the Canada's National Population Health Survey (NPHS) to assess the impacts of their long term exposure to various levels of walking-friendliness or 'walkability' of their neighbourhood environment. The primary outcome of interest for this objective was self-reported levels of utilitarian walking, measured every two years, over 12 years of follow-up. Walkability of urban neighbourhood environments was principally measured using the proprietary Walk Score®, which was determined to be strongly correlated with measures of street connectivity and land use mix over time. The NPHS also measured important individual covariates of utilitarian walking (age, sex, education level, leisure time physical activity, immigrant status and self-perceived health), which were included in a multivariate longitudinal model that accounted for the within-individual clustering of the repeated measures. NPHS respondents who moved over the follow-up

period were particularly interesting in that they allowed for a quasi-experiment of changes in utilitarian walking associated with changes in exposures to different levels of walkability.

3. To understand the role of the urban built environment on the body mass index (BMI) trajectories of urban Canadians. This objective was also achieved using the geocoded respondents to the NPHS. Heights and weights of the 2,943 working-age urban respondents were reported bi-annually over the follow-up period and converted to BMI (weight in kilograms divided by height in meters squared). Longitudinal trajectories of BMI were estimated for men and women separately (owing to the different determinants of BMI by sex), while accounting for known individual-level covariates of BMI (age, sex, education, smoking, marital status, immigrant status, leisure time and utilitarian walking). BMI trajectories for individuals who moved during the follow-up period were of particular interest within this objective as they allowed for a quasi-experiment of body mass changes in response to documented changes in environmental exposures.

1.2 BACKGROUND

The World Health Organization (WHO) identified transportation among the top ten social determinants of health (Commission on social determinants of health, 2008; Wilkinson & Marmot, 2003). In particular, the WHO was referring to “healthy transport”, defined as less driving with more utilitarian walking and bicycling, supported by public transportation. Healthy transport is also referred to as active transportation, which promotes health in four ways: it reduces air pollution; increases social contacts; reduces fatal accidents through decreasing the number of vehicles on the road; and provides an opportunity to be physically active (Sallis, Frank, Saelens, Kraft, & Engelke, 2004; Transport Canada, 2005; Wilkinson & Marmot, 2003).

The heavy dependence on single occupancy vehicles in North America and perceived lack of adequate time for physical activity is thought to contribute to poorer mental and physical health as well as development of chronic disease (Berke, Gottlieb, Vernez Moudon, & Larson, 2007; Jakicic & Gallagher, 2003; Wei et al., 1999b). Physical activity is known to reduce the risk of several health conditions including obesity, osteoarthritis, some types of cancers, and cardiovascular diseases and related risk factors including hypertension and diabetes (Jakicic & Gallagher, 2003). Individuals who engage regularly in physical activity with at least moderate energy expenditure have lower odds of reporting health problems such as heart disease or depression compared to those who are less active (Chen & Miller, 1999). La Monte, Blair and Church (2005) furthermore suggest that high levels of physical activity can protect individuals from premature mortality, even if they are overweight or obese and already diagnosed with a chronic disease, such as diabetes.

Research suggests that the way our modern societies are structured promotes sedentary life-styles (Egger & Swinburn, 1997) — a pattern of daily living that requires only a minimum amount of physical effort— which contributes to population-wide reductions in physical activity. According to the WHO (2003), at least 60% of the global population fails to achieve the minimum recommendations of 30 minutes of daily moderate physical activity. More than 40% of adults in high income countries were insufficiently active, based on the new physical activity guidelines recommendation (150 minutes of weekly moderate physical activity, which is equivalent to 30 minutes of daily moderate physical activity, 5 days a week) (World Health Organization, 2011). Here in Canada, fully two thirds of us are not meeting the recommended (Public Health Agency of Canada, 2008) minutes of moderate physical activity (Sari, 2009).

Prevalence of overweight and obesity is increasing rapidly around the world in both developing and developed countries, including Canada (Huot, Paradis, & Ledoux, 2004;

Katzmarzyk & Ardern, 2004; S. Macdonald, Reeder, Chen, & Despres, 1997; Torrance, Hooper, & Reeder, 2002; Tremblay, Katzmarzyk, & Willms, 2002) and this increase has been linked to a decline in physical activity (Jakicic & Gallagher, 2003). The prevalence of combined overweight and obesity in Canada increased from 48% to 57% among men and from 30% to 35% among women during the 15 years between 1981 and 1996 (Tremblay et al., 2002). Twenty five percent of Canadians who had been overweight in 1994/95 became obese by 2002/03 (Le Petit & Berthelot, 2006). Researchers argue that the cause of the rapid increase in overweight and obesity epidemic is explained by an environment that supports it, rather than a shift in the genetic composition of the population (Egger & Swinburn, 1997; Hill & Peters, 1998; Mackenbach et al., 2014; Poston & Foreyt, 1999). The argument is that environmental factors influence human behaviour, and in turn, human behaviour affects overweight and obesity.

1.3 RESEARCH RATIONALE

The core theoretical rationale for this thesis rests on the balance of historical evidence that public health interventions that have focused on individuals have met with modest success while interventions that have sought to alter environments to improve public health have been comparatively more effective (e.g., sanitation reforms in industrial Britain, British Health Act of 1848, and environmental policies to reduce smoking). Jurisdictions around the world are struggling for any effective policy response to the rise of sedentarism and obesity. Providing a built environment that supports routine physical activity is a conceptually appealing public health approach yet the evidence base to support how effective this type of intervention might be, and for whom it might be most effective, is lacking.

There is also a methodological rationale to this thesis. In Geography (Andrews, Hallb, Evansc, & Colls, 2012; Macintyre & Ellaway, 2003; N. A. Ross et al., 2007), Social

Epidemiology (Diez Roux & Mair, 2010; Feng, Glass, Curriero, Stewart, & Schwartz, 2010; Sallis et al., 2004; Sallis et al., 2009) and Urban Planning (Ewing & Cervero, 2010) there has been an ongoing debate on the role of the environmental factors in shaping health behaviour, in particular how utilitarian walking can affect overall physical activity and its associated health benefits.(e.g., lower body mass index).

The majority of the studies investigating the role of the built environment in shaping utilitarian walking in this field to date have been of cross sectional design (Cervero & Radisch, 1996; Forsyth, Oakes, Schmitz, & Hearst, 2007; Frank, Saelens, Powell, & Chapman, 2007; Handy, 1996b; Hannah & Grant, 2008; G. Hu, Pekkarinen, Hanninen, Tian, & Guo, 2001; Li et al., 2008; Lindström, 2008; Lopez-Zetina, Lee, & Friis, 2006; Smith et al., 2008). In cross sectional studies, information on variables is collected for different subjects (people) at a given point in time. Cohort (or panel) studies collect information about the same group of individuals over time. Cross sectional studies are much more frequently used than cohort studies due to the fact that cohort studies require longer time to collect data, and they are expensive to conduct (Frees, 2004).

Despite the expense and time involved, longitudinal studies have several advantages. First, they take time into consideration, which is an important element in determining causal relationships (Evans, 1995). Second, they allow us to deal with unobserved heterogeneity, where biases generated by time-constant unobserved or omitted variables can be removed. Often times these are variables like motivation, unchanged personal preference, and genetic composition. Longitudinal analysis also allows us to model trajectories, and understand the underlying factors that affect variations in these trajectories (Frees, 2004; Singer & Willet, 2003). Researchers have been recommending the use of longitudinal analysis for the study of a wide range of topics, including, travel behaviour and physical activity (Feng et al., 2010; Handy, 2005), due to these methodological advantages over cross sectional analysis.

1.4 DISSERTATION STRUCTURE AND OVERVIEW OF CHAPTERS

This dissertation is structured to follow McGill University guidelines for a manuscript-based dissertation. Chapter 2 presents the research framework, and a literature review of the current state of research examining the links between the built environment, utilitarian walking, physical activity and body weight of individuals. Chapters 3, 4 and 5 present three manuscripts that correspond to the three research objectives. Each chapter starts with a brief overview outlining the manuscript presented and statements connecting the chapters to the overall thesis. Each manuscript contains a separate introduction and literature review, followed by a methods section that describes the data, study context, and spatial and statistical research methods adopted.

Chapter Three addresses the first objective of this dissertation: To identify the extent to which public transit contributes to daily walking trips for 6,913 transit users in Montreal, Quebec, Canada. This study estimates the amount of daily walking associated with using public transportation in a large metropolitan area and examines individual and contextual factors associated with walking distances. Multilevel regression modelling was used to examine the underlying factors associated with walking to public transportation. Physical activity benefits of public transportation varied along gender and socio-economic lines. Men walked 59.4 meters (95% (C.I. 20.9, 97.9) (0.65 minutes) more than women. Individuals with low household income (less than \$20K) walked 201.51 metres (95% (C.I. -270.89, -132.14) (2.12 minutes) fewer per day than individuals with household incomes \$80K or higher. Recommended minutes of daily physical activity were achieved for public transportation users, especially train users living in affluent suburbs. Each trip taken by a suburban commuter train contributed to daily walking distances of approximately 1319.29 meters (95%

(C.I. 1074.55, 1564.02) (14.47 minutes). Commuter train trips were associated with the maximum walking minutes (34.59 to 49.91 minutes) per day.

Chapter Four addresses the second objective of this dissertation: To determine the influence of exposure to walkable neighbourhoods on utilitarian walking. The objective was achieved through longitudinal analyses of Canada's National Population Health Survey (NPHS), and other supplementary datasets. The analyses gave the opportunity to model utilitarian walking for a Canadian cohort that was followed for 12 years, from 1994 to 2008. The movers in the cohort also allowed for "quasi natural experiments" in that utilitarian walking could be assessed before and after residential relocations. Moderate utilitarian walking increased from 24% to 36% over the study period, with the highest increase (15%) for participants living in the most walkable neighbourhoods. Mixed effects ordered logistic regression was used to model the full range of utilitarian walking levels. Exposure to walkable neighbourhoods increased all levels of utilitarian walking over time and reduced low levels of utilitarian walking. Fixed effects logistic regression was used to model the influence of residential relocation on utilitarian walking. Moving to more walkable neighbourhood increased the odds of moderate and high utilitarian walking by 59% (95% C.I. 3%-140%) compared to other types of residential moves.

Chapter Five addresses the third objective of this dissertation: to understand the role of the urban built environment on BMI trajectories of urban Canadians. A trajectory analysis was conducted to identify the covariates associated with the BMI of Canadians over time. BMI increased annually by 0.13 kg/m^2 (95% C.I. 0.11 0.14). BMI of Canadians varied according to the friendliness of the urban built environment for walking, even after taking into account individual characteristics that influence body weight such as age, sex, education level and overall physical activity. Moving to a high walkable neighbourhood (two or more Walk Score® quartiles higher) decreased male BMI trajectories by approximately 1 kg/m^2

(95% C.I. -1.16, -0.17). Additionally, moving to a low walkable neighbourhood (two or more Walk Score® quartiles lower) increased BMI for men by approximately 0.45 kg/ m²(95% C.I. 0.01, 0.89). Walking 6 or more hours per week for utilitarian purposes decreased BMI for men by approximately 0.1 kg/m² (95% C.I. -0.21, 0.00). A signal of the role of the built environment on BMI for women was not detected. Findings were consistent across random coefficient and fixed effects models, confirming longitudinal associations of neighbourhood walkability with BMI.

Chapter Six concludes the dissertation. It summarizes the findings and contextualizes them in terms of broader research objectives and points to specific substantive, methodological and policy contributions of the thesis.

2 CHAPTER TWO: BACKGROUND AND RESEARCH APPROACH

2.1 OVERVIEW OF CHAPTER

This chapter provides a general literature review for the thesis as a whole. The discussion of background literature in this chapter is meant to be complementary to the work cited in each of the empirical chapters (Chapters 3, 4, and 5). The review starts with a general description of the research approach used in this thesis, followed by a brief description of the conceptual framework employed. The chapter then moves on to a detailed presentation of definitions of the built environment measures that determine neighbourhood walkability. This is followed by a summary of the main findings to date synthesising the different studies that have examined built environment influences on utilitarian walking and body mass index. This section has subheadings to divide the discussion between prior cross-sectional studies and those that are longitudinal, the latter being arguably more compelling. Given that the manuscripts were maintained in their original format for the dissertation, there is some overlap in the conceptual materials reviewed in this chapter and those in the manuscripts. This chapter ends by concluding that there has been substantial research in the domains covered by this thesis yet the evidence is often conflicting with non-trivial methodological gaps.

2.2 RESEARCH APPROACH

This thesis borrows conceptual pieces from the academic disciplines of Health Geography, Social Epidemiology and Urban Planning which share theoretical and methodological approaches. The most important unifying factor, and the basis for this research, is that human behaviour (including travel behaviour) and health outcomes are

determined not only by individual characteristics, but also by the environments to which one is exposed over one's lifetime.

Health Geography is a sub-discipline of Human Geography, which studies the interaction between people and the environment. This field adopts a holistic approach, encompassing the influence of society and place (e.g., studying effects of neighbourhood characteristics' on health outcomes) on human health (Meade & Earickson, 2000). In this context, health is considered a function of both individual characteristics (compositional factors) and of the environment or neighbourhoods in which we live and work (contextual factors). Individual characteristics might include attributes like age, sex, level of education, income, smoking, and genetic make-up. Contextual factors might include aspects of the social environment (e.g., social cohesion of places) and the physical (built) environment (e.g., neighbourhood walkability and accessibility to public transit) (Kawachi & Berkman, 2003). Health Geography acknowledges the role of both composition and context on human health but does emphasize contextual factors with the thinking that policies that are directed at changing environments may be more influential on improving the health of large groups of people.

Social Epidemiology is defined as “ the branch of epidemiology that studies the social distribution and social determinants of states of health” (Berkman & Kawachi, 2000, p. 6). *Social determinants of health* are basically the social factors that determine health inequities between or within different jurisdictions (nations, cities, neighbourhoods). The conditions in which people are born, grow, live, work and age contribute to these health inequities. These conditions are formed based on the allocation of money, power and resources, and are influenced by policies at different structural and organizational levels. Like *Health Geography*, *Social Epidemiology* tends to emphasize what might be understood as contextual features of places but perhaps there is a greater emphasis in *Social Epidemiology* on the

inequitable distribution of power, including that shaped by race and ethnicity, than there has traditionally been in *Health Geography*. Admittedly though, the two research areas have much in common and a contemporary read of scientific journals like *Health and Place* or *Social Science and Medicine*, for example, would reveal many papers that could likely be classified as originating in either sub discipline.

Urban Planning is a discipline that studies the process of organizing urban space; assigning the use of land including transportation infrastructure. Land-use planning is a branch of urban planning that regulates the use of land in an ethical and efficient manner. Previous research has signalled a relationship between neighbourhoods we live in — which are to a great extent shaped by land-use and transportation policies — and our travel behaviour (Badland & Schofield, 2005; Grasser, Van Dyck, Titze, & Stronegger, 2013; Handy, 2005; Heath et al., 2006). When we think of features of the social and physical environment that might influence health, we can probably generate a list of features which includes land-use and transportation (Macintyre & Ellaway, 2003). Urban planning, therefore, has likely more to offer in terms of policies to improve human health than has traditionally been realized.

2.3 CONCEPTUAL MODEL

This thesis follows a conceptual model that links neighbourhoods' physical characteristics, including urban form and transportation systems to utilitarian walking and body mass index. The overarching hypothesis is that urban form and land use measures determine how walkable neighbourhoods are, and, in turn, neighbourhood walkability influences individuals' utilitarian walking and body weight.

Figure 2.1 shows the different potential pathways linking utilitarian walking behaviour and body mass index, including individual characteristics and neighbourhoods' physical and social characteristics. A change in body weight results from an imbalance of energy intake from food and drink and energy spent during body metabolism and physical activity (Astrup, Hill, & Rössner, 2004). In order to manage body weight, we must change food intake and/or physical activity patterns. Although increasing physical activity might not be translated into significant reduction in body weight over time (Hirsch, Diez Roux, Moore, Evenson, & Rodriguez, 2014), maintaining regular exercise has proven clinical health benefits, and offset of several chronic diseases (Jakicic & Gallagher, 2003; I. Lee & Skerrett, 2001). Genetics play a role in determining body weight and the role of genes in body weight gained further attention after the discovery of leptin hormone, which has an important role in regulating body fat (adipose) tissues (Bouchard & Perusse, 1993). While we cannot discount the role of genetics, the reality is that most genetic predisposition is non-modifiable. Genetic interventions, as well as other medical interventions like surgery, do not have the capacity to shift population level inactivity or obesity. Hence, the over-arching goal of this dissertation is to understand the influence of the built environment and public transportation (which can be modifiable, through planning regulations) on utilitarian walking and body mass index.

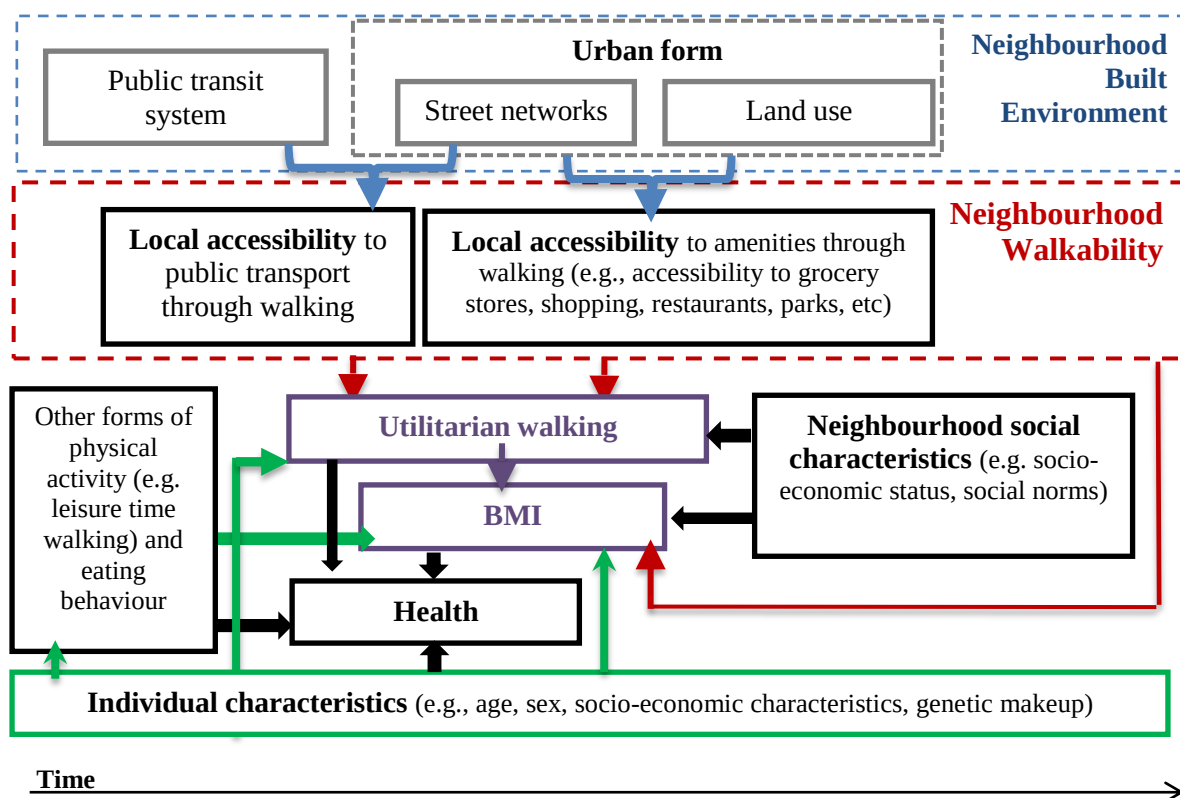


Figure 2.1: Conceptual model linking neighbourhood walkability to utilitarian walking and body mass index (BMI)

2.4 THE HEALTH BENEFITS OF WALKING

Walking is one form of physical activity which can be achieved both in leisure-time and during purposeful walking like to run errands or to go to work or school (utilitarian walking). The influence of overall physical activity on health is well documented. Lee and Skerret (2001) reviewed 44 studies that examined different forms of physical activity, including walking. They found a dose-response relationship of different forms of physical activity and all-cause mortality in young and old people for both men and women, although this research did not differentiate between types of walking (leisure versus utilitarian).

Studies have reported that walking has benefits similar to those of other forms of vigorous physical activity with respect to reduction of risk factors for cardiovascular disease and diabetes (F. Hu et al., 1999; Manson et al., 2002). Studies that have directly examined the

influence of utilitarian walking on risk reduction and health improvement are, however, scarce. A U.S. national survey, conducted on a random sample of 6,626 adults, found that the prevalence of walking doubled when leisure time and non-leisure time walking (including, walking at work, and walking for transport) were reported (81% vs 43%, respectively). Also the median weekly minutes walked almost doubled when total walking was reported (239 vs 130 minutes, respectively) (Bates et al., 2005).

There are studies from Europe and Asia that have shown associations between active commuting (walking, bicycling, and transit) and positive health indicators (Andersen, Schnohr, Schroll, & Hein, 2000; Bovens et al., 1993; Hayashi et al., 1999; G. Hu et al., 2001; G. Hu et al., 2002; Wagner et al., 2001). Active commuting was associated with lower body mass index, better blood lipid profiles, and lower blood pressure. Many of these associations persisted after controlling for individuals' leisure time physical activity and other factors influencing health like smoking and socioeconomic status

In California, Berrigan et al. (2006), found that inequalities in total physical activity decreased between groups when minutes from non-leisure time walking and bicycling (NLTWB)) was added to the minutes of leisure time physical activity (LTPA). Adherence to the recommended minutes of physical activity based on LTPA was greater in men than women. Adherence decreased with age, increased with education and income level, and was lowest in Latino compared to other ethnicities. On the other hand, adherence to the recommended minutes of physical activity based on NLTWB was similar in men and women. It showed a U-shaped relationship with age, decreased with education and income, and was highest in Latino compared to other races/ethnicities. In summary these few studies have shown that utilitarian walking has the potential to increase overall walking. Subsequently, it is worth investigating the determinants of utilitarian walking in order to increase overall walking, and potentially influence BMI and health.

2.5 ASSOCIATIONS OF NEIGHBOURHOOD WALKABILITY, UTILITARIAN WALKING AND BODY WEIGHT

The review¹ highlights the main findings from the body of literature that examines relationships between the built environment, utilitarian walking, overall physical activity and body weight. Overall, there is a growing number of studies to document cross sectional associations between the built environment utilitarian walking, and body mass index (Ewing & Cervero, 2010; Feng et al., 2010; Mackenbach et al., 2014). Associations between neighbourhood walkability and overall physical activity have shown mixed results (Ewing, 2005; Forsyth et al., 2007; Handy, 2005; Handy, Boarnet, Ewing, & Killingsworth, 2002; Smith et al., 2008). The majority of these studies employ self -reported walking levels and self-reported weights and heights. Two studies measured minutes walked associated with public transportation, showing mixed results on the connection between the use of public transportation and meeting recommended minutes of physical activity (Besser & Dannenberg, 2005; Morency, Trépanier, & Demers, 2011). Few studies used objective measures (pedometers or accelerometers) to measure overall walking (Bravata et al., 2007; Pedišić & Bauman, 2015).

Longitudinal studies in this field are comparatively rare, limiting causal inferences of the built environment correlates on walking behaviour and body mass index (Berry et al., 2010; Eid, Overman, Puga, & Turner, 2008; Hirsch et al., 2014; Knuiman et al., 2014;

¹ The review was conducted through an electronic search with PubMed, EBSOhost (Academic search premier), Transportation Research Information Services (TRIS), Science Direct and manual reference-checking for peer reviewed articles (empirical analysis, and review articles) published in English from 2005 to May 2015. Keywords and phrases used in the search strategy included: walking, utilitarian walking, transit, public transport, active commuting, active transport, active transportation, health, health outcomes, obesity, overweight, BMI, physical activity, built environment, land-use planning, land use and transportation, neighbourhood (neighborhood), neighbourhood walkability, Walk Score®, street connectivity, land use mix, urban sprawl.

Krizek, 2000). Before going into details of presenting the main finding from this body of literature, I will briefly present the variety of indicators of the built environment used to measure neighbourhood walkability.

2.5.1 Measures of the built environment

There are three categories of geographic/environmental measures that may reflect the physical activity-enabling aspects of the environment: 1) perceived measures obtained by telephone surveys or interviews; 2) measures obtained from systematic observations or technical audits; and 3) archived datasets that are measured and analyzed using geographic information system (GIS) (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009). Measures of the built environment conducted in GIS were first developed by urban planners to understand travel behaviour. From this original use, they have been adopted by a wider research community who have focused on the public health potential of studies on the links between built environment, physical activity and obesity (Grasser et al., 2013).

2.5.1.1 Objective measures generated, archived and analyzed using GIS

The first three measures of the built environment coined by Cervero and Kockelman (1997) and investigated since then by many researchers (Badland & Schofield, 2005; Ewing & Cervero, 2010; Forsyth et al., 2007; Grasser et al., 2013; Handy, 1996b; Handy et al., 2002; Handy, Cao, & Mokhtarian, 2008; Nelson & Woods, 2009; Saelens & Handy, 2008; Saelens, Sallis, & Frank, 2003; Smith et al., 2008) are known as the 3Ds: Density, Diversity and Design. Neighbourhoods with high land-use density, land-use diversity (mixed use) and street connectivity (street design) have been linked with active transportation (Ewing & Cervero, 2010; Grasser et al., 2013). There have been efforts to produce built environment measures expanding beyond the 3Ds to include Distance to transit, Destination accessibility (Cervero, 2001; Ewing, 2009; Handy, 2005) and Demand management (which includes

parking supply and cost) (Meyer, 1999). In addition to these six, Demographics in the neighborhood has been considered as a seventh D (Ewing & Cervero, 2010). The remainder of this section will focus on literature that has discussed 4 of the 6 Ds (Density, Diversity, Design, and Destination accessibility), and other composite indicators that measure neighbourhood walkability (the Walkability Index and the Walk Score®).

1. **Density**, measured as a count per unit area, can include population density, dwelling density, employment density or any other land-use of interest. High employment or retail density can also be interpreted as an accessibility measure. Density measures have shown positive association with utilitarian walking (Carlson et al., 2015; Saelens & Handy, 2008).
2. **Diversity** measures relate to the variety of land-uses in a given area and are typically labelled as measures of land-use mix. Land-use mix has been shown to be positively associated with leisure time and utilitarian walking (Cervero & Gorham, 1995; Grasser et al., 2013; Handy, 2005) as well as with overall physical activity (Frank et al., 2007; Handy, 2005; Li et al., 2008). Green and open spaces contribute to land use diversity, however, their presence is not associated with utilitarian walking (Handy, 2005). There are different methods used to calculate land-use mix (e.g., the entropy index, mean entropy, dissimilarity index and land-use interaction measure). The **entropy index** was adapted from the physical sciences (Cervero & Kockelman, 1997; Frank et al., 2007; Kockelman, 1997; Leslie et al., 2007). As constructed in Equation 2.1, “P” is the proportion of developed land, and “j” is the number of land-use categories. The entropy measure is normalized with respect to the natural log of the number of land-use categories; hence it varies between 0 and 1 with higher values for a more even mix.

Equation 2.1: $Entropy\ index = - \sum_j \frac{[P_j * \ln(P_j)]}{\ln(j)}$

The mean entropy measure can be used to avoid biases that may be introduced by undeveloped areas of land use and take into account different sizes of units of analysis. It can also incorporate the influence of the variety of land-uses in neighbouring units. Equation 2.2 shows how the mean entropy is calculated, where k represents the number of actively developed hectares in the neighbouring units around the unit of area of interest.

Equation 2.2:
$$\text{Mean entropy} = \sum k = \frac{-\sum j \frac{[P_j * \ln(P_j k)]}{\ln(j)}}{k}$$

The dissimilarity index developed by Cervero and Kockelman (1997) measures the dissimilarity of the adjoining (neighbouring) land uses. The study area of interest is divided into squares of one hectare of developed land. Each square is assigned a dissimilarity score (Equation 2.3), based on how different the land uses of the eight adjoining squares are from the central square. The dissimilarity index computation method is shown in Figure 2.2. For example, the Central C Square (hectare) is assigned a score of 5/8, since 5 from 8 adjoining squares have different land use from the central square. The drawback of the measure is that it is insensitive to the number of land uses in the neighbouring squares (e.g. 5/8 of the adjoining land uses could all be one land use category that is different from the central square, or there could be more).

Equation 2.3:
$$\text{Dissimilarity index} = \sum_k \frac{1}{k} \sum_i^8 \frac{X_{ik}}{k}$$

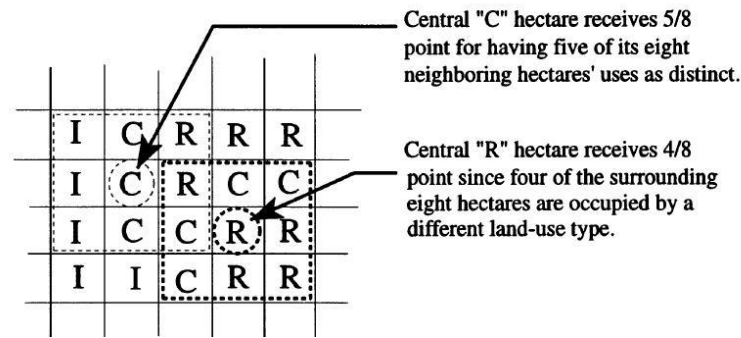


Figure 2.2: Computation method of dissimilarity index adapted from Kockelman (1997)

The land-use interaction measure looks at the amount of ‘interaction’ between different land-use categories (residential, commercial and industrial). The underlying assumption of the measure is that shorter travel distances that allow active transportation choices can be generated by the mixing of complementary land uses. It uses three complementary land-uses to calculate the interaction length between them (residential, commercial and industrial). The lines between two complementary uses are calculated (excluding the borders between open spaces, and other land use categories). The greater the length of the interaction lines between the complementary land-uses indicates a more mixed land use neighbourhood (Manaugh & Kreider, 2013).

3. **Design** refers to several built environment measures that usually differentiate between pedestrian-oriented and auto-oriented streets. They include design of street networks, which range from dense urban grids of highly connected straight streets, to low suburban networks of curved streets. The measures include average block size, number of four-way street intersections, or number of intersections per unit area. Design can also include side walk coverage (share of block face with sidewalks), pedestrian crossings, street lighting, trees, street furniture (e.g., benches) or other street features. The most common design measure used is street connectivity since it relies on readily available data in archived GIS databases. The other measures require extensive data

collection in the neighbourhoods of interest, making them more difficult and costly to use, particularly in studies that cover large geographic areas. Street connectivity defines how frequently streets are intersected. There are several methods to calculate street connectivity; the simplest is counting the number of street intersections within a walking geographic area (e.g., within census tracts or a 250 m walking buffer). Another approach is to count only four-way street intersections as these indicate heightened connectivity. In some studies street connectivity was positively associated with both leisure and utilitarian walking (Frank et al., 2007; Li et al., 2008; Van Dyck, Deforche, Cardon, & Dr Bourdeaudhuij, 2009).

Destination Accessibility is a measure of potential opportunities (Handy & Niemeier, 1997; Hansen, 1959). It is defined by Hansen (1959) as the ease of reaching destinations. Accessibility could be regional or local, according to the type of destination (Handy, 1993). Regional accessibility is commonly measured as the distance to the central business district (CBD). Others measure accessibility to destinations as the number of destinations that can be reached within a travel time (e.g., the number of jobs that can be reached within 15 minutes walking, bicycling, by transit, or any other mode of transportation) (Vickerman, 1974; Wachs & Kumagai, 1973). Local accessibility is defined by Handy (1993) as the distance to local stores from homes. Measures of accessibility are not commonly used in public health and physical activity disciplines. They are more familiar in land-use and transportation research (Handy & Niemeier, 1997; Hansen, 1959). The simplest method to measure accessibility is known as cumulative opportunity, which is basically counting opportunities (e.g., employment opportunities) that can be reached within a certain travel distance. The cumulative opportunity measure is correlated with other more cumbersome accessibility measures (El-Geneidy & Levinson, 2006). Public transportation could be considered as one of the destinations for which accessibility on foot could be calculated for (e.g., measuring

density of transit routes in a given walking area (i.e., an 800 meter walking buffer) or spacing between transit stations or stops (Murray & Wu, 2003). Alternatively distance to transit (the 5th D) is calculated.

Composite indices that incorporate multiple measure of the built environment have been combined by several researchers to represent the concept of overall walkability of a neighbourhood, for example the Walkability Index and the Walk Score®.

1. **The Walkability Index** is a composite measure that is calculated by adding normalized scores of various built environment measures such as residential density, land use mix and street connectivity (Frank, Schmid, Sallis, Chapman, & Saelens, 2005). A modified walkability index was updated by adding commercial density (also called Retail Floor Area Ratio) (Frank et al., 2006). The walkability index has shown positive associations with utilitarian walking in a number of cross-sectional studies (Frank et al., 2006; Frank et al., 2005; Sallis et al., 2009; Van Dyck et al., 2010).
2. **The Walk Score®** summarizes local accessibility to nine different amenities within a 1.5 mile (~2.4 km) radius. The algorithm calculates a straight line distance, known as Euclidean distance, to amenities such as grocery stores, restaurants, banks, and shopping among others. An algorithm assigns a percentage of a full score to each amenity based on a distance decay function, where nearby locations are given higher scores than those that are distant. The Walk Score® is self-proclaimed as the only international measure of walkability (Walk Score®, 2013). The Walk Score® has shown positive associations with utilitarian walking in a number of studies (Hirsch et al., 2014; Knuiman et al., 2014; Mackenbach et al., 2014; Manaugh & El-Geneidy, 2011; Tuckel & Milczarski, 2015) and is recognized by the general public as real estate companies increasingly report neighbourhood walkability.

Public health adoption of measures of the built environment has been rather haphazard with many variations of measures used. Several factors contribute to the inconsistency in choice of measures. Limited access to information is one factor. Land-use density, land-use mix, street connectivity, accessibility to public transit, and access to green and open spaces are the most frequent measures used and demonstrate associations with active transportation (Butler, Orpana, & Wiens, 2007; Cao, 2009a; Ewing & Cervero, 2010; Frank et al., 2007; Hinde & Dixon, 2005; Nelson & Woods, 2009; Van Dyck et al., 2009).

2.5.1.2 Observational measures

Observational measures of the built environment are those that are collected through technical audits conducted by trained personnel or researchers. Researchers select sites, define and sample segments to be audited, and train observers for data collection. These measures can be similar to any of the above discussed measures that can be observed and recorded through GIS (Brownson et al., 2009).

2.5.1.3 Perceived measures:

Perceived measures of the built environment are derived from impressions of local walking-friendliness of neighbourhoods reported by survey respondents. People's perception of the built environment features that make a neighbourhood supportive of walking is important to understand, because perceptions can influence behaviour. How people perceive their neighbourhood could be different from how walkable it is based on objective measures. Pikorta, Giles-Corti et al. (2003) were pioneers in identifying elements of the built environment that have been used later in questionnaires to identify perceptions of the built environment features that influence walking and cycling. The authors developed a framework to identify the built environment features that were perceived to be important for walking and

cycling (for utilitarian or leisure time purposes). They identified four domains under which perceived elements of the built environment were categorized. These elements were identified through previous empirical evidence, semi-structured interviews with experts from a range of disciplines working in the field of physical activity and active transport, and a Delphi² study with local, national and international experts to rank the importance of the built environment elements identified. The four domains identified were functional features, safety features, aesthetic features, and destinations, under which nine elements were ranked as the most important elements across these four domains (Table 2.1). Rankings of the built environment features were different between walking for recreation (leisure time walking), and walking for transport (utilitarian walking).

Table 2.1: Domains of perceived elements of the built environment linked to walking

Domain	Elements
Functional Features	Walking surface (e.g., sidewalks)
	Streets (e.g., connectivity)
	Traffic (e.g., presence of non-motorized trips)
	Permeability (e.g., mixed land uses)
Safety features	Personal (e.g., protective social environment, versus crimes)
	Traffic (e.g., traffic volume)
Aesthetic features	Streetscape (e.g., benches, light features, trees)
	Views (e.g., presence of a lake, tourist attractions)
Destination features	Facilities (e.g., amenities to go to)

² A Delphi method is a technique used to identify information and reach consensus on a subject that is not known, through a series of systematic interviews with experts in the field of study.

Some architectural attributes were also found to be associated with perceived walkability, in particular the presence of ground-floor windows and a street focal point (Oreskovic, Charles, Shepherd, Nelson, & Bar, 2014). People can also be asked about how they perceive any other built environment measure (e.g. density of neighbourhoods, street connectivity, diversity of land uses and accessibility to destinations). Previous research has found a mis-match between objective measures of walkability and perceived measures. Moreover, associations of leisure time walking and neighbourhood walkability were different based on whether they used objective measures or perceived measures of neighbourhood walkability (Gebel, Bauman, Sugiyama, & Owen, 2011).

2.5.2 Cross sectional associations

2.5.2.1 *Associations between utilitarian walking and use of public transportation*

Transit use is hypothesized to support utilitarian walking (Wilkinson & Marmot, 2003). There are two studies that have examined the amount of utilitarian walking involved with public transport use. Besser and Dannenberg (2005) found that Americans who use transit spend a median of 19 minutes of daily walking to and from transit stops; 29% of those who used transit achieve more than 30 minutes daily walking. On the contrary, Morency et al. (2011) found that recommended minutes of physical activity could not be achieved through the use of public transport for Canadians in Montreal.

Besser and Dannenberg (2005) used the 2001 National Household Travel Survey to examine total walking to light rail and public buses in the United States. The authors controlled for neighbourhood physical characteristics in their study, but did not incorporate transit service characteristics nor differentiate between trip purposes in their models. The importance of modelling travel behaviour by trip purposes has been noted in previous research (Handy, 1996a; Saelens et al., 2003). Large variation in walking distances and

durations by trip purpose were found in the 2009 National Household Travel Survey (Yang & Diez-Roux, 2012) as well as other studies in the Twin Cities (Iacono, Krizek, & El-Geneidy, 2010) and Montréal (Larsen, El-Geneidy, & Yasmin, 2010).

Morency et al. (2011) used a metropolitan trip diary to estimate total walking to public transportation in Montreal. The study had several major drawbacks. The modelling of distance walked in their study did not distinguish between trip purposes nor did it take into consideration important contextual factors of neighbourhood and transit service characteristics. Accordingly, their walking trip models were missing key variables that resulted in a poor explanatory power (e.g., R-squared value of 0.069). The utility of their results are further hindered in that they are not reproducible elsewhere with routinely available software.

2.5.2.2 *Associations between utilitarian walking and the built environment*

The relationship between utilitarian walking and the built environment has been examined in two bodies of literature (travel behaviour and physical activity literature). To date, there are more than 200 studies investigating the relationship between the built-environment and travel behaviour, including utilitarian walking (Ewing & Cervero, 2010). A review paper by Badland & Schofield (2005) found that land-use density, subdivision age, street connectivity and mixed land-use (diversity) are key urban design features for active transport-related physical activity. Another review paper by Saelens & Handy (2008) found that studies show consistent positive relationships between non-leisure or utilitarian walking and neighbourhood land-use density, distances to non-residential destinations, and land-use mix. Association of utilitarian walking with street connectivity, safety, access to parks and open spaces, however, are still inconsistent across studies. Handy commented in 2005 that the direction and magnitude of effect of environmental characteristics that correlate with

leisure time physical activity have not been well-estimated and the same could be said a decade later in 2015.

Handy's (2005) comments echo the neighbourhood and health research reviewed by Macintyre and Ellaway (2003) which suggests that there is little systematic research that examines which neighbourhood attributes affect which facets of health, in which population group, while taking time into consideration. Ewing and Cervero (2010) conducted a meta-analysis of the built environment and travel literature published until the end of 2009. The main purpose of this meta-analysis was to quantify effect sizes of the built environment measures. They produced elasticities³ from individual studies and pooled them to produce average weights. The authors evaluated more than 200 quantitative studies that examine built environment characteristics that correlate with travel behaviour. They computed effect sizes of 50 studies based on whether the studies controlled for demographic confounding factors, applied statistical tests to determine significance of associations, used sizable samples, captured more than one "D" variable in their study, and, most importantly, data was available to compute elasticities. The three outcome variables that were assessed by Ewing and Cervero in their meta-analysis were vehicle miles of travel (VMT), walking, and transit use.

The results of the weighted average elasticities estimated by Ewing and Cervero (2010) of walking with respect to the built environment variables are shown in Table 2.2. The authors clarified that the results of these effect sizes can only be used as rough estimates, due to the small sample sizes of studies that examined specific built environment variables and the multiple methods they used to compute the elasticities. In general, the results showed low elasticity between the built environment variables and walking. The largest magnitude of

³ Elasticity is the ratio of the percentage change in one variable associated with the percentage change in another variable. For example, for a continuous outcome variable like number of walking minutes, elasticity can be interpreted as the percent of change in walking minutes associated with a 1% increase in a specified independent variable. For categorical variables (e.g., walking compared to other modes of transportation), elasticity can be interpreted as the percent of change in the probability of walking compared to other modes, associated with a 1% increase in a specified independent variable.

weighted average elasticity was 0.39 which was the effect of street connectivity on walking. A 1% increase in street density corresponded to a 39% increase in walking. The meta-analysis showed that the likelihood of walking trips was most strongly associated with neighbourhood design and diversity. For street connectivity, the density of intersections was more important than the number of intersections per se. This may be because a neighbourhood could be well connected with clear grid like streets, but if the blocks are large, this might decrease walking.

Table 2.2: Weighted average elasticities of walking relative to built environment variables

Built environment variables		Total number of studies (n= 54)	Number of studies with controls for self-selection	Weighted average elasticity of walking
Density	Household/population density	10	0	0.07
	Job density	6	0	0.04
	Commercial floor area ratio	3	0	0.07
Diversity	Land-use mix (entropy index)	8	1	0.15
	Jobs-housing balance	4	0	0.19
	Distance to a store	5	3	0.25
Design	Intersection/street density	7	2	0.39
	% 4-way intersection	5	1	-0.06
Destination accessibility	Job within one mile	3	0	0.15
Distance to transit	Distance to nearest transit stop	3	2	0.15

Grasser et al. (2013) reached similar conclusions to Ewing and Cervero (2010). Grasser et al. (2013) examined studies that correlated built environment objective measures conducted using GIS (density, street connectivity, land use mix and walkability indices developed by Frank et al. (2005) and Frank et al. (2006) with active transport and body weight. Based on 34 studies that were eligible for their review, the authors found that the

walkability measures that were consistently correlated with measures of transport-related physical activity were gross population density, intersection density (a measure of street connectivity) and walkability indices.

Noticeably, there are substantial numbers of studies that did not control for self-selection. The argument behind self-selection is that people move into neighbourhoods that are more walkable because they already have a preference for walking. When this is true, we cannot imply that neighbourhood walkability has a causal effect on walking behaviour. However, if people move to a walkable neighbourhood and go on to develop a positive attitude towards walking, then one can argue that the built environment had a causal effect. Handy (2005) found that majority of studies in the field of physical activity and travel behaviour have neglected this issue. Handy and Mokhtarian (2005) raise the question of which comes first, the neighbourhood or the walking. A few researchers have addressed the self-selection issue by designing their own surveys and asking questions about self-selection and attitudes or preferences (Cao, 2009a, 2009b; Frank et al., 2007; Handy & Clifton, 2001).

Cao et al. (2009) reviewed 30 empirical studies that used different approaches to control for self-selection. These approaches included: direct questioning (asking participants the factors that affect their walking behavior), statistical control of attitudinal questions asked in a survey, and propensity scores assigned to participants in different neighbourhoods to compare respondents with the same individual characteristics. Cao et al. (2009) argue that studies that use longitudinal designs explicitly address self-selection as longitudinal studies can be used to control for attitudes as long as they do not change over time.

A substantial literature on the measurement of the built environment now exists; every type of measure has limitations as well as advantages. Brownson et al. (2009) recommended that further research should be conducted to improve these measures and understand which measures are more relevant for different population groups. It is worth mentioning that

different results were found in studies based on whether they used objective measures of physical activity versus self-reported measures (Salvo et al., 2014; Van Dyck et al., 2010) and whether they used objective measures of neighbourhood walkability versus perceived measures (Gebel et al., 2011). Recall bias can be induced from self-reported measures of physical activity; however it is more of a problem in cross sectional analyses compared to longitudinal ones, specifically if the reporting bias is systematic and consistent over time. (Frees, 2004).

2.5.2.3 *Associations between body mass index and the built environment*

Despite the growing consensus on the role of the built environment in shaping obesity trends (Egger & Swinburn, 1997; Hill, Wyatt, & Melanson, 2000; Peters, 2003; Swinburn, Caterson, Seidell, & James, 2004), the overall advancement in developing and testing hypotheses has been slow. The main conceptual idea that links the built environment to obesity is that physical characteristics and accessibility to different amenities might influence physical activity and eating behaviour. Accumulation of physical activity could result from leisure time physical activity (e.g, leisure time walking) and non-leisure time physical activity (e.g., utilitarian walking). Eating behaviours might be shaped by food environments to be sure and measures of the food environment (e.g., accessibility to fast food, supermarkets, groceries, ethnic foods, restaurants, etc.) have been tested in a number of studies. This thesis, however, focuses on understanding how the built environment influences body mass index primarily through utilitarian walking and other socio-demographic factors.

The most common measure used in obesity research to measure overweight and obesity is the body mass index (BMI). BMI is the easiest measure to calculate because it basically needs information about the weight and height of individuals (Equation 2.4). A BMI from 25

to $29.9 \frac{kg}{m^2}$ is considered overweight and greater than or equal to $30 \frac{kg}{m^2}$ is considered obese.

Equation 2.4: $BMI = weight / height^2 \quad \frac{kg}{m^2}$

Contradictory findings have been seen in the literature regarding associations of the built environment with body mass index. The majority of the studies examining the influence of the built environment on BMI have been cross sectional in design. In the U.S., Gordon-Larsen, et al. (2005) found that the majority of young adults in California do not use active transportation. Most adolescents use cars to go to work (90%) and school (74.7%). These researchers found that the proportion of individuals using active transportation to go to work or school was higher among those that were active and not overweight than those that were less active and overweight by 9.2%- 15.2% for work trips and 29.7%- 3.7% for school trips. Lopez- Zetina, et al. (2006) confirms the association between BMI of individuals and their travel behaviour for auto users. They found that people with the highest BMIs travelled longer distances with their cars (i.e., higher VMT) than others. Similar trends have been shown in two other studies in Australia and Europe (Hannah & Grant, 2008; Hinde & Dixon, 2005; Lindström, 2008).

Feng et al. (2010) conducted a systematic review of 37 studies examining the evidence of the built environment and obesity. They divided the studies into two categories based on how those studies identified place (the spatial unit of analysis). Twenty two studies identified place through pre-determined administrative boundaries (e.g., census tracts), these studies were referred to in the review as “Contextual Studies”. Fifteen studies identified their spatial unit of analysis through constructing individual unique geographic buffers around households; these studies were referred to as “Buffer Studies”. The 22 Contextual Studies identified 80 relationships between the built environment and BMI (BMI was modelled as a continuous variable, or as a categorical variable, identifying the odds of overweight and

obesity). Forty of the associations were statistically significant and in a direction consistent with the authors' hypothesis (supporting the idea that the built environment characteristics which increase neighbourhood walkability are negatively associated with the risk of overweight and obesity). Thirty eight of the studies did not show statistical significance and two studies were in the opposite direction of the authors' hypothesis. The 15 Buffer Studies identified 40 relationships between the built environment and BMI, 24 of them were statistically significant and in the hypothesized direction.

In the Contextual Studies, only six environmental measures were identified by 3 or more studies; population density; density of fast food; full service restaurants; convenience stores; grocery stores and county sprawl index. Approximately 50% of the studies reported no significant associations of the examined measures with obesity, with the exception of the county sprawl index where 3 of the 4 studies reported significant associations. In the Buffer Studies seven environmental measures were identified; density, diversity, design, connectivity, spatial access to the food environment and physical activity opportunities, and walkability. The built environment measures were not linked to body mass index, nor with the odds of being overweight and obese, with the exception of increased land use diversity, which showed negative associations with BMI. The authors concluded the review stating that despite positive findings of built environment measures that correlate with BMI, the heterogeneity in the built environment measures used, and the mixed results found limit what can be learned on the influence of the built environment on BMI.

Hoehner et al. (2011), found geographic patterning of BMI in Texas by neighbourhood walkability. Neighbourhood walkability was objectively measured at the US Census block-group level; a principal component analysis was conducted to reduce the built environment measures that are conducive to walking into three factor indicators. The first factor indicator

was named “High density” block groups, where higher values corresponded to block-groups with higher population and housing unit density. The second factor indicator was named “Traditional core” block groups, where higher values corresponded to block groups with older homes and residents with shorter commute times. Finally, the third factor indicator was named “Non-auto commuting” block groups, where higher values corresponded to block-groups with a higher proportion of commute trips made by walking, bicycling, or public transportation. Findings revealed that men and women in neighborhoods that were one standard deviation (SD=1.0) above the mean of the “Traditional core” block group factor indicator had BMIs 0.77 and 0.84 kg/m² lower, respectively, than those living in neighborhoods less than one standard deviation below the mean. These findings were unadjusted for outdoor physical activity and cardio-respiratory function.

A recent systematic review by Mackenbach et al. (2014) examined the links between the physical environment and adult body weight status. The authors classified the studies according to the mode of measurement and study area (continent). Physical environment characteristics examined in the studies were divided into several domains, including: physical activity environment, referring to the physical environment that gives opportunities for physical activity; food environment, referring to food purchasing opportunities; and transportation opportunities. Any other physical environment characteristics that were not classified into the previous domains were classified as “others” (e.g., population density). The authors systematically searched five databases, examining studies published between 1995 and 2013. They identified 92 relevant studies that were included in the review; seven of them used longitudinal designs, in which, only three examined the link between physical activity environments and body weight. The majority of the studies (74) were conducted in North America (66 in the US, 8 in Canada), 12 were conducted in Europe (6 of them in the UK) and

six were conducted in Australia. Nearly half of the studies (45) were published from 2010 to 2013 (i.e. they were new studies that were not included in the review by Feng et al. (2010)).

Objective measures of the built environment were used in most of the studies (75 studies), while perceived measures of the built environment were used in 17 studies. Nine of the studies examined both objective and perceived measures of the built environment. The Mackenbach et al. (2014) results align with results of previous reviews (Feng et al., 2010; Papas et al., 2007) on the link between the built environment and obesity, showing weak associations of built environment measures with body weight. Overall to date, the most consistent associations have been between BMI, urban sprawl, land use diversity and accessibility.

2.5.3 Longitudinal associations

Longitudinal research examining the relationship between the built environment, utilitarian walking and BMI is emerging (Hirsch et al., 2014; Knuiman et al., 2014; Krizek, 2000). Krizek (2000) examined 549 households that changed their residential location within Puget Sound, Washington, USA. Of the 549 households, 44% of them relocated to a neighbourhood with a different walkability level (characterized by residential density, diversity of land-uses, and street design to form different levels of “Less Auto-Dependent Urban Form” (LADUF) neighbourhoods). Krizek (2000) compared change in percentage of walking trips done by households who moved to higher walkable neighbourhoods (low to medium, low to high, medium to high) or lower walkable neighbourhoods (high to low, high to medium and medium to low), to those who moved to neighbourhoods with same walkability levels. Households that moved from high to medium LADUF were the only ones that showed a significant change (reduction by 9.9% SD 25%, ($p= 0.35$)) in the percentage of walking and transit trips conducted.

On the contrary, the RESIDE study in Perth, Australia (Knuiman et al., 2014), showed significant positive change in the odds of utilitarian walking when moving from low to high walkable neighbourhoods. The RESIDE study (n=1,813 at baseline) tracked, over a 7 year period, the walking behaviour of people who relocated to new suburban housing developments. This study found that the odds of walking for utilitarian purposes had positive association with local accessibility to amenities (measured as the number of amenities within 1,600 meters buffer from respondent's homes). Being in a neighbourhood with high local accessibility (8 to 15 amenities within a 1,600m buffer) was associated with an increase in the odds of walking by around 30% ($p=0.04$) compared to being in a neighbourhood with low local accessibility (0 to 3 amenities within a 1,600m buffer).

The third study comes from an opportunistic analysis of data collected as part of the American Multi-Ethnic Study of Atherosclerosis for older adults (45 to 85 years old) (Hirsch, Diez Roux et al., 2014). The sample was drawn from six cities in the United States, expanding the geographic range beyond that described in the first two studies. Moving to a more walkable neighbourhood (a 10 point higher Walk Score®) was associated with increasing the odds of meeting "Every Body Walk" campaign goals (≥ 150 minutes/week of walking) by 11% (95% C.I. 0.2%, 21%) and with a 0.06 lower BMI (95% C.I. 0.12, 0.01), which is equivalent to 0.36 pounds less in an average women (164.1 cm) and 0.42 pounds less in an average men (178.2 cm).

Eid et al. (2008) examined the American National Longitudinal Survey of Youth that began collection in the United States in the 1970s. The authors examined BMI of 4,426 youth (14 to 21 years old at baseline (1978)) that were followed for 7 years. They did not find any causal effects of urban sprawl on BMI, arguing that the high prevalence of overweight and obesity in sprawling areas is due to self-selection. Similar conclusions were reached by a study in Edmonton, Alberta (Berry et al., 2010), the only longitudinal study to have

examined adults (18 years and older at baseline, who resided in the same neighbourhood for 6 years). The authors reported a non-significant association of BMI with neighbourhood walkability, but they did find that BMI change was associated with socio-economic characteristics of the neighbourhoods.

2.6 SECTION SUMMARY, DISCUSSION AND CONCLUSIONS

The purpose of this chapter was to give a general overview of the research approach and conceptual model of this dissertation. The chapter then presented a review of the bodies of literature that examine the relationship between neighbourhood physical characteristics, utilitarian walking and body weight. The review of the literature showed cross sectional associations between the built environment physical characteristics (mainly urban sprawl, land use mix, and Walk Score®), utilitarian walking and body mass index. (Handy, 2005; Mackenbach et al., 2014; Thielman, Rosella, Copes, Lebenbaum, & Manson, 2015; Tuckel & Milczarski, 2015).

Utilitarian walking was positively associated with land use diversity, and neighbourhood walkability, and negatively associated with urban sprawl. Associations of the built environment with overall physical activity were inconsistent across studies (Bauman et al., 2009; Grasser et al., 2013). Utilitarian walking has the potential to increase overall walking minutes, however, the extent to which utilitarian walking can add to overall recommended minutes of physical activity is not yet fully understood. Links between neighbourhood walkability and body mass index have been detected in studies with cross sectional designs (Mackenbach et al., 2014).

The few longitudinal studies that have been conducted to date revealed mixed findings. Krizek (2000) did not find that moving to high walkable neighbourhoods increased utilitarian walking, while Hirsch et al. (2014) and Knuiman et al. (2014) found significant associations.

Moreover, there were no longitudinal studies that examined the link between neighbourhood walkability, adults' utilitarian walking and BMI, where utilitarian walking could be a potential mediating factor between neighbourhood walkability and BMI.

One of the conceptual and methodological challenges in studying the effect of environmental factors on health behaviour is the ability to tease out individual versus neighborhood effects on health outcomes. Multi-level modeling, also known as Hierarchical Linear Modeling (HLM), is one of the statistical approaches that allows individual characteristics to be estimated and compared to neighbourhood characteristics. The principal advantage of multi-level regression models over ordinary least squares (OLS) is that OLS tends to deflate the standard errors of the regression coefficients, resulting in misleading tests of significance (Bickel, 2007). In Chapter 3, multi-level regression models are used to understand associations of transit use with daily levels of utilitarian walking in Montreal. The literature showed that there is a need for more studies that disentangle individual and environmental factors and look at longitudinal associations over time. This dissertation will fill these gaps in the literature and address some of the conceptual and methodological challenges that are found in previous research (e.g., reducing bias from self-selection).

A technique used in achieving the second and third objectives of the thesis (Chapters 4 and 5) was fixed effects regression modeling. Fixed effects approaches have the advantage of eliminating biases caused by unmeasured time constant personal characteristics (un-observed heterogeneity). Unmeasured personal characteristics, in this area of research, cause over-estimation of the effect of neighbourhood characteristics on travel behaviour and body mass index. Another major (generic) problem in modeling is controlling for confounding variables to get more precise coefficient estimates. Although researchers try their best by developing conceptual models and including confounding variables, they can be easily criticized that they left a confounder out of the equation. The fixed effects approach offers a solution to this

problem. It is a statistical technique that controls for all confounding variables even without measuring them, when these omitted or unmeasured confounders are time constant variables (i.e., do not change over time for each individual). Fixed effects models omit the portion of the error term that is generated from time constant omitted variables (Allison, 2005; Frees, 2004)

We can also have unbiased estimates on how changes in neighbourhood characteristics affect travel behaviour by looking at respondents who moved from one neighbourhood to the other using fixed effects in a quasi-experimental design. Fixed effects have been employed in sociology and public health research. In sociology, for example, Burnett and Farkas (2009) used fixed effects models to examine the effect of poverty and family structure on children's mathematics achievement. In public health, Fujiwara and Kawachi (2009) used fixed effects models to examine the causal relationship between education and a number of health behaviours and health outcomes.

Overall, there has been significant research effort to date to identify the relationship between the built environment, walking and body weight. Most of the research has been of a cross-sectional nature and many of the results were mixed, depending upon the population under study or choice of built environment measure. Longitudinal studies should bring significant advances but those that have been conducted to date are narrow in geographic scope or focus on special populations. Increased clarity on the promise of the built environment to deliver public health benefits like more utilitarian walking and reductions in body weight in entire populations can only help to move us toward effective public policy in this area.

3 CHAPTER THREE: ACHIEVING RECOMMENDED PHYSICAL ACTIVITY LEVELS THROUGH PUBLIC TRANSPORTATION USE: UNPACKING INDIVIDUAL AND CONTEXTUAL EFFECTS

3.1 OVERVIEW OF CHAPTER

In this chapter, I address the first objective of this dissertation, namely to identify the extent to which public transit contributes to daily walking trips for transit users. The analysis is conducted using the 2006 Origin-Destination (OD) survey in Montreal, Quebec – Canada's second largest metropolitan area. It draws upon and contributes to health, transportation, and physical activity literature related to neighbourhood effects on walking and body weight. This manuscript has been published in the journal of *Health and Place*:

Wasfi, R., Ross, NA., & El-Geneidy, A. (2013). Achieving recommended daily physical activity levels through commuting by public transportation: Unpacking individual and contextual influences. *Health and Place*, 23, 18-25. doi:10.1016/j.healthplace.2013.04.006.

3.2 ABSTRACT

This paper estimates the amount of daily walking associated with using public transportation in a large metropolitan area and examines individual and contextual characteristics associated with walking distances. Total walking distance to and from transit was calculated from a travel diary survey for 6,913 individuals. Multilevel regression modelling was used to examine the underlying factors associated with walking to public transportation. The physical activity benefits of public transportation varied along sex and socio-economic lines. Recommended minutes of daily physical activity can be achieved for public transportation users, especially train users living in affluent suburbs.

3.3 INTRODUCTION

The World Health Organization (WHO) identified transportation as one of the top ten social determinants of health (Commission on social determinants of health, 2008; Wilkinson & Marmot, 2003). Physical activity associated with the use of public transportation leads to a number of health benefits including reduced rates of obesity and many chronic diseases (B. Brown & Werner, 2007; Jakicic & Gallagher, 2003; J. MacDonald, Stokes, Cohen, Kofner, & Ridgeway, 2010; Sallis et al., 2004; Transport Canada, 2005; Warburton, Nicol, & Bredin, 2006; Wilkinson & Marmot, 2003). Previous research has shown that walking has the potential to have widespread public health impact, mainly due to its ease and low cost (I. M. Lee & Buchner, 2008).

Walking associated with daily commuting by public transportation can have a considerable impact on public health; however, the extent to which different groups of the population can benefit from this routine activity is rarely studied. Zhao et al. (2003) measured walking distances to transit stops to forecast transit accessibility and El-Geneidy et al. (2010) measured walking distances to transit stops to estimate bus service areas around stops. Another study has looked at the number of theoretical steps ‘in reserve’ if non-users were to start using public transportation (Morency, Demers, & Lapierre, 2007). This study, however, did not incorporate characteristics of individuals, transportation service networks or neighborhoods in their understanding of the public health potential of public transportation.

Two studies have measured overall walking to transit, the first by Besser and Dannenberg (2005) in the United States and the second by Morency et al. (2011), in Montréal, Canada. Besser and Dannenberg (2005) used the 2001 National Household Travel Survey to examine total walking to light rail and public buses in the United States; however, they did not incorporate transit service characteristics nor differentiate between trip purposes

in their models. Previous research has pointed to the importance of modeling different trip purposes separately, as each trip purpose has different characteristics and interacts differently with the built environment (Handy, 1996a; Saelens et al., 2003). Large variation in walking distances and durations by trip purpose were found in the 2009 National Household Travel Survey (Yang & Diez-Roux, 2012) as well as other studies in the Twin Cities (Iacono et al., 2010) and Montréal (Larsen et al., 2010).

Morency et al. (2011) used the same survey data (Origin Destination survey) that is used in our analysis to estimate total walking to public transportation, similar to Besser and Dannenberg (2005). The study by Morency et al. (2011), however, did not distinguish trip purposes and did not take into consideration important contextual factors of neighbourhood and transit service characteristics. Accordingly, their walking trips model was missing key variables that may have contributed to a poor explanatory power (R-squared value of 0.069). The utility of their results is further hindered in that they are not reproducible elsewhere with routinely available software.

This paper estimates the amount of daily walking that can be achieved when commuting by public transportation by way of analyses of a travel behavior survey (Origin-Destination Survey) in Montréal, Canada. Our analyses unpack the underlying individual (e.g., age, gender, income level) and contextual factors (e.g., transportation service characteristics, land use diversity, street design, neighbourhood social characteristics) associated with this type of physical activity. Our research improves the current knowledge on this subject by: (1) focusing exclusively on commuting trips (work and school); (2) incorporating the influence of contextual factors of neighbourhood and transit service characteristics on daily walking in a multilevel modelling framework; and (3) providing a clear replicable methodology for use in other cities.

3.4 BACKGROUND

Our modern urban environments tend to promote sedentary lifestyles (Egger & Swinburn, 1997). The heavy dependence on single occupancy vehicles in North America and perceived lack of adequate time for physical activity can contribute to poor mental and physical health as well as the onset of chronic disease such as obesity, cardiovascular diseases, hypertension, osteoarthritis, some types of cancers and type 2 diabetes (Frank, Andresen, & Schmid, 2004; Jakicic & Gallagher, 2003; Katzmarzyk, 2004; Wei et al., 1999a). Physical inactivity is identified as the fourth leading risk factor for global mortality, estimated to contribute to 6% of deaths worldwide. It is clear that the overall burden of physical inactivity is a major public health concern and, from an economic perspective, a source of increasing health care utilization and expenditure (W. Brown, Hockey, & Dobson, 2008; Finkelstein, Fiebelkorn, & Wang, 2003; Sari, 2009).

At least 60% of the global population fails to achieve the minimum recommendation of 30 minutes of daily moderate physical activity (WHO 2003). In Canada, two-thirds of the population are not meeting this level of physical activity (Katzmarzyk, Gledhill, & Shephard, 2000; Public Health Agency of Canada, 2008; Sari, 2009). Advising people to increase physical activity is one solution, through public health campaigns and during individual patient encounters. It is notoriously difficult to change human behaviour, however, and so the general thinking is that such advice must be combined with macro-scale policies that have the potential to affect entire populations. Substantial public health benefits may require structural modifications in the transport system and the built environment, marketing policies, and the education system (Ekelund, 2012).

The use of active transportation provides an opportunity to introduce routine, daily physical activity into the lives of large groups of people and thus may be conceptualized as an

important population health intervention tool (Sallis et al., 2004; Transport Canada, 2005). Public transportation is considered an active mode of transportation since it involves walking to and from stations. In Canada, approximately 15.2% of work trips involve public transportation (Hollingworth et al., 2010), and in Montréal the figure is 13.7% (Agence métropolitaine de transport, 2003).

In this paper, total walking distances to and from transit stops for a variety of public transportation services (metro, commuter train, urban and suburban bus services) are estimated. These are further translated into minutes of physical activity in order to estimate the contribution of public transportation to achieving the public health goal of 30 minutes of daily physical activity⁴. Our analyses are informed by the general hypothesis that both individual factors (age, sex, socioeconomic status) and factors related to neighbourhoods and transit systems influence the amounts of physical activity that can be achieved by using public transportation. Knowledge of these factors can help inform the potential public health impacts of investments in public transportation.

3.5 METHODS

3.5.1 Study area, selection and description of participants

Montréal, Québec, is the second-highest populated metropolitan region in Canada with 3.7 million residents. Participants in this study were drawn from a travel behavior survey known as the Origin-Destination (OD) Survey (Agence métropolitaine de transport, 2003). The OD Survey is a phone survey conducted every five years in the Montréal metropolitan region by the Agence Métropolitaine de Transport (AMT) – the agency responsible for regional public transportation in Montréal. The OD Survey covers around 5% of the Montréal

⁴ New physical activity guidelines recommendation is 150 minutes of weekly moderate physical activity, which is equivalent to 30 minutes of daily moderate physical activity, 5 days a week (World Health Organization, 2011).

population (169,900 individuals). One person in every household contacted is asked to report all trips made by her/himself and every other member of the household in the previous day. Although this method might impose some error in the estimates of walking because of the proxy reporting, the Montréal OD survey has been extensively tested and several validation tools have been in place for several decades to ensure the quality of the collected data (Chapleau, 2003). For every trip, participants were asked to record the place where they started their trip (origin) and the place where they ended it (destination). Participants were also asked to record the mode of transportation used for each trip (i.e., bus, train, metro, car, cycling, walking, etc.). For participants using public transportation, additional questions were asked regarding which transit route they selected. All public transportation trips were tested against a database including all existing schedules in the region to ensure the accuracy of the reported trips.

Trips included in the analyses of this study were trips that were made by public transportation (i.e., bus, metro and train), where participants walked to and from public transit stops or stations. They represent 13.7% of the total trips in the OD survey. Participants cycling to trains were excluded since they comprise a tiny proportion of total trips (less than 0.0001%). Additionally, participants were non-retired adults 18 years and older for whom their primary trip purpose (first trip in the day) was going to work or school (college/university) - around 45% of all reported trips in the survey. These are the main trips that people conduct on a daily basis and are the routine trips that have the potential to support frequent and enduring physical activity (Figure 3.1).

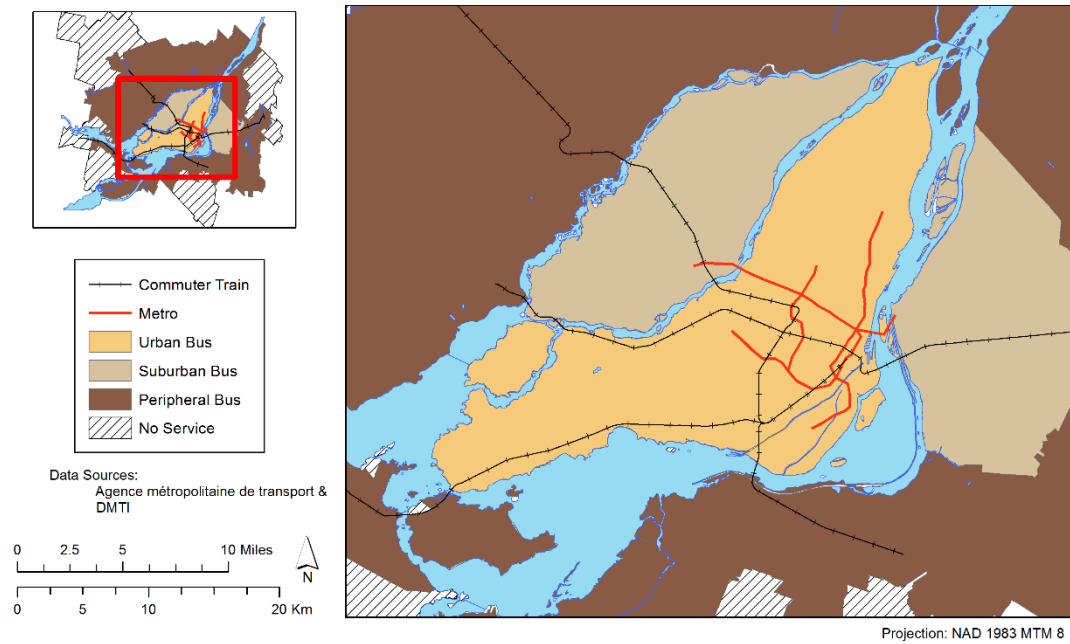


Figure 3.1: Transit services in the Montréal metropolitan region⁵

3.5.2 Calculation of variables used in the study

For each respondent, total distance walked to and from transit stops was computed in a Geographic Information System (GIS) environment. In the OD survey, respondents were not asked to report the actual transit stop or station they used, but were asked to report the transit route (e.g., bus number, metro line, etc). Total distance walked was measured on the street network from participants' origin location to the nearest transit stop or station of the transit route they used. Transit stop locations were obtained from different transit agencies in the region as XY locations, while origins and destinations were reported as XY coordinates in the OD Survey. The distance that participants walked at the end of their trip, from the nearest transit stop to their destination, was measured using the street network as well. Small paths

⁵ The Agence métropolitaine de transport (AMT) is an agency responsible for regional transit in Montréal. In this study, the region served by AMT is used as the study region.

and alleyways were included as part of the pedestrian network used, while freeways and any facility that did not allow pedestrians were excluded. For every transit trip, in-vehicle distance, which is the distance travelled inside the public transportation vehicle during the trip, was calculated using the transit network. Daily walking distances were calculated as:

Equation 3.1: $TDist = \sum_{T=1}^2 (WDO + WDD)$ Where:

TDist = Total distance walked for every person in the OD survey who used public transportation.

WDO = Walking distance measured from the trip origin to the nearest transit station or stop along the transit route.

WDD = Walking distance measured from the trip destination to the nearest transit station or stop along the transit route.

T = Number of transit trips made by a participant who walked to and from the transit stops.

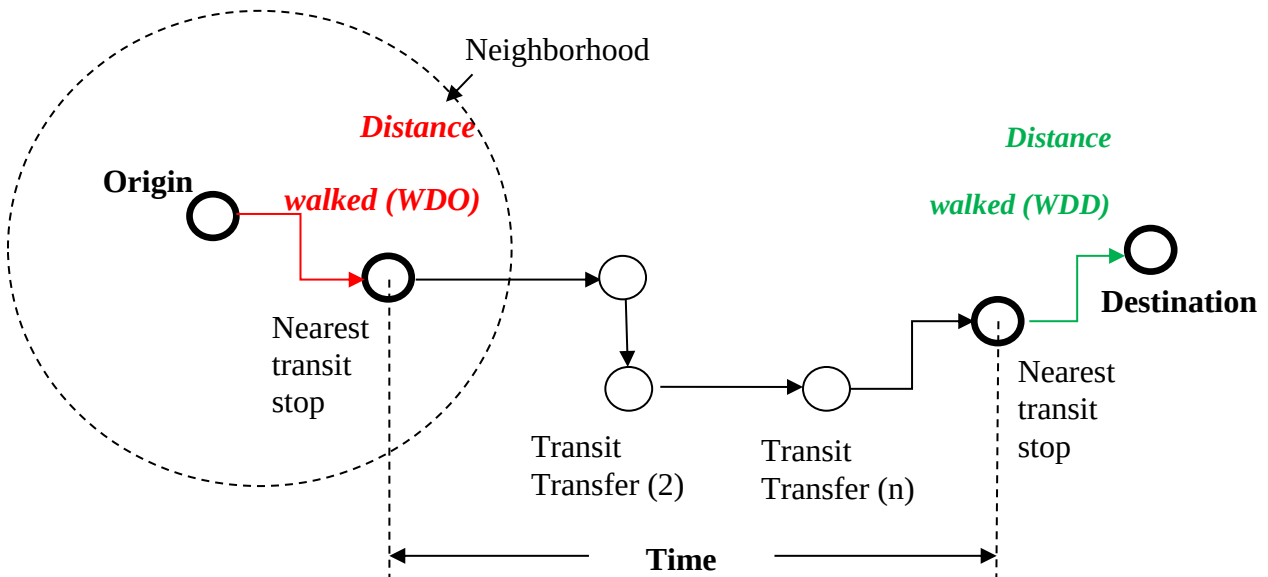


Figure 3.2: Hypothetical model of walking trips associated with transit use

Figure 3.2 shows a typical transit trip and its various components. Distances walked by respondents were then translated into walking minutes based on average walking speed. Observed average walking speed for adults varied from 4.8 to 5.7 km per hour (3 to 3.6 mile per hour) between different studies in North America and Australia (Bennett, Felton, & Akçelik, 2001; Fruin, 1971; Knoblauch, Pietrucha, & Nitzberg, 1996). The mid-range average speed observed by Knoblauch et al. (1996) was 5.4 km per hour (3.4 miles per hour or 90.6 meter per minute) for individuals 14-64 years old. Since our simulation models (described below) are based on a typical 20 year old male and a typical 34 year- old male, walking minutes are calculated based on the mid-range average walking speed (5.47 km/hour (3.4 miles/hour)).

3.6 MULTILEVEL ANALYSIS

OD respondents were placed into census tracts (CTs). CTs are defined by Statistics Canada as “small, relatively stable geographic areas that usually have a population of 2,500 to 8,000 with homogenous characteristics” (Statistics Canada, 2003). Census tracts have been shown to be valid proxies of residential neighborhoods of individuals (N. A. Ross, Tremblay, & Graham, 2004). A total of 547 CTs were included in the study; the median number of respondents included in each CT was 17 persons. A CT in Montréal covers an average area of 5.2 square km. Other data were collected as well at the CT level of analysis to control for neighborhood characteristics that might influence walking to transit service. These data included street center line files (street hierarchy, real length and speed limits) and enhanced points of interest files (e.g., retail, restaurants, recreation centers, etc.) obtained from Desktop Mapping Technologies Inc. (DMTI) (CanMap) datasets; land-use classifications obtained from the city of Montréal; and socioeconomic neighborhood characteristics obtained from the 2006 Census of Canada.

The level of attractiveness of a transit stop depends on individual, neighborhood and public transportation characteristics. Transit service characteristics that affect the amount of walking, include the type of service, its frequency and reliability (El-Geneidy et al., 2010; Fielding, Glauthier, & Lave, 1978). A multi-level regression analysis was conducted to measure the effect of individual, neighborhood and transit service characteristics on walking. Key variables at the individual level included age, sex, income and individual travel behavior, including type of transit used, and trip distance. Key variables at the neighbourhood level included education level, population density, land use density, land use diversity, street connectivity and public transportation characteristics, including type of transit service, frequency and schedule of transit service (Table 3.1).

Table 3.1: Variable definitions

Variables	Definition
<i>Total walking distance</i>	Individuals' total walking distance during the day for all trips done to and from transit stops or station (Equation 3.1)
Individual characteristics	
<i>Individual socio-economic characteristics</i>	
<i>sex (ref. =female)</i>	Dummy variable for sex of the individual
<i>Age</i>	Age of the individual in years
<i>Household income</i>	High Household income (\$80K>), Medium household income,(\$20K-79K), and low household (\$<20K)
<i>Individual travel behavior</i>	
<i>School</i>	Dummy variable for school trips
<i>Trip distance in (km)</i>	Total trip distance travelled while sitting in transit
<i>Type of transit service</i>	
<i>City bus</i>	Number of times city bus is used in a day
<i>Train</i>	Number of times the commuter train is used in a day
<i>Metro</i>	Number of times the Metro (subway) is used in a day
<i>Suburban bus</i>	Number of times the suburban bus is used in a day
<i>Peripheral bus</i>	Number of times the peripheral bus is used in a day
Neighborhood characteristics	
<i>Social characteristics</i>	
<i>Education</i>	Percent of people with university degrees
<i>Physical characteristics</i>	
<i>Built environment characteristics</i>	
<i>Population density/ km2</i>	Population density at the home location of the individual
<i>Retail density/ km2</i>	Retail density at the home location of the individual
<i>Street intersections/km2</i>	Number of street intersections around trip origin within 500 meters
<i>Transit service characteristics</i>	
<i>Time between every two consecutive transit vehicles (headway)</i>	The headway of the transit route used at the beginning of the day in minutes
<i>Time between every two consecutive transit vehicles squared (headway squared)</i>	The headway squared
<i>Transit service runs only in the morning (ref. All day service)</i>	A dummy variable that equals to 1 if the first trip started from (6AM to 9AM) and equals to 0 otherwise
<i>Transit service runs only in the evening (ref. All day service)</i>	A dummy variable that equals to one if the first trip started from (3:30 PM to 6:30 PM) and equals to 0 otherwise

3.7 RESULTS

3.7.1 Sample

There were 37,411 public transportation trips reported in the 2003 OD survey. These trips were made by 18,445 individuals residing in the Montréal metropolitan region in 2003 (Agence métropolitaine de transport, 2003). The sample was limited to respondents who made a maximum of 6 transit trips per day – representing 99.93% of the total sample (18,429 individuals) –who were adults (workers and students) 18 years or older (3,089 individuals under 18 years old, and 1,267 retired individuals were excluded from the sample). Some outliers were deleted: individuals who resided in households owning more than 4 cars (22 observations); individuals who resided in households with more than 8 people (14 observations); and one individual whose age was more than 90 years. This left a sample of 14,057 people. From this total, 12,775 individuals started their first trip from their home, and of these, 29 individuals were excluded as they lived outside the study region. Respondents whose primary trip purpose (first trip in the day) was going to work (7,289 people) or going to school (college/ university (3,432 people)) were included (at total of 10,721 people). There were 1,894 individuals who did not report their income and 159 individuals had other missing data and these respondents were excluded. Finally, individuals doing complex ‘trip chains’ (1,755 people) were excluded from the study. A trip chain is a trip that incorporates various destinations. These were excluded due to our focus on the routine, daily, commuting-style trips, leaving a final sample of 6,913 respondents. All origins and destinations were then plotted in a GIS environment, and compared against all transit trips reported in the OD Survey, to ensure the filtering process did not lead to any systematic bias in the distribution of the subset of trips included in our analysis.

3.7.2 Descriptive Statistics

3.7.2.1.1 Respondent characteristics

Just over half (57%) of the respondents were females, and the average age of the group was 33.6 years (SD 12.4 years). The majority of the sample (66%) was employed while 33% were students. Approximately 18% of the respondents lived in households earning less than \$20K per year. For about 65% of respondents, their household incomes were between \$20K and \$79K; and just over 16% lived in households with incomes greater than \$80K per year.

3.7.2.1.2 Neighborhood characteristics

There were 547 CTs in the Montréal metropolitan area in 2006. The percentage of university graduates across the CTs varied from 5.8% to 80% with an average of 31% (SD 15.3%); population density varied from approximately 67 to 44,078 individuals per square km with an average of 7,288 (SD 6,826); retail density had an average of 302.5 retail establishments per square km (SD 494.1). Street connectivity had an average of 145 street intersections within a 500 meter buffer (SD 58.4).

3.7.2.1.3 Trip characteristics

The Metro (subway) and city bus were used in approximately 57% of the trips; train was used in 39% of the trips; suburban buses in 15% and peripheral buses in 3% of the trips. The number of transfers made in a day during all trips ranged from none to a maximum of 8 transfers, with 2 transfers at the 75th percentile (SD 1.7). The average one way trip distance was 10.75 km leading to 21.5 km (SD 15.08km) of total distance traveled by transit in a day by individuals.

The average total utilitarian walking distance per day was 1,480 meters (SD 950m). On average, across all ages, females walked 1.24 minutes fewer than males. Walking to and from

public transit stops decreased with advancing age, with the average walking distance dropping by approximately 206 metres (2.3 minutes) between females aged 18 to 25 years old and 55 to 65 years old, and approximately 105.9 meters (1.2 minutes) between males aged 18 to 25 years old and 55 to 65 years old.

3.7.3 Multi-level regression findings

We tested two types of statistical models. The first was a linear regression model and the second was a multi-level model. While the linear regression model had an r-squared value of 0.234, suggesting significant improvement in explanatory power over past models of walking to transit (e.g., Morency et al. (2011) had an r-squared value of 0.067), the likelihood ratio test that compares the multi-level regression model to the linear regression model was significant, which suggested that it is important to take into consideration that respondents of the OD survey were nested within neighborhoods.

There was a statistically significant difference in walking distance between males and females, with males walking 59.44 meters (0.65 minutes) more than females when holding all other factors at their mean (Table 3.2). Walking distances decreased around 36 meters (0.39 minutes) with every decade increase in age. Walking distance differed significantly by household income level. Individuals with low household income (less than \$20K) walked 201.51 metres (2.12 minutes) fewer per day than individuals with household incomes \$80K or higher. Walking to transit for a school trip was slightly higher than walking to transit for a working trip by 78.5 meters (0.86 minutes).

Walking distances were associated with public transportation characteristics but not with neighborhood socio-economic (e.g., education) or physical characteristics (e.g., population density, land use mix and street connectivity). Each trip conducted by a commuter train contributed to daily walking distances of approximately 1319.29 meters (14.47

minutes). Trips made using buses serving the peripheral areas contributed to walking distances of approximately 899.53 meters (9.86 minutes) while Metro (subway) trips contributed 633.84 meters (6.9 minutes) of walking. Bus trips made the smallest contribution, with every trip made using suburban bus service adding 455.95 meters (6.95 minutes) and city buses adding 273.34 meters (2.99 minutes) to walking distances.

Trip length did not achieve statistical significance in the model, yet, it had a negative impact on the total walking distances. Transit headway (which is the time between two consecutive transit vehicles) had a negative impact on the total walking distances. A decrease in the transit headway reflects an increase in the frequency of service and hence more walking. For example, if the time difference between two consecutive buses (headway) was 10 minutes near the home origin, the total walking distance decreased by 71 meters (0.77 minutes). Meanwhile, if the headway is changed to 15 minutes, the average total walking distance decreases by 104 meters (1.14 minutes).

3.7.3.1 *Interpretation of the random part of the model*

The random part of the model shows the standard deviations of the intercept and residuals (error term). In general, the idea of the random coefficient demonstrates that the overall error variance consists of two parts: the first results from the random variation of the intercept (standard deviation of the constant), and the second results from the variance of the error (standard deviation of the residual). The intra-class correlation coefficient showed that approximately 6.67% of the total variance in walking distance was explained from variation between the CTs. It was estimated that 95% of the random coefficient of the walking intercept varied between 183.39 meters and 242.49 meters, suggesting significant variability in walking to public transportation between CTs in Montréal.

Table 3.2: Multi level regression model, total walking distance /day in meters

Variable	Coefficient (meters)	Z	P> Z	95% confidence interval	
Individual level					
Individual socio-economic characteristics					
Sex (reference=female)	59.44**	3.03	0.00	20.99	97.88
Age	-3.60**	-3.83	0.00	-5.44	-1.75
Medium income (\$20K - 79K)	-122.62**	-4.43	0.00	-176.90	-68.34
Low income (<\$20K)	-201.51**	-5.69	0.00	-270.89	-132.14
Individual travel behaviour					
School Dummy	78.50**	3.10	0.00	28.79	128.20
Trip distance in (km)	-0.32	-0.38	0.70	-1.97	1.33
Number of times transit service used					
City bus	273.34*	2.29	0.02	39.12	507.56
Commuter train	1319.29**	10.57	0.00	1074.5	1564.02
Metro	633.84**	5.28	0.00	398.39	869.30
Suburban bus	455.95**	3.76	0.00	218.11	693.80
Peripheral bus	899.53**	6.99	0.00	647.48	1151.58
Neighborhood characteristics					
Social characteristics					
Percentage of people with university degree	-0.56	-0.59	0.56	-2.43	1.31
Physical characteristics					
Built environment characteristics					
Population density/ km2	0.00	-0.25	0.80	0.00	0.00
Retail density/ km2	0.02	0.82	0.41	-0.03	0.06
Street intersections/km2	0.07	0.36	0.72	-0.30	0.44
Transit service characteristics					
Schedule of service					
Time between every two consecutive transit vehicles	-7.10**	-6.07	0.00	-9.39	-4.81
(Time between every two consecutive transit vehicles) ²	0.01**	5.71	0.00	0.01	0.01
Transit service runs only in the morning (ref. All day service)	-234.60**	-3.64	0.00	-360.78	-108.43
Transit service runs only in the evening (ref. All day service)	389.53**	5.50	0.00	250.73	528.33
Constant	812.12**	3.26	0.00	323.83	1300.42
Random-effects parameters					
Canadian census tract : Identity	Estimate	Std. Error	95% confidence interval		
sd (Constant)	211.08	15.14	183.39 242.94		
sd (Residual)	790.97	6.98	777.39 804.79		

** Statistically significant at the 99% confidence level

* Statistically significant at the 95% confidence level.

3.7.4 Achieved minutes of walking

In order to show the impacts of total walking to transit on physical activity, walking minutes to transit stops were estimated for each mode of public transit based on the multi-level regression model. The simulation is derived from multiplying the coefficients obtained from the statistical model by the mean values of every variable. Each simulation was conducted for a work or school trip made by a typical male respondent of 20 years and 34 years with a household income between \$20K and \$ 79K (Table 3.3). For dummy variables the value of 1 is multiplied by coefficients of the specific public transportation mode to derive the simulation results for certain modes. All multiplication outputs are then added to derive the expected walking time when certain trip characteristics are met. This method was used in previous research to highlight how different changes in the independent variables affect the dependent variable (El-Geneidy et al., 2010; Tétreault & El-Geneidy, 2010).

Approximately 11% of commuters achieved the 30 minutes of recommended physical activity solely through walking to and from public transit stops to commute to work or school. Simulated trips that met the recommended 30 minutes of physical activity by walking to and from public transit stops during a daily commute are reported in bold. Italicized values indicate that the trip meets the above mentioned criteria through bouts of at least ten minutes of activity as recommended by the WHO (2010b). Commuter train trips were associated with the maximum walking minutes (34.59 to 49.91 minutes), while trips made by bus serving the peripheral areas were the next highest (25.38 to 40.7 minutes). This was followed by walking to Metro (subway) (19.55 to 34.87 minutes). Average minutes achieved through walking to and from suburban bus stops were higher than those achieved through walking to bus stops on the island of Montréal (city buses). These findings can be linked to the distribution of service in the suburban areas and/or type of service (frequency and final destination location).

On average, walking time achieved through walking to and from suburban bus stops was between 15.56 to 30.97 minutes compared to 11.65 to 26.96 for city bus stops.

Table 3.3: Achieved walking minutes and distance to and from transit stops and stations for work and school trips

Mode of Transport	School Trips			Work trips		
	No Transfers	2 Transfers to Metro	2 Transfers to City Bus	No Transfers	2 Transfers to Metro	2 Transfers to City Bus
City bus	1190.52 (13.06)	2458.21 (26.96)	1737.20 (19.06)	1061.68 (11.65)	2329.37 (25.55)	1608.36 (17.64)
Commuter train	3282.41 (36.00)	4550.10 (49.91)	3829.09 (42.00)	3153.57 (34.59)	4421.26 (48.50)	3700.25 (40.59)
Metro	1911.53 (20.97)	3179.21 (34.87)	2458.21 (26.96)	1782.69 (19.55)	3050.38 (33.46)	2329.37 (25.55)
Suburban bus	1555.74 (17.06)	2823.43 (30.97)	2102.42 (23.06)	1426.90 (15.65)	2694.59 (29.56)	1973.58 (21.65)
Peripheral bus	2442.90 (26.80)	3710.58 (40.70)	2989.58 (32.79)	2314.06 (25.38)	3581.75 (39.29)	2860.74 (31.38)

Note: Distance reported in meters, while time reported between parentheses in minutes

3.8 DISCUSSION AND CONCLUSIONS

This paper sought to estimate the extent to which daily physical activity requirements can be met by using public transportation in the daily commute to school or work, with the additional aim of identifying characteristics associated with this type of utilitarian walking. Females walked less than males (by 0.65 minutes per day), walking decreased with age and was higher for individuals with higher household incomes compared to the less affluent. Minutes walked to and from public transportation varied to a great extent with each mode of public transit used. The maximum minutes walked were by commuter train users (49.91 minutes per day with two transfers to a Metro).

Findings are consistent with previous research that identified guidelines for maximum walking distances to public transportation. Walking guidelines vary from 400 to 482 meters (0.25- 0.3 miles) for bus stops (Gutiérrez & García-Palomares, 2008; Hsiao, Lu, Sterling, & Weatherford, 1997; Kimpel, Dueker, & El-Geneidy, 2007; Murray & Wu, 2003; Neilson & Fowler, 1972; O'Neill, Ramsey, & Chou, 1992; Zhao et al., 2003) and 800 meters (0.5 miles) for rail stations (Kuby, Barranda, & Upchurch., 2004; Schlossberg, Agrawal, Irvin, & Bekkouche, 2007). Approximately 11% of commuters achieved the 30 minutes of recommended physical activity just through walking to and from public transit stops to commute to work and school. These results align with those of Besser and Dannenberg (2005) who suggested that public transit users can meet recommended minutes of physical activity and that commuter train users tend to have the most success in achieving public health recommendations. Morency et al. (2011) did not find that any commuter types met the 30 minutes of physical activity and these contradictory findings seemingly are related to differences in modeling techniques and variables included in their models.

One of the major reasons why walking distances to bus stops are lower than walking to other modes of public transportation has to do with the standards of bus stop spacing compared to other types of transit. In general, bus stop spacing is denser in North America compared to European cities. Bus spacing is also closer in the central areas of cities compared to suburbs (El-Geneidy, Strathman, Kimpel, & Crout, 2006). Increasing bus stop spacing is currently being discussed in several North American regions with the goal of increasing the efficiency and reliability of service and this should also increase the potential for physical activity for these users. Other ideas include stop removals (stop consolidation) in areas where the spacing is too tight with the goal of increasing efficiency without harming accessibility for less mobile users

The type and characteristics of the public transportation service used by commuters was more important than the physical and socio-economic characteristics of neighborhoods for walking. We found that individuals with low household income (less than \$20K) walked approximately 201.51 metres (2.21 minutes) less per day compared to individuals living in the most affluent households. These differences are related to the way the public transportation network is structured. Wealthy suburban neighborhoods are generally low density and harder to serve when compared to denser, lower income neighbourhoods closer to the city centre. Interestingly, viewed as a public health intervention, public transportation may produce unintended outcomes that could actually increase health disparities related to physical activity. Existing commuter trains in the Montreal area tend to service wealthy Montréal neighbourhoods and these commuters walk the most minutes compared to users of other modes of public transportation. A new commuter train line is currently proposed to serve low income suburbs in Montreal, which could, in turn, balance out these findings.

Access to public transportation service, which is the opportunity of having a reliable transit service within a reasonable walking distance, was positively associated with walking in this study as well as an earlier study (Schlossberg et al., 2007). Contrary to earlier studies that examined determinants of walking in neighborhoods, neighborhood physical characteristics (e.g. land use mix, street connectivity and land use density) (Ewing & Cervero, 2010; Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Saelens & Handy, 2008) did not show any statistical association with walking to public transportation. Positive associations with walking distances found in earlier studies included population and dwelling density; land-use mix (Finkelstein et al., 2003; Hsiao et al., 1997; Loutzenheiser, 1997; Zhao et al., 2003) well connected streets (Hsiao et al., 1997; Loutzenheiser, 1997; Zhao et al., 2003); number of parking spaces at the stations (Loutzenheiser, 1997); and safety (Hsiao et al., 1997; Loutzenheiser, 1997; Zhao et al., 2003).

Our study confirms the role of public transportation in supporting active transportation and we demonstrate that suburban train users can meet recommended minutes of daily physical activity just by commuting to work or school. Although the recommended minutes of physical activity were not achieved by users of other modes of public transportation, we should not discount the smaller amounts of physical activity achieved by these different groups. In the words of the WHO (2010b), *“Inactive people should start with small amounts of physical activity and gradually increase duration, frequency and intensity over time.”* Public transportation can be used as a tool to start this process for many individuals. That said, being viewed as a public health intervention, public transportation planning must balance public service provision with an aim of increasing physical activity for all socioeconomic groups across the city, especially in areas where bus users walk less than other transit users.

3.9 STUDY LIMITATIONS

The OD Survey provides a representative sample of Montréal travel behavior (5% of the population). However, it is a one day travel diary that does not take into account seasonal influences in travel behaviour in a city with weather extremes. There could be some error associated with the fact that land use and census data are from different years than the OD survey (2006, versus 2003). Walking between transfers could add to the total achieved minutes per day; however it was technically difficult to measure walking during transfers in this study. Also we used the shortest distance to the nearest stop. If, however, an individual chose to walk longer distances for safety or other reasons, these additional walking distances would not be captured. Presence of sidewalks, stop signs, and traffic signals were not included in this study mainly due to lack of available information.

4 CHAPTER FOUR: EXPOSURE TO WALKABLE NEIGHBOURHOODS IN URBAN AREAS INCREASES UTILITARIAN WALKING: LONGITUDINAL STUDY OF CANADIANS

4.1 OVERVIEW OF THE CHAPTER

In this chapter, I addressed the second objective of this dissertation, namely, examining the effect of exposure to highly walkable neighbourhoods on utilitarian walking. This objective was achieved through a longitudinal study that is conducted using the National Population Health Survey (NPHS), and other supplementary datasets (e.g., DMTI street center lines, and DMTI enhanced points of interests and measures of local accessibility (Walk Score®). The longitudinal analysis gives the opportunity to model utilitarian walking for a Canadian cohort that is followed for 12 years, from 1994 to 2008. The manuscript draws upon and contributes to the health geography, social epidemiology and urban planning literature related to neighbourhood effects on walking. This manuscript has been accepted for publication in the *Journal of Transport and Health*). “Exposure to walkable neighbourhoods in urban areas increases utilitarian walking: longitudinal study of Canadians”. *Journal of Transport and Health*. doi: 10.1016/j.jth.2015.08.001.

4.2 ABSTRACT

4.2.1 Background

Purposeful or utilitarian walking may allow a time-efficient, low cost accumulation of physical activity. While constructing a built environment that supports utilitarian walking is conceptually appealing, longitudinal research investigating the enduring influences of the environment on walking behavior has been limited.

4.2.2 Purpose

This research examines the relationship between utilitarian walking levels and neighbourhood walkability through longitudinal analyses of a population-based cohort.

4.2.3 Methods

Data are from Canada's National Population Health Survey (n=2,976; biannual assessments 1994- 2006). Socio-demographic and health data were linked to residential neighbourhoods via postal code. Walkability was measured by the Walk Score®. Levels of utilitarian walking were modeled as a function of Walk Score® and socio-demographic and behavioural covariates using mixed effects ordered logistic regression and fixed effects logistic regression.

4.2.4 Results

Moderate utilitarian walking increased from 24% to 36% over the study period, with the highest increase (15%) for participants living in the most walkable neighbourhoods. In multivariate analyses, a one unit increase in the probability of spending more time in the 4th vs 1st Walk Score® quartile neighbourhoods increased moderate utilitarian walking by 4% (95% C.I. 2.9%, 5.1%). The influence of neighbourhood walkability persisted through adjustment for individual co-variables including leisure time physical activity. Moving to a higher walkable neighbourhood increased the odds of moderate and high utilitarian walking by 59% (95% C.I. 3%-140%) compared to other types of residential moves.

4.2.5 Conclusions

Exposure to more walkable neighbourhoods and moving from less walkable to more walkable neighbourhoods were associated with increases in utilitarian walking, even for individuals who were otherwise inactive in their leisure time. Walkable neighbourhood

environments have the potential to increase utilitarian walking and walking-friendly neighbourhood design should be considered amongst policy options for increasing population level physical activity.

4.3 INTRODUCTION

Constructing a built environment that facilitates walking is conceptually appealing and there are studies that signal an association between built environmental influences and utilitarian walking (Besser & Dannenberg, 2005; Cervero & Gorham, 1995; Cervero & Radisch, 1996; Handy, 1996b; Handy et al., 2002; Handy & Clifton, 2001; Kitamura, Mokhtarian, & Laidet, 1997; Thielman et al., 2015; Wasfi, Ross, & El-Geneidy, 2013).

For example, the energy expenditure calculated from the number of estimated weekly utilitarian walking trips reported by residents of highly walkable neighbourhoods in Canadian cities was consistently higher by approximately 1.7 kcal/kg/day than that reported by residents of low walkable neighbourhoods (Thielman et al., 2015). Similar associations between neighbourhood walkability and utilitarian walking persisted in a number of studies in the United States and Canada (Ewing & Cervero, 2010; Grasser et al., 2013; Saelens & Handy, 2008). There are, however, a number of inconsistencies in the body of research examining associations between built environmental influences and physical activity (Ewing, 2005; Forsyth et al., 2007; Handy, 2005; Handy et al., 2002; Smith et al., 2008). Research in this area has struggled to establish causal relationships because of reliance on cross-sectional study designs and their concomitant problems of self-selection of residents, who may already be motivated walkers, into more walkable neighbourhoods.

A longitudinal analysis in the United States (the Multi-Ethnic Study of Atherosclerosis (MESA)), estimated the impact of neighbourhood walkability on utilitarian walking for a sample of older adults (45 to 84 years old at baseline) who changed their residential location

(Hirsch et al., 2014). Moving to a more walkable neighbourhood (a 10 point higher Walk Score®) was associated with increasing the odds of meeting “ Every Body Walk” campaign goals (≥ 150 minutes/week of walking) by 11% (95% C.I. 0.2% , 21%).

Our study aims to add to this emerging longitudinal evidence base of the influence of the built environment on utilitarian walking with a large population sample that includes both movers (people who changed their residential neighbourhood during the 12 years of the survey follow up) and non-movers (people who stayed in the same neighbourhood for the entire 12 years of follow up). We model not only the likelihood of walking for utilitarian purposes, but also levels of utilitarian walking (a revealed limitation in the MESA study due to insufficient sample size (n=701)).

4.4 METHODS

4.4.1 Data sources and sample size

Our sample comes from the National Population Health Survey (NPHS), a longitudinal survey conducted biannually by Statistics Canada starting in 1994/95. The target population of the NPHS is household residents in the ten Canadian provinces excluding some special groups (e.g. persons living on Indian Reserves and Crown Lands) (Statistics Canada, 2009). We used the first seven cycles of data collection. Access to the data was granted by the Social Sciences and Humanities Research Council of Canada (#09-SSH-MCG-2068). Analyses were performed at the McGill-Concordia Quebec Inter-University Center for Social Statistics (QICSS).

We restricted our analysis to adults (18 to 55 years old at baseline) living in urban areas ($> 50,000$ population), who answered the following utilitarian walking question: *“In a typical week in the past 3 months, how many hours did you usually spend walking to work or to school or while doing errands? (none, less than one hour, 1 to 5 hours, 6 to 10 hours, 11 to*

20 hours, more than 20 hours)”. We included participants who either did not change their residential location or who relocated to a new neighbourhood once during the follow-up period, to allow for sufficient exposure time. Respondents with inconsistent answers (i.e., those who reported some utilitarian walking but also reported their inability to walk in another question) and those who stopped answering the survey after the first cycle were excluded from the analyses.

4.4.2 Description of variables

4.4.2.1 Outcome measure

The primary outcome of interest was utilitarian walking. We reclassified the six categories of utilitarian walking to four: (1) None, (2) Low (less than an hour per week), (3) Moderate (1 to 5 hours per week), and (4) High (6 hours or more per week). This is consistent with previous research in this field (Bauman et al., 2009; Blair, Cheng, & Holder, 2001).

4.4.2.2 Neighbourhood walkability

The Walk Score® has demonstrated very strong explanatory capacity for utilitarian walking (Manaugh & El-Geneidy, 2011) and it was our primary exposure of interest. The Walk Score® is based on distances to various weighted amenities (e.g. shopping, schools, parks and restaurants) and scores range from 0 to 100. We used the 2012 Walk Score® in the analyses. We divided the Walk Score® into four quartiles as follows: Low walkable neighbourhoods 0 to 39; Low-medium walkable neighbourhoods 40 to 55; Medium-high walkable neighbourhoods 56 to 69; and highly walkable neighbourhoods 70 to 100. We computed cumulative exposure to each Walk Score® quartile (WSQ) for all respondents based on the biannual reported residential locations and year of moving to a new residential neighbourhood, captured for every respondent as follows: *Proportion of cumulative exposure time (PCET) of respondent X to Walk Score® in quartile I after T survey years = (No. of total*

years in WSQI)/T. In our analysis I ranged from 1 to 4, indicating the four Walk Score® quartiles and T ranged from 2-12 (in multiples of 2), representing the time spent in each neighbourhood quartile level. Table 4.1 demonstrates an example of an individual (x) who moved from a low-medium walkable neighbourhood (WSQ2) to a high walkable neighbourhood (WSQ4) 6 years from baseline. The table shows the cumulative exposure time (CET) spent in each neighbourhood type at each cycle of the survey (from 1994 to 2006), and the proportion of cumulative exposure time (PCET) to these neighbourhoods at each cycle.

Table 4.1: Demonstration of neighbourhood walkability cumulative exposure variable

Year	Time (T)	Individual ID (X)	WSQ (I)	*CET to WSQ1 in years	CET to WSQ2 in years	CET to WSQ3 in years	CET to WSQ4 in years	**PCET to WSQ1	PCET to WSQ2	PCET to WSQ3	PCET to WSQ4
1994	0	x	2	0	0	0	0	0	0	0	0
1996	2	x	2	0	2	0	0	0	2/2	0	0
1998	4	x	2	0	4	0	0	0	4/4	0	0
2000	6	x	4	0	6	0	0	0	6/6	0	0
2002	8	x	4	0	6	0	2	0	6/8	0	2/8
2004	10	x	4	0	6	0	4	0	6/10	0	4/10
2006	12	x	4	0	6	0	6	0	6/12	0	6/12

*CET: Cumulative exposure time

**PCET: Proportion of cumulative exposure time

NPHS respondents who moved over the follow-up period were particularly interesting as they provided a quasi-experiment of changes in utilitarian walking associated with changes in exposures to different levels of walkability. To determine the effect of moving between neighbourhoods with different walkability levels, we centered the Walk Score® quartile (WSQ) variable for each survey respondent around their baseline Walk Score® quartile. Centering variables around initial status is a common practice in longitudinal analysis to detect change (Singer & Willet, 2003). From the centered Walk Score® quartile variable, we constructed two dummy variables that indicated whether the respondents “changed/ moved” two or more Walk Score® quartiles (in either direction) after relocation. A positive change in

Walk Score® quartile indicated an increase in walkability, and a negative change indicated a decrease in walkability.

4.4.2.3 *Other potential determinants of utilitarian walking*

The individual-level potential determinants of walking considered were age, sex, education, leisure time physical activity, and perceived health status. It has been suggested that a supportive built environment is insufficient on its own to guarantee that people will be physically active; motivation and good health are important drivers of utilitarian walking (Handy & Mokhtarian, 2005). Accounting for these factors allows for more precise estimates of the incremental influence of the built environment on utilitarian walking. A physical activity index calculated from leisure time physical activity (Statistics Canada, 2009) was classified as inactive (energy expenditure (EE) less than 1.5 kcal/kg/day), and moderately active (combined moderate (EE 1.5 to 2.9 kcal/kg/day) and active (EE greater than 3 kcal/kg/day), education level was classified as having a post-secondary education (yes/no), and perceived health was classified as unhealthy (poor or fair) versus healthy (good, very good, or excellent).

4.4.3 Statistical analysis

At the outset, we conducted an attrition analysis to ensure that the remaining sample reflected similar characteristics to the original cohort. Attrition (i.e., the loss of participants over time) can be a methodological problem for longitudinal studies if participants do not drop out at random, (Little & Rubin, 2002). We then used a mixed effects ordered logistic regression to model levels of utilitarian walking in order to take full account of the range of ordered responses to the utilitarian walking question. Our models did not violate the proportionality assumption of ordered logit. Marginal effects for each category of the dependent variable were computed. Marginal effects present the change in probability of a

particular alternative as a function of a unit change in the independent variable (see (Eluru, Bhat, & Hensher, 2008) for a more detailed discussion). The mixed effects ordered logistic regression was advantageous for accounting for multiple observations across the seven cycles of the NPHS. We also estimated a binary fixed effects logistic regression model of utilitarian walking for those who moved over the study period (i.e., respondents who “changed/ moved” 2 or 3 Walk Score® quartiles in either direction after relocation versus other movers) to estimate the effect of moving on utilitarian walking.

Computing fixed effects estimates in the ordered and binary regression models allowed us to control for unobserved heterogeneity, which is a limitation of standard regression analyses (e.g., ordinary least squares or random effects models). The fixed effects approach accounts for any unmeasured confounding variables that are constant over time (e.g., time constant personal preferences), thereby reducing estimation biases (Allison, 2005; Frees, 2004). To explain the methods behind the fixed effects estimators, in a simplified manner, let us assume that there is only one source of unobserved group heterogeneity (for example, time constant personal preferences). In this case the fixed effects estimator would be equivalent to de-meaning the dependent and independent variables with respect to the group (i.e., the person in the case of multiple observations of the same person in longitudinal data) and then estimating the model using ordinary least squares. This is why in binary fixed effects regression models, estimates of time constant control variables (e.g., sex) are not computed. They depend on within-person changes. Fixed effects give us unbiased estimates for the main exposure of interest – in this case the change in Walk Score® quartiles as a result of moving – from potential measured or unmeasured time constant confounders.

4.5 RESULTS

4.5.1 Sample description

From the 17,276 members of the original NPHS cohort in cycle 1, there were 10,367 adults living in urban areas, and 6,545 of them were between the age of 18 and 55 years at baseline (i.e., by last follow-up they were still mainly working age adults). From the 6,545 respondents, 3,483 did not change their residential locations, or moved once during the survey follow-up period. After exclusions of respondents with inconsistent answers, and people who were lost after the first cycle, we were left with a sample of 2,976 (Figure 4.1). Our attrition analysis showed no meaningful differences in health status or utilitarian walking for people who were lost compared to those who remained in the sample (see Appendix 2).

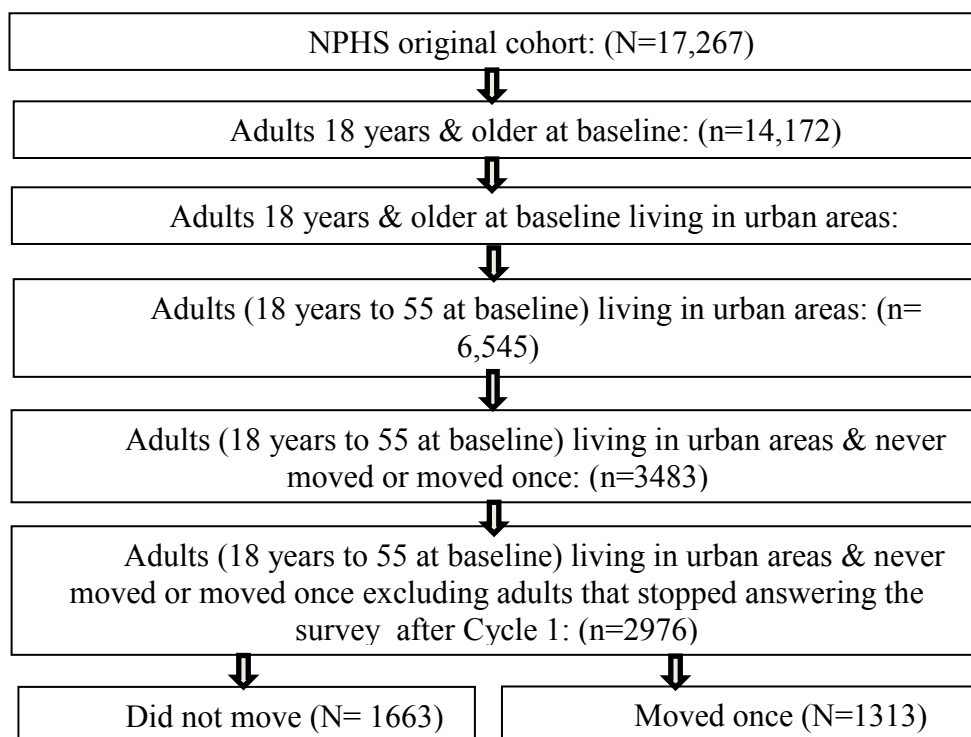


Figure 4.1: Description of sample selection

4.5.2 Summary statistics

Men comprised 48% of the final sample, with mean age of 38 years old (SD=9) at baseline. There were 1,313 individuals (48% men) who changed their residential locations once and 1,663 individuals who did not move (52% men). At baseline, approximately 59% of the sample completed post-secondary education. More than half of the sample was inactive at baseline (60%); the vast majority (93%) reported themselves to be healthy (Table 4.2). Approximately one third of inactive people changed to being active over the follow-up period and 29% of active people became inactive, keeping the overall percentage of inactive people similar across the follow-up period.

Table 4.2: Summary statistics at baseline (Cycle 1)

Variables	%, or Mean (SD)				
	Overall sample at baseline	Living in WSQ1 at baseline	Living in WSQ2 at baseline	Living in WSQ3 at baseline	Living in WSQ4 at baseline
Age (SD)	38 (9)	39 (9)	39 (9)	38 (9.5)	37 (9.7)
Men	48%	53%	48%	46%	45%
Completed post-secondary education	59%	58%	57%	59%	57%
Good perceived health	93%	94%	94%	92 %	93%
Active in leisure time	40 %	42%	40%	35%	41%
No utilitarian walking	41%	46%	41%	40%	40%
Low utilitarian walking (less than an hour)	17%	14%	17%	18%	19%
Moderate utilitarian Walking (1 to 5 hours)	24%	21%	24%	24%	25%
High utilitarian walking (6 hours or more)	18%	19%	18%	18%	16%
Sample (n = 2976)	100%	37%	15%	29 %	19%

There was an overall increase in the percentage of people who walked for utilitarian purposes in all neighbourhoods over time. At baseline, 41% of the sample did not walk at all for utilitarian purposes; this percentage decreased to 32% after 12 years. Similarly, the proportion of respondents reporting moderate utilitarian walking increased from 24% to 36% over the study period. The increase in the percentage of respondents that walked for

utilitarian purposes was more pronounced in neighbourhoods with higher Walk Score® values compared to lower ones. For those living in the least walkable neighbourhoods (Walk Score® quartile 1), the percentage of people reporting moderate utilitarian walking increased by 10% (from 21% at baseline to 31% after 12 years) whereas it increased by 15% (from 25% to 40%) for those in highly walkable neighbourhoods (Walk Score® quartile 4). Changes in utilitarian walking were detected for both non-movers and movers. Around 21% of non-movers who did not walk for utilitarian purposes at baseline, and were living in the least walkable neighbourhoods, changed to moderate walking, compared to 27% of non-movers living in high walkable neighbourhoods. Similarly, 25% of non-movers with low utilitarian walking at baseline living in the least walkable neighbourhoods changed to moderate walking compared to 40% in high walkable neighbourhoods (Figure 4.2).

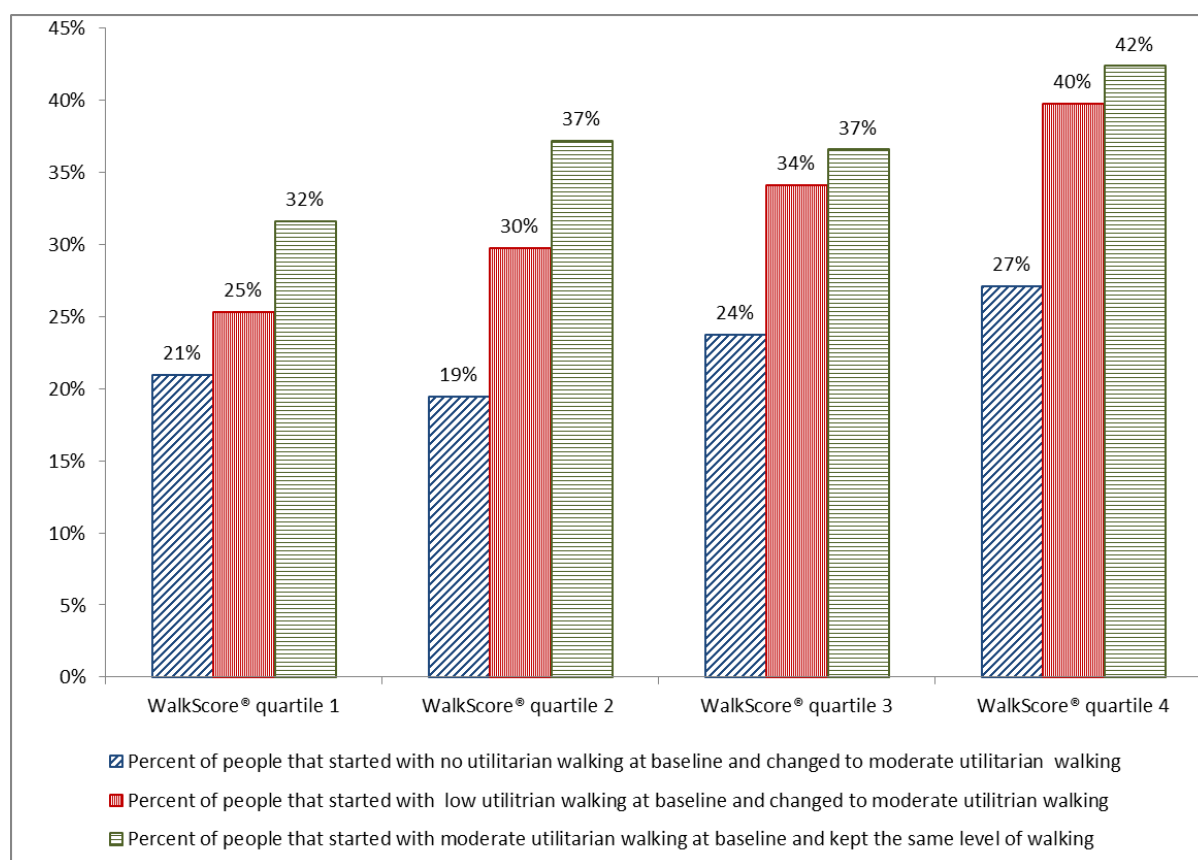


Figure 4.2: Changes in utilitarian walking levels for urban-dwellers “non-movers”; NPHS, 1994-2006

Nearly 44% of people who moved from low to highly walkable neighbourhoods increased their utilitarian walking, compared to 31% of those who moved from high to low walkable neighbourhoods. Around 41% of individuals who moved to lower walkable neighbourhoods decreased their utilitarian walking compared to 27% of those who moved to higher walkable neighbourhoods (Figure 4.3).

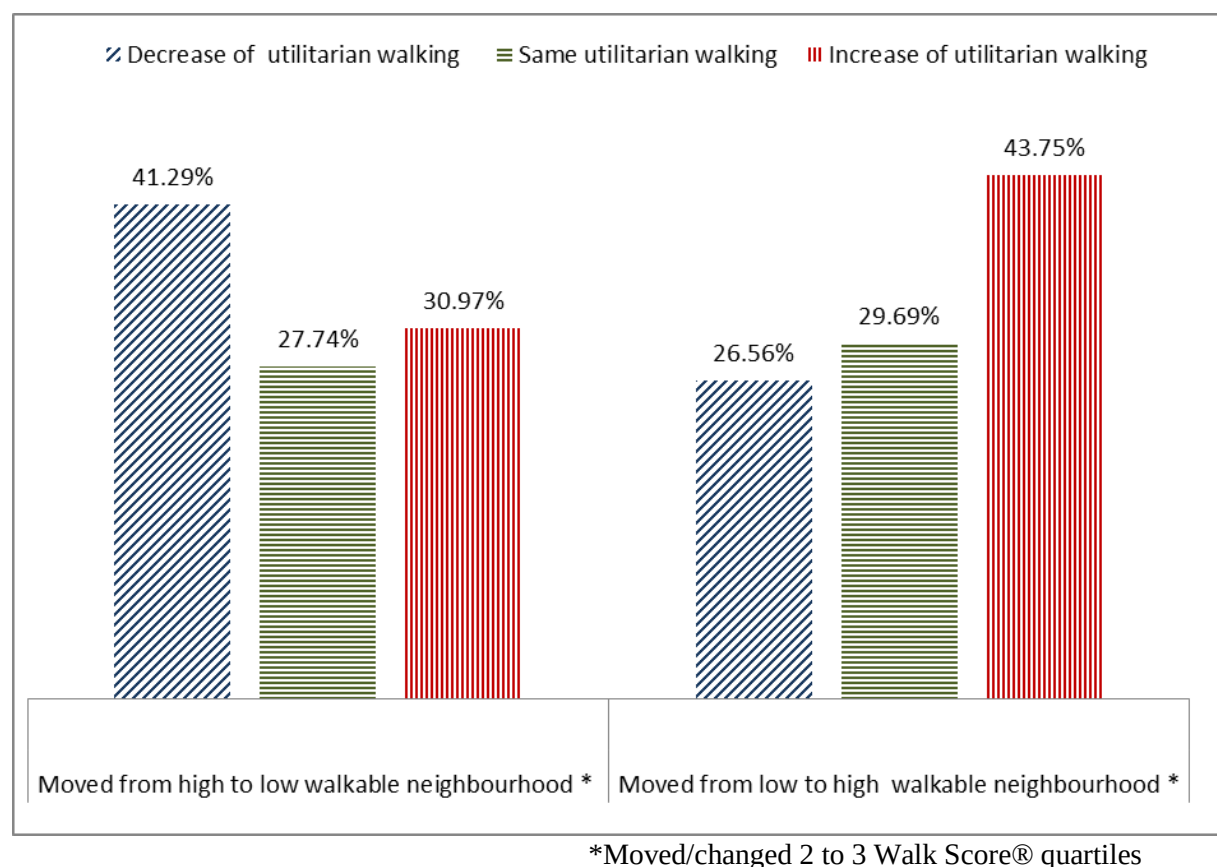


Figure 4.3: Change in utilitarian walking for urban-dwellers “movers”; NPHS, 1994-2006

4.5.3 Multivariate analyses

4.5.3.1 *Ordered logistic regression analysis for overall sample - interpreting the influence of walkability on utilitarian walking*

Exposure to higher walkable neighborhoods (third and fourth Walk Score® quartiles,) had positive associations with utilitarian walking compared to exposure to low walkable

neighbourhoods (first Walk Score® quartile) in multivariate analyses. The marginal effects of the ordered logistic regression can be interpreted as the change in probability of being in a particular alternative (in our case none, low, moderate and high utilitarian walking) as a function of a unit change in the independent variable (in our case the probability of spending more time in the second, third or fourth Walk Score® quartiles relative to spending time in the first Walk Score® quartiles). A unit increase in the probability of spending more time in the third Walk Score® quartile neighbourhoods increased the probability of moderate (1.4%, 95% C.I. 0.4%, 2.4%) and high utilitarian walking (2.7%, 95% C.I. 0.7%, 4.7%) compared to spending the same time in low walkable neighbourhoods (first Walk Score® quartile neighbourhoods). A unit increase in the probability of spending more time in the fourth Walk Score® quartile neighbourhoods increased the probability of moderate (4%, 95% C.I. 2.9%, 5.1%) and high utilitarian walking (7.7%, 95% C.I. 5.8%, 9.7%) compared to spending the same time in low walkable neighbourhoods (first Walk Score® quartile neighbourhoods) (Table 4.3).

4.5.3.2 *Interpreting other covariates*

Women were more likely to walk for utilitarian purposes at moderate (3%, 95% C.I. 2.4%, 3.6%) and high levels (5.8%, 95% C.I. 4.3%, 7.3%) than men (Table 4.3). Post-secondary education increased the probability of moderate (1.8%, 95% C.I. 1.3%, 2.3%) and high utilitarian walking (3.5%, 95% C.I. 2.3%, 4.6%). Being active in one's leisure-time increased the probability of walking for utilitarian purposes at moderate (1.5%, 95% C.I. 0.5%, 2.6%) and high levels (3%, 95% C.I. 0.8%, 5%) compared to being inactive in leisure-time; importantly, the influence of neighbourhood walkability persisted with this variable in the model. Individuals who perceived themselves as healthy were more likely to walk for utilitarian purposes at moderate (0.8%, 95% C.I. 0.1%, 1.6%) and high levels (1.6%, 95% C.I. 0.1%, 3.2%) than those who perceived themselves as unhealthy. A 0.01 year increase in

age decreased the probability of moderate (0.1%, 95% C.I. 0.1%, 0%) and high utilitarian walking (0.1%, 95% C.I. 0.2%, 0%).

There was an increase in utilitarian walking levels for the entire sample starting at cycle 4. This increase was more pronounced for high utilitarian walking (3.8%, 95% C.I. 1.8%, and 5.7%), with a steady increase (11.8%, 95% C.I. 8.5%, 14.3%) in utilitarian walking until cycle 7. Family structure and perceived neighbourhood safety were also tested to see whether they had an impact on the likelihood of changing utilitarian walking levels, but did not demonstrate any consistent associations.

Table 4.3: Marginal effects estimates of a mixed effects ordered logistic regression model of utilitarian walking, NPHS (1994-2006)

Dependent Variable (Amount of Utilitarian Walking per week)	None Marginal Effects ⁶ [95% Conf. Interval]	Low Marginal Effects [95% Conf. Interval]	Moderate Marginal Effects [95% Conf. Interval]	High Marginal Effects [95% Conf. Interval]
Women (<i>ref. men</i>)	-0.073*** [-0.081, -0.052]	-0.015*** [-0.019, -0.010]	0.030*** [0.024, 0.036]	0.058*** [0.043, 0.073]
Age	0.002*** [0.000, 0.002]	0.000*** [0.000, 0.000]	-0.001*** [-0.001, 0.000]	-0.001*** [-0.002, 0.000]
Good perceived health (<i>ref. unhealthy</i>)	-0.020** [-0.035, -0.001]	-0.004** [-0.008, 0.000]	0.008** [0.001, 0.016]	0.016** [0.001, 0.032]
Active in leisure time (<i>ref. inactive</i>)	-0.037*** [-0.057, -0.010]	-0.008*** [-0.012, -0.002]	0.015*** [0.005, 0.026]	0.030*** [0.008, 0.050]
Post-secondary education (<i>ref. below post-secondary</i>)	-0.044** [-0.051, -0.028]	-0.009** [-0.012, -0.005]	0.018** [0.013, 0.023]	0.035** [0.023, 0.046]
PCET* to neighbourhoods				
Walk Score® quartiles (WSQ) (<i>ref. PCET to WSQ1</i>)				
PCET to WSQ2	-0.006 [-0.028, 0.017]	-0.001 [-0.006, 0.004]	0.003 [-0.007, 0.013]	0.005 [-0.015, 0.025]
PCET to WSQ3	-0.034** [-0.053, -0.008]	-0.007** [-0.011, -0.001]	0.014** [0.004, 0.024]	0.027** [0.007, 0.047]
PCET to WSQ4	-0.098*** [-0.112, -0.066]	-0.020*** [-0.025, -0.014]	0.040*** [0.029, 0.051]	0.077*** [0.058, 0.097]
Time: (<i>ref. Cycle 1: 1994</i>)				
Cycle 2: 1996	0.002 [-0.020, 0.024]	0.000 [0.002, 0.003]	0.000 [0.011, 0.009]	0.000 [0.011, 0.009]
Cycle 3: 1998	0.008 [-0.012, 0.029]	0.009 [-0.014, 0.032]	-0.004 [-0.016, 0.007]	-0.006 [-0.020, 0.009]
Cycle 4: 2000	-0.046*** [-0.066, -0.024]	-0.010*** [-0.016, -0.004]	0.018*** [0.011, 0.026]	0.038*** [0.018, 0.057]
Cycle 5: 2002	-0.071*** [-0.099, -0.053]	-0.020*** [-0.028, -0.013]	0.023*** [0.017, 0.029]	0.069*** [0.046, 0.092]
Cycle 6: 2004	-0.072*** [-0.094, -0.049]	-0.021*** [-0.028, -0.013]	0.023*** [0.017, 0.029]	0.070*** [0.046, 0.094]
Cycle 7: 2006	-0.097*** [-0.115, -0.078]	-0.035*** [-0.044, -0.025]	0.176*** [0.009, 0.025]	0.114*** [0.085, 0.143]

**statistically significant at 95% confidence level

***statistically significant at 99% confidence level

*PCET: Proportion of cumulative exposure time

⁶ The marginal effects show the change in probability of a particular alternative as a function of a unit change in the independent variable. For categorical independent variables with more than two possible values, the marginal effect shows the difference in the predicted probabilities for cases in one category relative to the reference category. For continuous independent variables, the marginal effect measures the change in probability due to a small change in the independent variable (instantaneous change). The value is obtained by differentiating the probability expression with respect to the independent variable and is computed using differential equations in analytical statistical software (Stata 13)

4.5.3.3 *Binary fixed effects regression analysis for movers:*

We also estimated a binary logistic regression model for those who changed residence during the study period (i.e., respondents who “changed/ moved” 2 or 3 Walk Score® quartiles in either direction after relocation compared to other movers). Moving from low to high walkable neighbourhoods increased the odds of moderate and high utilitarian walking by 59% (95% C.I 3%, 140%), compared to moving to a neighbourhood with a similar walkability level, (i.e., within one Walk Score® quartile change). In terms of covariates, the odds of moderate or high utilitarian walking were approximately 28% higher for active people compared to inactive people (Table 4.4). Recall that sex and post-secondary education are time constant variables and therefore do not have direct estimates in the fixed effects binary model. The estimation of effects in this model was based entirely on within-person changes; hence there is no potential bias from measured or unmeasured time-constant confounders.

Table 4.4: Odds ratio estimates from a fixed effects binary logistic regression model of utilitarian walking, NPHS (1994-2006)

Dependent Variable (reference: none or low utilitarian walking per week)	Moderate or high utilitarian walking per week
	Odds Ratio [95% Conf. Interval]
Good perceived health (ref. <i>unhealthy</i>)	1.18 [0.90, 1.53]
Active in leisure time (ref. <i>inactive</i>)	1.28** [1.11, 1.47]
Moving between neighbourhoods (ref. moving to a neighborhood with the same Walk Score® quartile, or change of one Walk Score® quartile)	
Moving from low to high walkable Neighbourhood*	1.59*** [1.03, 2.46]
Moving from high to low walkable Neighbourhood*	1.07 [0.78, 1.48]
Time: (ref. Cycle 1: 1994)	
Cycle 2: 1996	1.07 [0.89, 1.28]
Cycle 3: 1998	1.12 [0.93, 1.35]
Cycle 4: 2000	1.10 [0.91, 1.33]
Cycle 5: 2002	1.45*** [1.19, 1.78]
Cycle 6: 2004	1.48*** [1.22, 1.84]
Cycle 7: 2006	1.90*** [1.53, 2.35]

*Moved/changed 2 to 3 Walk Score® quartiles

**statistically significant at 95% confidence level

***statistically significant at 99% confidence level

4.6 DISCUSSION

Cumulative exposure to highly walkable neighborhoods (3rd and 4th Walk Score® quartiles) was associated with increased utilitarian walking. Long term exposure to high and medium walkable neighbourhoods reduced the likelihood of no utilitarian walking incrementally more than exposure to low walkable neighbourhoods. Moving to higher

walkable neighbourhoods increased utilitarian walking while moving to lower walkable neighbourhoods did not show a significant decrease in utilitarian walking.

Our findings align with two longitudinal studies of utilitarian walking. The first is the Multi-Ethnic Study of Atherosclerosis (MESA) Study, (Hirsch et al., 2014) which measured utilitarian walking before and after relocation to new neighbourhoods. Moving to a more walkable neighbourhood (a 10 point higher Walk Score®) was associated with an increase in the odds of meeting “Every Body Walk” campaign goals (≥ 150 minutes/week of walking) by 11% (95% C.I. 0.2% , 21%)) for middle-aged to older adults. In our study, we estimated that moving to neighbourhoods of 2 or 3 WalkScores® quartile higher (15 to 45 points higher Walk Score®) was associated with an increase in the odds of moderate or high utilitarian walking per week (≥ 60 minutes/ week of utilitarian walking) of 59% (95% C.I. 0.33%, 145%). The second is the RESIDE study in Perth, Australia, a quasi-experimental longitudinal study (n=1,813 at baseline) that tracked, over a 7 year period, the walking behaviour of subjects who relocated to new suburban housing developments. The RESIDE study found that the odds of walking for utilitarian purposes had a positive association with local accessibility to amenities (measured as the number of amenities within 1,600 meters buffer from respondents homes). Being in a neighbourhood with high local accessibility (8 to 15 amenities within a 1,600m buffer) was associated with an increase in the odds of walking by around 30% (p= 0.04) compared to being in a neighbourhood with low local accessibility (0 to 3 amenities within a 1,600m buffer).

Our study differed from the MESA and RESIDE studies in several ways. First, our sample did not only consist of movers but non-movers as well. Second, our outcome variable was modeled across several levels to capture more information about utilitarian walking. Third, we accounted for confounding that may be introduced by health status and leisure time

physical activity, providing increased precision in our estimates of the true influence of the environmental exposure (revealed as a limitation in the RESIDE study).

We detected an overall secular trend towards increased utilitarian walking over time, starting in 2000. This timeframe corresponds to the general trend of promoting active living that has been growing in North America in response to the high rates of inactivity (Federal-Provincial/Territorial Advisory Committee on Fitness and Recreation, 1997; Lavizzo-Mourey & McGinnis, 2002; Transport Canada, 2005; Wharf-Higgins, 2002). The trend towards increased utilitarian walking was more pronounced for high levels of utilitarian walking than for low ones. This secular trend could be explained by recall bias, generated as a result of repeated self-reported measures over time (Hassan, 2005). If the increased trend were due to bias, however, we would have expected the same increase across all levels of utilitarian walking. New evidence in the US has found that people are driving less, and shifting towards more sustainable modes of transport (Tomer & Kane, 2014). This increasing trend in utilitarian walking was not seen in the MESA study, possibly because of the advanced age of their sample (Hirsch et al., 2014) nor in the RESIDE study (Knuiman et al., 2014), which showed a decline in the frequency of utilitarian walking (9% decline from baseline) after subjects relocated to new homes in suburban neighbourhoods around Perth, Australia.

In our study, the highest walkable neighbourhoods had Walk Score® values between 70 and 100 and represent neighbourhoods like one might find in the core of densely populated urban areas that have many amenities and where one could easily live without access to a private automobile. It was these types of neighbourhoods that had the largest influences on increases in high levels of utilitarian walking over time and corresponding declines in low levels of utilitarian walking. It suggests that land use planning needs to understand features of these very walkable places in order to have the largest possible impact on population level physical activity. Our study also suggests that any land use policies

implemented to increase neighbourhood walkability may not prompt an immediate change in utilitarian walking; exposure over time may be needed to detect an influence of the environment.

The assumption that only active people will walk more in a walkable environment did not hold true in our study. Longer cumulative exposure to highly walkable neighbourhoods was associated with increases in utilitarian walking for both people who were active in their leisure time and those who were not. That both leisure time active and inactive people increase their utilitarian walking in response to a walkable environment speaks to the population-wide potential for built environment interventions aimed at increasing physical activity.

Our study relies on self-reported information about utilitarian walking. Self-reported walking information is a clear limitation in cross-sectional studies. If, however, respondents over-report or under-report utilitarian walking levels, the direction of their misrepresentation is likely consistent over time. Reporting bias is arguably less of a problem in longitudinal analyses. Longitudinal studies have several advantages over cross sectional studies yet the problem of controlling for confounding variables to obtain precise coefficient estimates remains. Fixed effects regression (used in our analysis) offers a solution as it is a statistical technique that controls for all confounding variables even without measuring them (e.g., attitudes and preferences about walking), as long as they do not change over time (Allison, 2005; Frees, 2004; Singer & Willet, 2003). Another possible limitation of our work is the lack of availability of historical Walk Score® data. That said, neighbourhoods do not usually change their physical characteristics quickly and we tested other measures correlated with Walk Score® (street connectivity and population density) that we computed from street network and Census data in 1996 and 2006 for all the NPHS respondents residential

neighbourhoods. Measures computed at the two time periods were highly correlated (Pearson correlation coefficient = 0.94; $p < .01$).

Individual and interpersonal factors, for example, personal attitudes and motivation, were measured in a number of studies, and found to be important for physical activity (Handy & Mokhtarian, 2005). Thus Handy (2005) has argued that a supportive built environment is not sufficient alone to guarantee that people will be physically active. We found, however, that long term exposure to highly walkable neighbourhoods was associated with higher reported levels of walking for utilitarian purposes in this 12-year follow-up of Canadians. This finding in a large sample across a wide age range suggests that features of neighbourhoods are, over the long term, influencing how much Canadians move, at least for utilitarian purposes. Sustained behaviour change to support better health is difficult to achieve. Our findings suggest that increasing neighbourhood walkability will lead to some increases in utilitarian walking, even for individuals who are otherwise inactive.

4.7 CONCLUSION

This study is the first national level longitudinal study to determine the impact of cumulative exposure to high walkable neighbourhoods on different levels of utilitarian walking. Previous studies do signal associations between the built environment and utilitarian walking; however, research in this area has been plagued by problems of causal attribution from an almost exclusive reliance on cross-sectional studies. Longer exposure to highly walkable neighbourhoods increases utilitarian walking levels, even for individuals who are otherwise inactive, and should be included amongst policy options for increasing population level physical activity.

5 CHAPTER FIVE: BODY MASS INDEX TRAJECTORIES AND NEIGHBOURHOOD WALKABILITY: LONGITUDINAL STUDY OF CANADIANS

5.1 OVERVIEW OF THE CHAPTER

In this chapter, I addressed the third objective of this dissertation, namely, *understanding the role of the urban built environment on the body mass index (BMI) trajectories of urban Canadians*. This objective was achieved using the same dataset as in Chapter 4 (geocoded NPHS respondents who reported their height and weight). Heights and weights of the 2,935 working-age urban respondents were reported bi-annually over the follow-up (12 years) and converted to BMI (weight in kilograms divided by height in meters squared). Longitudinal trajectories of BMI were estimated for men (n=1,407) and women (n=1,528) separately. This is the first national level longitudinal study linking neighbourhood walkability to BMI trajectories of adults, following people that lived in the same neighbourhood over the course of the study, and following people who changed their residential location. This manuscript is intended for submission to the *American Journal of Public Health*.

5.2 ABSTRACT

5.2.1 Objectives

The objective of the study is to understand the impact of neighbourhood walkability on body mass index (BMI) trajectories of urban Canadians.

5.2.2 Methods

Data are from Canada's National Population Health Survey (n=2,935; biannual assessments 1994- 2006). Walkability was measured by the Walk Score®. BMI trajectories were modeled as a function of Walk Score®, socio-demographic and behavioural covariates using growth curve models and fixed effects regression models.

5.2.3 Results

BMI in men increased annually by an average of 0.13 kg/m² ((95% C.I. 0.11, 0.14) over the 12 years of follow-up. Moving to a high walkable neighbourhood (two or more Walk Score® quartiles higher) decreased BMI trajectories for men by approximately 1 kg/m² (95% C.I. -1.16, -0.17). Moving to a low walkable neighbourhood increased BMI for men by approximately 0.45 kg/m² (95% C.I. 0.01, 0.89). There was no detectable influence of neighbourhood walkability on body weight for women.

5.2.4 Conclusions

Our study of a large sample of urban Canadians followed for 12 years confirms that neighbourhood walkability influences BMI trajectories for men, and may be influential in curtailing male age-related weight gain.

5.3 INTRODUCTION

Over the past three decades, there has been a decline in physical activity and a rise in obesity prevalence worldwide (Huot et al., 2004; Katzmarzyk & Ardern, 2004; Statistics Canada, 2015a). The burdens of physical inactivity and obesity are recognized as major public health concerns due to their associated health risks (Jakicic & Gallagher, 2003; I. Lee & Skerrett, 2001), accounting for substantial disability, health care utilization and

expenditure (Finkelstein et al., 2003; Sari, 2009). Given the public health threats associated with the decline in physical activity and increase in body weight, and difficulty in maintaining a healthy body weight (Twells, Gregory, Reddigan, & Midodzi, 2014), there has been a growing interest and significant expansion of theoretical and empirical work investigating the underlying social and environmental causes of overweight and obesity. One specific area of interest has been on the role of the built environment, including neighbourhood walkability, in shaping physical activity and influencing body weight. The aim of our study is to understand the influence of neighbourhood walkability on adult BMI trajectories over a 12 year period, using a national representative cohort sample of urban Canadians adults.

Previous cross-sectional studies have signalled geographical variations in body mass index, (BMI, a measure of body weight that accounts for height) for men and women (Feeny et al., 2014; Mackenbach et al., 2014; Pouliou, Elliott, Paez, & Newbold, 2014; N. A. Ross et al., 2007). However, associations of the built environment measures with BMI have shown mixed results in cross sectional studies. The exception are those studies showing a connection with urban sprawl, which has been consistently positively associated with BMI, and land use mix which has been consistently negatively associated with BMI (Feng et al., 2010; Mackenbach et al., 2014). Few longitudinal studies have considered the relationship between a neighbourhood's walking-friendliness and BMI. One longitudinal study of older adults in the United States (Hirsch et al., 2014) showed weak association: moving to a more walkable neighbourhood (a 10 point higher Walk Score®) was associated with a 0.06 lower BMI (95% C.I.0.12, 0.01). A national study of American youth showed no association (Eid et al., 2008). One study to date has considered an adult population (18+) but this was a local study in one metropolitan area (Edmonton, Alberta, Canada) with a modest follow-up time (6 years). This

study found no significant association of BMI with neighbourhood walkability (Berry et al., 2010).

Our study is the first to model adult BMI trajectories from a large population-based sample of adults, where the exposure of interest is neighbourhood walkability. Our sample includes both movers (people who changed their residential neighbourhoods) and non-movers, giving us the opportunity to model change in BMI in relation to changes in neighbourhood walkability using residential relocations. Longitudinal trajectories of BMI are estimated for men and women separately (owing to the different determinants of BMI by sex), while accounting for known individual-level covariates of BMI.

5.4 METHODS

5.4.1 Data sources and sample size

Our sample comes from the National Population Health Survey (NPHS), a longitudinal survey conducted biannually by Statistics Canada starting in 1994/95. The target population of the NPHS was household residents in the ten Canadian provinces excluding some special groups (e.g. persons living on Indian Reserves and Crown Lands) (Canada, 2007). Access to the data was granted by the Social Sciences and Humanities Research Council of Canada (#09-SSH-MCG-2068). Analyses were performed at the McGill-Concordia Quebec Inter-University Center for Social Statistics (QICSS). We used the first seven cycles of data collection, including baseline (1994/1995 to 2006/2007).

We restricted our analysis to young and middle-aged adults (18 to 55 years old at baseline) living in urban areas (> 50,000 population), who reported their weight and height. We included participants who either did not change their residential location or were relocated to a new neighbourhood once during the follow-up period to allow for sufficient exposure time to neighbourhoods with different walkability levels. We did not include

individuals who moved more than once during follow-up to allow for sufficient exposure to the neighbourhood environment. Participants weighing less than 35kg were excluded from the analysis.

5.4.2 Outcome measure

The primary outcome of interest was body mass index (BMI). The NPHS respondents were asked to report their weight and height every cycle, and BMI was calculated by dividing the weight in kilograms by their height in meters squared (pregnant women were excluded). We modeled BMI as a continuous variable, which was normally distributed in our sample.

5.4.3 Primary exposure of interest

The primary exposure of interest was neighbourhood walkability as captured by the Walk Score® (0-100). The Walk Score® is based on distances to various weighted amenities (e.g., shopping, schools, parks and restaurants). The measure has been validated against objective walkability measures (Car, Dunsiger, & Marcus, 2010; Duncan, Aldstadt, Whalen, Melly, & Gortmaker, 2011) and has shown associations with BMI in a number of studies (Hirsch et al., 2014; Thielman et al., 2015). We divided the Walk Score® into four quartiles. Totally car-dependent neighbourhoods had scores from 0 to 39. Somewhat car-dependent neighbourhoods had scores from 40 to 55 and somewhat walkable neighbourhoods had scores from 56 to 69. Highly walkable neighbourhoods had scores from 70 to 100. We constructed a variable that represented Walk Score® quartiles for NPHS addresses (postal codes) at baseline, representing initial neighbourhood walkability. We then constructed another variable by centering the Walk Score® quartiles (WSQ) around their initial quartile level at baseline (cycle 1). This method is commonly used in longitudinal data analysis to measure change and allows for better interpretability of model estimates (Singer & Willet, 2003). From the centered Walk Score® quartile variable, we constructed four time-varying dummy

variables that indicated whether the respondents moved to a more walkable neighbourhood (one Walk Score® quartile higher or two or more Walk Score® quartiles higher) or moved to a less walkable neighbourhood (one Walk Score® quartile lower or two or more Walk Score® quartiles lower), from one cycle to another.

5.4.4 Other potential determinants of BMI

We stratified the BMI models by sex, following previous studies that have shown differences in associations of BMI with covariates for men and women (Eid et al., 2008; N. A. Ross et al., 2007). We controlled for individual socio-economic characteristics (age, education, marital status, and immigration status), and individual behaviours (leisure time physical activity, utilitarian walking, and smoking status). Age was recorded at baseline as a continuous variable, education level was classified as having a post-secondary education, (yes/no), marital status was classified as (married, single, or divorced), and immigration status indicated whether the participants had immigrated to Canada in the past 5 years (at baseline) (yes/no). A physical activity index was calculated from leisure time physical activity (Statistics Canada, 2009) and classified as inactive (energy expenditure (EE) less than 1.5 kcal/kg/day), moderately active (combined moderate (EE 1.5 to 2.9 kcal/kg/day) and active (EE greater than 3 kcal/kg/day)). Utilitarian walking measured the amount of walking per week to work, shopping or other errands, but not for recreation (i.e., not leisure time), and was classified into four categories (none, less than one hour, 1 to 5 hours, 6 hours or more). Smoking status had three categories: never smoker (fewer than 25 lifetime cigarettes and current non-smoker), former smoker (used to smoke daily or occasionally) and current smoker (daily or occasionally).

5.4.5 Statistical analysis

We conducted an attrition analysis to ensure that participants lost to follow-up did not unduly influence sample characteristics (Little & Rubin, 2002). BMI trajectories for men and women were modelled using random coefficient and fixed effects regression models in Stata 14. Random coefficient regression models are used widely in longitudinal data analysis to measure change over time, estimating within and between subject variance. They are also called growth curve models when time is the main covariate of interest (Singer & Willet, 2003). Fixed effects regression estimates were compared to the random coefficient regression estimates. Fixed effects models eliminate bias resulting from unobserved heterogeneity caused by omitted confounders of time constant covariates (Allison, 2005). To take into account the NPHS survey complex sampling design, population weights and bootstrap weights were used, and compared to the unweighted regression estimates.

5.5 RESULTS

5.5.1 Sample description

The response rate to the NPHS was 92.8% in cycle 2, ending with 77% in cycle 7, with an average attrition rate of 2.3% across cycles. Our sample consisted of the NPHS respondents' aged 18 to 55 years, living in urban areas that moved once or did not move at all during the 12 years of survey follow up, and answered the survey at least twice (2 cycles). People who did not answer the survey starting from the second cycle were dropped from the sample. There were no significant differences in the mean health status, the mean leisure time physical activity, or the mean BMI of people who were lost compared to those who remained in the sample (see Appendix 2). We ended up with a final sample of 2,943 individuals who reported their BMI (1,526 women and 1,417 men). We restricted the reporting of findings for

the analyses for men as we did not find any influence of neighbourhood walkability on women BMI (see Appendix 5).

5.5.2 Descriptive statistics

The sample used in this analysis consisted of 1417 men (48% of the overall sample) with mean age of 38 years old (SD=9). There were 371 men who changed their residential locations once and 1046 men who did not move. The proportion of men that were overweight and obese at baseline was 55%, and this increased to 61% at the end follow-up. At baseline, the BMI of Canadian men was 1 kg/m² higher for individuals living in car-dependent neighbourhoods (WSQ1) compared to their counterparts living in highly walkable neighbourhoods (WSQ4) (Table 5.1). The percentage of men with post-secondary education who moved from totally car-dependent to highly walkable neighbourhoods was 9% more than those who moved from high to low walkable neighbourhoods. The percentage of male immigrants was 15% lower among those living in totally car-dependent neighbourhoods compared to those living in highly walkable neighbourhoods. The percentage of married men was 28% higher among those living in totally car-dependent neighbourhoods compared to those living in highly walkable neighbourhoods. The percentage of men with children living in totally car-dependent neighbourhoods was 30% higher than those living in highly walkable neighbourhoods at baseline. More than half of men were inactive in their leisure time at baseline across all Walk Score® quartiles.

Around 50% of respondents who were living in WSQ1 did not report any utilitarian walking compared to 38% living in WSQ4. The mean BMI for men (non-movers) at survey follow-up intervals was patterned by neighborhood walkability; the lowest mean BMI at each time point was for those living in the most walkable neighbourhoods (Walk Score® quartile 4) (Figure 5.1).

Table 5.1: Characteristics of men at baseline, NPHS (1994)

Variables	Mean (SD)/ Percent					
	Living in WSQ1 at baseline	Living in WSQ2 at baseline	Living in WSQ3 at baseline	Living in WSQ4 at baseline	Moved from low to high WSQ	Moved from high to low WSQ
BMI	26.0 (3.9)	26.1 (3.8)	25.9 (4.1)	25.0 (3.8)	25.8 (3.5)	25.9 (4.0)
Age	39 (8.7)	38 (9.9)	38 (9.9)	37 (10)	37 (9.8)	36 (9)
Completed post- secondary education	59 %	55%	54%	58%	62%	53%
Immigrants	16%	21%	27%	31%	28%	17%
Married	78%	71%	66%	50%	66%	65%
Single	15%	23%	24%	37%	26%	24%
Divorced	7%	6%	10%	12%	8%	11%
Have children	74%	67%	61%	44%	64%	54%
Never smoker	36%	37%	38%	39%	40%	40%
Former smoker	29%	30%	29%	27%	24%	30%
Current smoker	34%	32%	33%	35%	36%	30%
Inactive in leisure time	55%	57%	62%	53%	60%	56%
Moderately active in leisure time	26%	24%	21%	26%	20%	29%
Active in leisure time	19%	19%	17%	21%	20%	15%
No utilitarian walking	50%	45%	47%	38%	46%	35%
Low utilitarian walking (less than an hour)	14%	17%	18%	17%	20%	20%
Moderate utilitarian Walking (1 to 5 hours)	18%	22%	19%	32%	15%	30%
High utilitarian walking (6 hours or more)	18%	17%	15%	13%	20%	15%

5.5.3 Multivariate analyses

We estimated BMI growth curve models (random coefficient regression models) and fixed effects regression models for men and women. We compared the estimates to understand whether there was any bias in the random coefficient model estimates as a result

of unobserved heterogeneity of time constant confounders. Estimates from the weighted and unweighted regression models were similar. Additionally there were minimal differences in the confidence intervals of the weighted fixed effects estimates, before and after applying bootstrap weights. The bootstrap weights did not change the statistical significance of the variables suggesting that the complex design sampling nature of the NPHS did not induce any significant error in our sample. We discuss the un-weighted random coefficient estimates as they are more efficient (have smaller standard errors) (Winship & Radbill, 1994).

5.5.3.1 *Interpreting the influence of time on BMI*

Interpreting the influence of time on BMI

Over each year of follow-up, BMI for men increased by 0.13 kg/m², regardless of baseline age. For every year increase in age at baseline, BMI increased by approximately 0.06 kg/m².

5.5.3.2 *Interpreting the influence of neighbourhood walkability on the BMI trajectories for men:*

At baseline, the mean BMI of men residing in the most walkable neighbourhoods (fourth Walk Score® quartile) did not demonstrate a conclusively different BMI from those in less walkable neighbourhoods (first Walk Score® quartile) but the point estimate was lower (0.4 BMI less (95% C.I., -0.95, 0.22)). Moving from low to high walkable neighbourhoods (2 Walk Score® quartiles higher) was associated with approximately a one unit (kg/m²) decrease in BMI for men (95% C.I. -1.7,-0.3). This effect is equivalent to 3kg (~6.8 lbs) for a man of average height (178.2 cm). The estimates were consistent across weighted random coefficient models (-1.10 BMI, (95% C.I. -1.9, -0.36)) and weighted fixed effects model (-1.09, (95% C.I. (-1.77, -0.41)). Moving from high to low walkable neighbourhoods (2 Walk Score® quartiles lower) was associated with an increase in BMI for

men of approximately 0.45 kg/m², (95% C.I. 0.01, 0.89), (0.4 kg/m² increase in BMI, (95% C.I. -0.11, 0.98) for the weighted random coefficient estimate) compared to staying in a high walkable neighbourhood (Walk Score® quartile 3 and 4). Weighted fixed effects estimates were slightly higher - 0.6 BMI increase (95% C.I. -0.02, 1.22).

The influence of neighbourhood median household income was also tested but did not achieve significance, nor improve the model fit, and was dropped from the models. The intra-class correlation showed that approximately 88% of the variance in the random parameters was explained by between-subject variance.

5.5.3.3 *Interpreting other covariates*

Moderate utilitarian walking (6 hours or more per week) was associated with 0.1 kg/m² lower BMI in men (95% C.I. -0.21, 0.00), and approximately 0.17 BMI decrease (95% C.I. -0.31, -0.03) after eliminating bias resulting from time constant omitted confounders. This is equivalent to an approximate 0.5kg (1.1 lb) lower weight for a man of average height (178.2 cm). Smoking status, leisure time physical activity, marital status and recent immigrant status all influenced BMI. Current smokers had an estimated 0.43 lower BMI (95% C.I. 0.29, -0.05) compared to never smokers. Those active in their leisure time had 0.17 lower BMI (95% C.I. 0.02, 1.79) compared to less active men. The BMI of single men was 0.45 lower (95% C.I. -0.05, -0.34) than for married men. The BMI for recent immigrants (those who arrived to Canada 5 years or less before 1994 (cycle 1)) was approximately 1.1 kg/m² lower (95% C.I. -1.60, -0.63) than for non-immigrants. Completing post-secondary education did not have a significant effect on BMI.

Table 5.2: Random coefficient and fixed effects estimates of Body Mass Index (BMI), NPHS (1994-2006)

BMI	Unweighted random		Weighted random		Weighted fixed	
	coefficient	estimates	coefficient	estimates	effects	estimates
	Coef.	95% C.I.	Coef.	95% C.I.	Coef.	95% C.I.
Time	0.13***	[0.11, 0.14]	0.13***	[0.11, 0.15]	0.13***	[0.11, 0.15]
Age centered around baseline mean age	0.06***	[0.04, 0.09]	0.09***	[0.06, 0.11]	-----	-----
Baseline Walk Score® quartile (<i>ref. baseline WSQ1</i>)						
Baseline WSQ2	0.31	[-0.24, 0.89]	0.51	[-0.14, 1.16]	-----	-----
Baseline WSQ3	0.23	[-0.36, 0.87]	0.23	[-0.45, 0.91]	-----	-----
Baseline WSQ4	-0.40	[-0.95, 0.22]	-0.47	[-1.12, 0.18]	-----	-----
Change in Walk Score® quartile (<i>ref. same WSQ</i>)						
Moved one Walk Score® quartile higher	0.10	[-0.41, 0.51]	0.10	[-0.49, 0.71]	0.07	[-0.41, 0.55]
Moved two or three Walk Score® quartiles higher	-1.02***	[-1.16, -0.17]	-1.13***	[-1.90, -0.36]	-1.09***	[-1.77, -0.41]
Moved one Walk Score® quartiles lower	0.19	[-2.07, -0.13]	0.41	[-0.27, 1.09]	-0.08	[-0.53, 0.37]
Moved two or three Walk Score® quartiles lower	0.45**	[0.01, 0.89]	0.44	[-0.11, 0.98]	0.60*	[-0.02, 1.22]
Utilitarian Walking (<i>ref. no utilitarian walking</i>)						
Low utilitarian walking	0.04	[-0.07, 0.15]	0.03	[-0.10, 0.16]	0.02	[-0.12, 0.16]
moderate utilitarian walking	-0.08	[-0.18, 0.02]	-0.10	[-0.22, 0.04]	-0.10	[-0.23, 0.04]
High utilitarian walking	-0.11*	[-0.21, 0.00]	-0.11*	[-0.23, 0.01]	-0.17**	[-0.31, -0.03]
Leisure time physical activity (<i>ref. inactive</i>)						
Moderately active in leisure time	-0.11	[-0.01, 0.84]	-0.07	[-0.19, 0.04]	-0.08	[-0.20, 0.05]
Active in leisure time	-0.17***	[-0.02, -1.79]	-0.16**	[-0.31, -0.02]	-0.18**	[-0.34, -0.03]
Smoking status (<i>ref. never smoker</i>)						
Former smoker	0.15	[-0.20, -0.01]	0.20	[-0.04, 0.45]	0.19	[-0.09, 0.47]
Current smoker	-0.42***	[-0.29, -0.05]	-0.44**	[-0.79, -0.10]	-0.51**	[-0.93, -0.09]
Marital status (<i>ref. married</i>)						
Single	-0.45***	[-0.05, -0.34]	-0.51***	[-0.76, -0.27]	-0.55***	[-0.86, -0.24]
Divorced	-0.21*	[-0.70, -0.17]	-0.24*	[-0.50, 0.02]	-0.15*	[-0.45, 0.15]
Education level (<i>ref. completed post-secondary education</i>)						
Did not complete post-secondary education	-0.04	[-0.67, -0.22]	0.00	[-0.23, 0.23]	0.20	[-0.09, 0.50]
Recent immigrant (<i>ref. non-immigrants</i>)	-1.11***	[-1.60, -0.63]	-1.14***	[-1.67, -0.61]	-----	-----
Constant	26.39***	[25.95, 26.84]	26.26***	[25.74, 26.78]	26.16***	[25.97, 26.36]

Table 5.2, Continued

Random-effects parameters		Unweighted random coefficient estimates		Weighted random coefficient estimates		Weighted fixed effects estimates
		Estimate	[95%C.I]	Estimate	[95%C.I]	Estimate
Standard deviation (AGEC+)		0.15	[0.14, 0.18]	0.15	[0.13, 0.17]	
Standard deviation (constant)		3.61	[3.37, 3.86]	3.61	[3.37, 3.86]	3.93
Correlation (AGEC, constant)		0.15	[0.01, 0.28]	0.15	[0.01, 0.28]	
Standard deviation (Residual)		1.38	[1.30, 1.47]	1.38	[1.30, 1.47]	1.55
Intra class correlation		0.87		0.87		0.86

*statistically significant at 95% confidence level

***statistically significant at 99% confidence level

**statistically significant at 95% confidence level

+AGEC: Age centered around the population mean

5.5.4 Sensitivity analysis

From the growth curve model (Table 5.2), predicted BMI of each survey respondent (men) was estimated at each point in time (i.e., based on individual and neighbourhood characteristics). The average predicted BMI of different groups of men was then calculated based on the walkability of their residential location. Figure 5.1 shows the average predicted BMI of men at baseline (in 1994) and in 2006 (with 95% C.I.) and the change in BMI between the two points in time. The average predicted BMI of men living in highly walkable neighbourhoods (Walk Score® quartile 4) was 26.05 kg/m² (95% C.I. 25.95, 26.15) at baseline and 27.77 kg/m² (95% C.I. 27.67, 27.87) in 2006. Increases in BMI were lowest for men who moved from totally car-dependent to highly walkable neighbourhoods walkable neighbourhoods, with predicted BMI of 25.65 kg/m² (95% C.I. 25.33, 25.89) in 1994 and 26.48 kg/m² (95% C.I. 26.12, 26.84) in 2006. Increase in the mean predicted BMI for men who moved from highly walkable neighbourhoods to totally car-dependent neighbourhoods was the highest compared to all other groups, with predicted BMI of 25.54 kg/m² (95% C.I. 25.32, 2.76) in 1994 and 27.83 (95% C.I. 27.58, 28.08) in 2006.

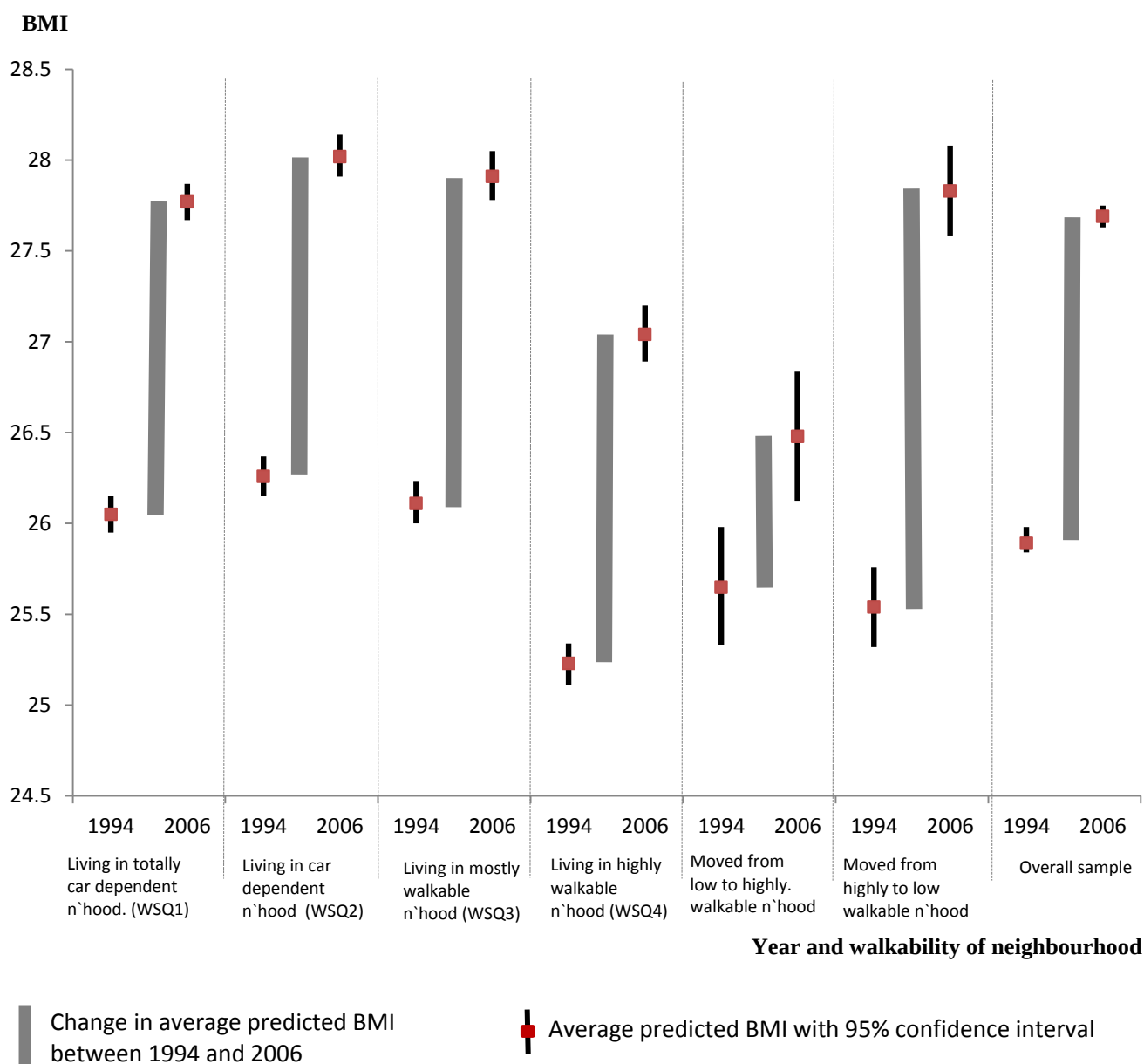


Figure 5.1: Change in average predicted BMI of men between baseline (1994) and last year of survey follow up (2006) by neighbourhood Walk Score® quartile (WSQ), NPHS, 1994 and 2006

BMI trajectory curves were then drawn from the predicted average BMI for each point in time (Figure 5.2). The trajectory curves were presented as linear “curves” (straight line) since there was no quadratic effect of time on BMI during the twelve years of survey follow-up. Figure 5.2 shows the predicted average BMI trajectory for the overall sample of men

compared to average BMI trajectories for four groups of men. The first group consisted of men who lived the entire follow-up period in car-dependent neighbourhoods (1st Walk Score® quartile). The second group consisted of those who lived the entire follow-up period in a highly walkable neighbourhood (4th Walk Score® quartile). The third group was made up of men who moved from low to high walkable neighbourhoods (2 Walk Score® quartiles change) and the fourth group consisted of those who moved from high to low walkable neighbourhoods (2 Walk Score® quartiles change).

The average BMI (intercept) was 0.4 kg/m² (95% C.I. -0.95, 0.22) lower for those who lived in highly walkable neighbourhoods compared to those who lived in totally car-dependent neighbourhoods. Moving to higher walkable neighbourhoods was associated with a one unit (kg/m²) decrease in BMI (95% C.I. -1.7,-0.3). Moving from high to low walkable neighbourhoods was associated with an increase in BMI for men by approximately 0.45 kg/m², (95% C.I. 0.01, 0.89) compared to those who did not move from their low walkable neighbourhoods.

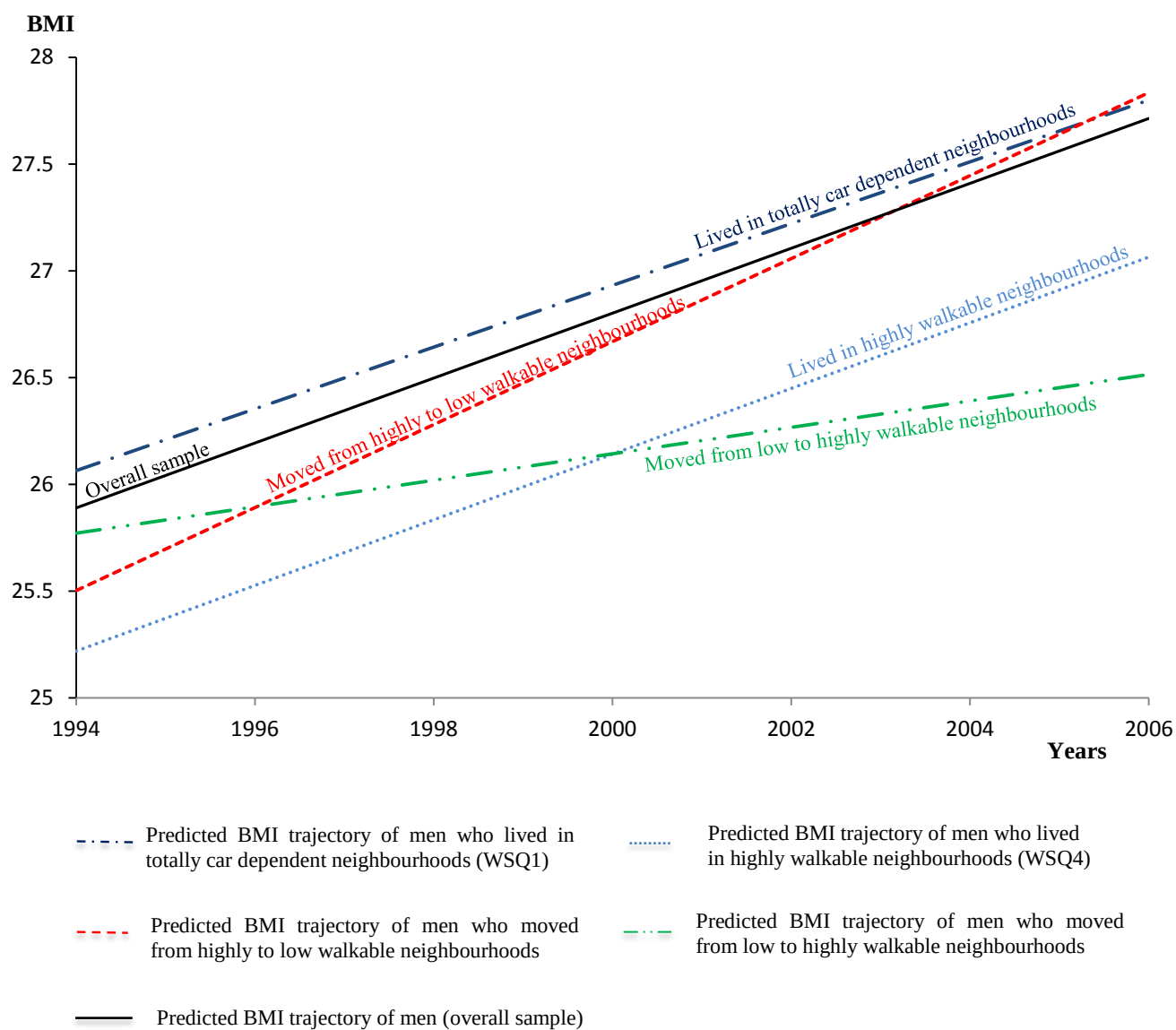


Figure 5.2: Predicted BMI trajectories for men by Walk Score® quartile (WSQ), NPHS, 1994-2006, Non-movers and movers

5.6 DISCUSSION

Living in the most walkable urban Canadian neighbourhoods (4th Walk Score® quartile) was associated with the lowest mean BMI for men. Moving from low to high walkable neighbourhoods was associated with a reduction in BMI by approximately 1 kg/m², or 3kgs for a man of average height. Similarly moving from high to low walkable neighbourhoods was associated with an increase in BMI by approximately 0.45 kg/m². BMI for women did not show any association with neighborhood walkability.

Our findings are consistent with Ross et al (2007) and Eid et al (2008) who acknowledged sex differences in the associations of BMI with the built environment characteristics. They also align with previous studies that found cross sectional associations between neighbourhood physical characteristics and BMI (Feng et al., 2010; Mackenbach et al., 2014). Hirsch, Diez Roux et al. (2014), found weak associations between moving to more walkable neighbourhoods (a 10 point higher Walk Score®) and BMI (reduction of 0.06 kg/m² (95% C.I.0.12, 0.01)). It is worth noting that Hirsch, Diez Roux et al. (2014) were looking at older adults (45 to 85 years old at baseline), many of whom may not be interacting daily with their local built environment for utilitarian purposes.

Our findings contradict two previous longitudinal studies of neighbourhood walkability and body weight. Eid et al. (2008) examined the BMI of 4,426 youth (14 to 21 years old) who responded to the U.S. National Longitudinal Survey of Youth in 1979 and were followed for 7 years. These researchers did not find any influence of the built environment (measured as urban sprawl) on BMI, concluding that high prevalence of overweight and obesity in sprawling areas was due to self-selection. The young age of the cohort, duration of follow-up (7 years), and the focus on urban sprawl (which is conceptually different from walkability), could be some of the underlying reasons why their findings did not align with ours. The third

longitudinal study followed 500 adults in Edmonton, Alberta for 6 years and found non-significant associations of BMI with neighbourhood walkability (Berry et al., 2010), although these authors reported that change in BMI was associated with socio-economic characteristics of neighbourhoods.

We showed that moving to highly walkable neighbourhoods (2 or more Walk Score® quartiles higher) was associated with a reduction of BMI of 1 kg/m² (C.I. 95% -1.77, -0.41). The highest walkable neighbourhoods had Walk Score® values between 70 and 100 and represented neighbourhoods similar to those in high densely populated urban areas where one can access many amenities on foot. These types of neighbourhoods were the ones that were associated with the lowest BMI trajectories for men. Interestingly, the second Walk Score® quartile neighbourhoods (Walk Score® values between 40 to 55) were associated with the most unfavourable BMI trajectories, and not the least walkable neighbourhoods (those similar to the typical low density suburban neighbourhoods with Walk Score® values between 0 to 39). One possibility is these least walkable neighbourhoods are actually reasonably well serviced by public transportation that induces utilitarian walking and lower BMI in their residents (Wasfi et al., 2013). Neighbourhood walkability was an important predictor of male BMI trajectories even after controlling for utilitarian walking. This suggests that there could be other factors like neighbourhood social norms that might influence body weight and are worth further exploration.

Our study relies on self-reported information about weight and height for the BMI calculation. Self-reported BMI is a clear limitation in cross-sectional studies. If, however, respondents over-report or under-report their weight or height, the direction of their misrepresentation is likely consistent over time, and hence reporting bias is arguably less of a problem in longitudinal analyses. Controlling for confounding variables to obtain precise coefficient estimates remains a problem even with longitudinal models. Fixed effects

regression (used in our analysis) demeans⁷ all variables, including the random parameters, hence, eliminates bias in the error term that results from time constant confounding variables (Allison, 2005; Frees, 2004; Singer & Willet, 2003).

Another possible limitation of our work is the lack of availability of historical Walk Score® data. We used 2012 Walk Score® data, which did not correspond to the time frame of the NPHS follow up (1994-2006). That being said, neighbourhoods do not usually change their physical characteristics quickly and we tested other measures correlated with Walk Score® (street connectivity and population density) that we computed from street network and Census data in 1996 and 2006. Measures computed at the two time periods were highly correlated (Pearson correlation coefficient = 0.94; $p < .01$).

Lack of reliable nutrition variables in the NPHS is another limitation of this study. Nutrition information collection began in cycle 5 in the NPHS. We tested the amount of fruit and vegetable consumption as a potential predictor of BMI and it did not influence the effect of neighbourhood walkability on BMI trajectories for men. We have chosen not to use the nutrition variable so as not to lose the full range of years to predict BMI trajectories.

We demonstrated a clear signal of the influence of moving to both higher and lower walkable neighbourhoods on male BMI trajectories, even after controlling for unobserved heterogeneity from time constant omitted confounders. Our findings suggest that neighbourhood walkability is an important factor in curbing the population-level rise of BMI with age for men, and that men who move to highly walkable places enjoy a BMI advantage over time. Given that there have been so few policy options for the obesity epidemic that have had widespread success, these results are compelling for considering built environment modifications amongst policy options for obesity control in populations.

⁷ Demeaning variables, indicates subtracting the within subject mean from each individual variable at each point in time. (i.e., variables that do not change overtime, when demeaned will take a value of zero).

5.7 CONCLUSION

Our study is the first national longitudinal study to examine associations of BMI trajectories with neighbourhood walkability. Living in highly walkable neighbourhoods was associated with lower BMI for men and, in particular, moving into highly walkable neighbourhoods from car-dependent ones was associated with more favourable BMI trajectories for men. Our findings suggest that male age-related weight-gain could be curtailed by living in a highly walkable neighbourhood. We found no important associations between neighbourhood walkability and body weight for women. Associations of neighbourhood walkability with BMI persisted after controlling for many individual-level covariates, including utilitarian walking. Understanding the precise mix of neighbourhood attributes (both physical and social) that are associated with reductions in body weight would be useful to direct the types of environmental modifications that could be implemented to link more directly urban planning policy with health policy, consistent with the World Health Organization's 2010 Kobe statement "to integrate health and health equity in all urban public policies (World Health Organization, 2010a).

6 CHAPTER SIX: SUMMARY AND CONCLUSIONS

This dissertation has examined the influence of urban built environments on utilitarian walking (i.e., walking for a specific purpose like to go to work or school or to run an errand) and body weight (measured by the body mass index) in Canada. The thesis had three objectives, all of which were informed by an over-arching hypothesis that urban environments that are more supportive of walking will be associated with higher levels of utilitarian walking and lower body weights. The three objectives were:

- 1) *To estimate the levels and determinants of utilitarian walking involved in commuting by public transportation in Montreal, Quebec, Canada.*
- 2) *To determine the effect of exposure to walkable neighbourhoods on utilitarian walking of urban Canadians.*
- 3) *To understand the role of the urban built environment on the body mass index (BMI) trajectories of urban Canadians.*

This chapter concludes the dissertation by outlining substantive contributions to knowledge, methodological contributions, and policy implications. The chapter also points to some of the limitations of the research and ends with some concluding remarks that include directions for future research.

6.1 Substantive Contributions to Knowledge

This section of the dissertation documents the substantive contributions to knowledge of the research. Key findings are shaped by the three objectives of this dissertation, all of which were achieved and presented in the three manuscripts in Chapter 3, 4 and 5. The first manuscript demonstrated that residents of Montreal who walked to public transit en route to work or school achieved the recommended daily levels of physical activity (≥ 30 minutes of

walking). Utilitarian walking was highest among residents of affluent suburban neighbourhoods in Montreal served by commuter rail service. Transit service characteristics, specifically transit schedules, influenced how much people walked to transit stops, and increasing frequency of transit service was associated with more utilitarian walking to public transit stops. This study was among the first to objectively measure the amount of walking associated with public transportation use.

The second manuscript showed that utilitarian walking of Canadians increased between 1994 and 2006. Long term exposure to highly walkable neighbourhoods was associated with increased high levels of utilitarian walking in Canadians even for individuals who were otherwise sedentary in their leisure time. A quasi-experiment of individuals who moved over the course of the study follow-up period suggested that moving to highly walkable neighbourhoods increased utilitarian walking, even after accounting for the influence of confounding from time-constant unmeasured characteristics such as attitudes and preferences. This study was the first national level longitudinal study to determine the impact of cumulative exposure to walkable neighbourhoods on different levels of utilitarian walking for adults. The longitudinal nature of the population-level data and the statistical approaches meant that this study could overcome some methodological issues of past research which has relied on cross-sectional approaches almost exclusively.

The third manuscript assessed whether exposure to walkable neighbourhoods might translate into meaningful influences on body weight. At baseline, the BMI of Canadian men and women was higher for individuals living in less walkable neighbourhoods compared to their counterparts living in more walkable neighbourhoods. Moving to highly walkable neighbourhoods resulted in a 1-point reduction in the BMI of Canadian men, after taking into consideration the influence of individual characteristics. This effect was not demonstrated in women. This was the first national longitudinal study to consider associations of BMI

trajectories with neighbourhood walkability for adults. The evidence points to an important influence of the walkability of neighbourhoods on the BMI trajectories for men. This influence appears to curtail what we have come to expect as a ‘natural’ increase in BMI with age.

6.2 METHODOLOGICAL CONTRIBUTIONS

This thesis used spatial and longitudinal modelling techniques to decipher the influence of the built environment on the utilitarian walking levels of Montrealers and Canadians and on the body mass index of Canadians. Efforts were taken to adopt the appropriate modelling techniques to support the hypotheses of the research (e.g., fixed effects modelling, trajectory modelling) but the adoption of these techniques was not methodologically innovative. Their adoption is perhaps best described as using the carefully considered appropriate available tools.

There were, however, two important methodological innovations of this thesis. The first was the varied approach to the measurement of utilitarian walking (GIS-based estimation from a travel diary and self-reported from survey data). There is a movement in the physical activity literature to use biosensors to measure steps per day (pedometers) or overall physical activity (accelerometers) (Bravata et al., 2007). Biosensors have the advantage of not having to rely on respondents’ imperfect memories to recount their levels of activity. These instruments do still have limitations regarding generalizability, affordability, validity and comprehensiveness, especially when used for large populations. The variation in the devices used and the constant technological developments and methodologies makes it difficult to have uniform use in population studies (Pedišić & Bauman, 2015). More importantly, when it comes to measuring utilitarian walking, biosensors are inappropriate. Biosensors can only record total step counts or total physical activity. They cannot distinguish steps taken for

utilitarian purposes from those taken for leisure-time activity. Given that utilitarian walking is the subset of physical activity that is likely most responsive to policy-induced changes to the built environment, it is imperative that researchers isolate utilitarian walking.

This thesis adopted two approaches to isolating utilitarian walking. This first was a novel approach that linked addresses of travel diary respondents to Montreal's Origin and Destination survey to their closest public transit stop. Utilitarian walking to public transportation could thus be directly estimated based on distance to transit stops rather than asking individuals to recall the amount of their utilitarian walking. This was an especially important methodological innovation in the cross-sectional component of the research where response bias (particularly individuals over-estimating how much walking they actually do) can severely challenge conclusions of regression models. The second approach was the adoption of the self-reported measurement of utilitarian walking in longitudinal modelling whereby the unmeasured response bias likely remained constant over the follow-up period and was less able to influence model interpretations.

The second methodological innovation of this research was the application of a quasi-experimental research design within a population-based survey. This approach required the addition of multiple environmental variables to a large, longitudinal national cohort and involved the tracing of residential patterns of survey respondents over a 12-year follow-up period. This methodological innovation allowed for the one of most robust findings to date in the literature about the true influence of the built environment on utilitarian walking and body weight.

6.3 POLICY IMPLICATIONS

This thesis is academically situated at the intersections of Health Geography, Social Epidemiology and Urban Planning. In all of these fields it is the case that our evidence base is

large but the policy adoption of evidence to improve population health is only modest. The thesis provides sound evidence for a meaningful role of the built environment for utilitarian walking and body mass index (especially for men).

This evidence is important for two key reasons. The first is that individual approaches that formed the mainstay of behavioural epidemiology of the 1970s and 1980s proved inadequate at achieving long-standing behavior change and reduction in chronic disease risk (Susser & Susser, 1996; Syme, 2000). Achieving health behavior change by relying on individual-level interventions remains challenging. Consider, for example, the poor results of the Multiple Risk Factor Intervention Trial (MRFIT). In MRFIT an intervention group of 6,428 American men who were smokers and shared other risk factors that put them at high risk for premature mortality from cardiovascular disease were randomised into a special MRFIT clinic where they received intensive one-on-one supports to change their risky behaviours. The control group was 6,438 men who were informed of their risk and sent back to their regular doctors. After 8 years there was no significant difference between the intervention and control groups in their risk profiles for cardiovascular disease. Similarly other intervention studies that targeted behavioural change (e.g., the large and costly US National Cancer Institute's Community Intervention Trial for Smoking Cessation (COMMIT)) have reached similar conclusions: even in the presence of state-of-the-art behavioural change interventions, sending individuals back to an environment that supports old behaviours will reproduce the risk. A change in paradigm was needed as it was becoming increasingly evident that widespread improvements to the health of populations was going to require policy that addresses features of the built environment in order for individuals to make sustained changes to their behavior (Syme, 2000) and thus provide a viable context for individual-level interventions.

The thesis offers evidence that meeting recommended minutes of physical activity can be achieved by walking to public transportation. People walked more to use public transport services that were more frequent, emphasizing the importance of waiting time for public transportation. If transit agencies improve service provision, increasing frequency and service reliability, people will walk more to use the service. Moreover, transit reliability may attract more ridership into the system. It might also be helpful to include stop removals (stop consolidation) in areas where the spacing is too tight with the goal of increasing efficiency without harming accessibility for less mobile users (El-Geneidy et al., 2006). In general, urban planning interventions that can improve transit service and make it more appealing for people to use, could have indirect positive spill-over effects on population-wide physical activity.

The second key policy implication of the evidence is the multi-sectoral benefits of built environments that support walking. Wilson and Marmot (2003) list the wide-sweeping benefits of active transport (of which utilitarian walking is a subset). Increasing active transport has been identified as one of the top ten most important social determinants of health by the World Health Organization, which argues that it could:

- increase physical activity;
- reduce air pollution;
- reduce greenhouse emissions;
- reduce fatal motor vehicle accidents; and
- increase social contact between people.

Overall then, any land use and transportation policies that increase neighbourhood walkability could be potential levers to not only increase utilitarian walking and reduce body weight but also have tremendous societal benefits in other domains.

6.4 DISSERTATION LIMITATIONS

Readers should note some limitations to the research presented in this thesis. The thesis makes use of self-reported measures of utilitarian walking and height and weight. Data using self-reported walking present a clear limitation in cross-sectional studies as it may be difficult for subjects to recall their walking accurately and they may feel social pressure to report more than they actually do. In the cross sectional study in this thesis, respondents to Montreal's Origin-Destination Survey were asked to fill a detailed travel diary with the type of trips they made, and mode of transport they used (e.g. train or bus and the bus number they took, or train station name). We measured distances from the respondents' home addresses to the closest public transit stop using GIS, rather than asking individuals to recall the amount of their utilitarian walking. In longitudinal studies, if respondents over-report or under-report their utilitarian walking levels, or weight and height, the direction of their misrepresentation is likely consistent over time, and hence reporting bias is arguably less of a problem in longitudinal analyses like those reported in the second and third manuscript as we were more interested in changes than absolute levels.

Reliance on the question that was asked on the NPHS to measure utilitarian walking could be indicated as a limitation, since it was self-reported. However, this same question appears on other surveys in in Canada (e.g., the smaller but biometrically rich Canadian Health Measures Survey) which is important for comparative research. Another possible limitation of our work is the lack of availability of historical Walk Score® data, used in the second and third manuscripts, to measure neighbourhood walkability. We used 2012 Walk Score® data, which did not correspond to the time frame of the NPHS follow up (1994-2006). That said, neighbourhoods do not usually change their physical characteristics quickly and we tested other measures correlated with Walk Score® (street connectivity and

population density) that we computed from street network and Census data in 1996 and 2006. Measures computed at the two time periods were highly correlated.

There was a substantial effort directed toward an attrition analysis of the NPHS for the research topics of this thesis (Appendix 2). Loss of health survey respondents through death and loss-to-follow-up is the single biggest methodological threat to conclusions reached through longitudinal research efforts. If attrition is non-random, this can lead to an increasingly healthy sample that is no longer like the group that one started with. We found that there were no meaningful differences in health status, utilitarian walking, and BMI of people who were lost compared to those who remained in the sample (Appendix 2). Despite the favourable findings of the attrition analyses for the thesis objectives, the NPHS is representative of the Canadian population in 1994 and as such we should be cautious of a contemporary interpretation of the findings. Canada in 2015 is substantially more ethnically diverse (Statistics Canada, 2015b) than it was in 1994 and it is substantially older (Statistics Canada, 2015c).

There are seasonal deficits in walking (Dasgupta et al., 2010; Tucker & Gilliland, 2007) and this thesis is conducted in urban environments which experience vast differences in climate by season. The timing of the trip diary or the NPHS interview could affect individuals' behavior. In the cross sectional analysis in Montreal, the trip diary was filled in September and October of 2003. We would expect our estimates to be lower if the trip diary was filled in winter. For the NPHS, it is really difficult to adjust for seasonality, mainly due to the nature of the utilitarian question asked in the survey. The question asked participants to report their utilitarian walking minutes conducted in a typical week, during the previous 3 months from the interview date. There is no way to really adjust for this in the current analysis, but there was awareness about some of the uniquely Canadian, indeed uniquely Montreal, and aspects of the work.

It is always hoped that one can draw substantive conclusions from any research endeavor and generalize these to other situations and contexts. That said, the amount of utilitarian walking to public transit we found in Montreal may be higher than one might find in other jurisdictions given Montreal's unique culture. It is also important to note that the longitudinal analyses in Chapters 4 and 5 involved the urban subset of respondents to the NPHS who were working-age at baseline and so the study design, while incorporating thousands of respondents, is not intended to be representative of the entire population of Canada.

6.5 CONCLUDING REMARKS

This dissertation draws from and contributes to inter-disciplinary approaches to understanding human health in urban environments, adopting perspectives from Health Geography, Social Epidemiology and Urban Planning. In Health Geography, the role of 'place' in the determinants of health framework is emphasized (Cummins, Curtis, Diez Roux, & Macintyre, 2007; Macintyre, Ellaway, & Cummins, 2002; Marmot, 1998; C. Ross & Mirowsky, 2008; Siergrist, 2000). 'Place' constitutes and contains social relations and physical characteristics that might influence health. Tackling those social relationships and physical characteristics rather than illness might have a greater overall impact on the health of the population (Frohlich, Ross, & Richmond, 2006). The focus on the link between place and health gained much attention with the development of contemporary health philosophy, which is based on the ideas of health rather than medicine (White, 1981). In contemporary health philosophy, the socio-ecological model of health replaced the biomedical disease model with a perspective of redirecting the goals from treatment to prevention. The socio-ecological model holds that individuals' characteristics (e.g., age, gender), their socio-economic characteristics and how they interact with their social, cultural, and physical

environment have an impact on their health (Kearns, 1993; McLeroy, Bibeau, Steckler, & Glanz, 1988; Veenstra et al., 2005).

The overall impact of the research presented in this dissertation is the contribution to the body of evidence showing the influence of neighbourhood physical characteristics (neighbourhood walkability) and transportation systems on utilitarian walking and BMI. Exposure to walkable neighbourhoods increases utilitarian walking for men and women and is associated with lower BMI trajectories for men. One might assume that the pathway between neighbourhood walkability and BMI is via walking for utilitarian purposes. Yet even after controlling for utilitarian walking levels, neighbourhood walkability still had a substantial association with men's body weights, suggesting that there are other factors that are important. A direction for future research is to understand, in more detail, the precise mix of factors that makes these walkable neighbourhoods unique. Future research will need to not only to concentrate on the physical environment, but to try and understand how people interact with their social and cultural environments in these walkable neighbourhoods. Designing studies that have more qualitative aspects, to understand the dynamics of the social relations in those walkable neighbourhoods, could also prove informative for specific policy adoption.

REFERENCES

- Agence métropolitaine de transport. (2003). Enquête origine-destination 2003. Montréal, QC.
- Allison, P. (2005). *Fixed effects regression methods for longitudinal data using SAS*. Cary, NC: SAS Institute, Inc.
- Andersen, L., Schnohr, P., Schroll, M., & Hein, H. (2000). All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. *Archives of Internal Medicine*, 160, 1621–1628.
- Andrewsa, G., Hallb, E., Evansc, B., & Colls, R. (2012). Moving beyond walkability: On the potential of Health Geography. *Social Science & Medicine*, 75(11), 1925-1932. doi:10.1016/j.socscimed.2012.08.013
- Astrup, A., Hill, J., & Rössner, S. (2004). The cause of obesity: Are we barking up the wrong tree? *Obesity Reviews*, 5(3), 125-127.
- Badland, H., & Schofield, G. (2005). Transport, urban design, and physical activity: An evidence-based update. *Transportation Research: Part D*, 10, 177-196.
- Bates, J., Serdula, M., Khan, L., Jones, D., Gillespie, C., & Ainsworth, B. (2005). Total and leisure-time walking among U.S. adults: Should every step count? *Amercian Journal of Preventive Medecine*, 29(1), 46–50.
- Bauman, A., Bull, F., Chey, T., Craig, C., Ainsworth, B., Sallis, J., . . . The IPS Group. (2009). The International Prevalence Study on Physical Activity: Results from 20 countries. *International Journal of Behavioral Nutrition and Physical Activity*, 6-21.
- Bennett, S., Felton, R., & Akçelik, R. (2001). *Pedestrian movement characteristics at signalised intersection*. Paper presented at the 23 rd Conference of Australian Institutes of Transport Research, Melbourne, Australia.
- Berke, E., Gottlieb, L., Vernez Moudon, A., & Larson, E. (2007). Protective association between neighborhood walkability and depression in older men. *The American Geriatrics Society*, 55, 526-533.
- Berkman, L., & Kawachi, I. (2000). A historical framework for social epidemiology. In L. Berkman & I. Kawachi (Eds.), *Social Epidemiology*. New York: Oxford University Press.
- Berrigan, D., Troiano, R., McNeel, T., Disogra, C., & Ballard-Barbash, R. (2006). Active transportation increases adherence to activity recommendations. *Amercian Journal of Preventive Medecine*, 31(3), 210-216.

- Berry, T., Spence, J., Blanchard, C., Cutumisu, N., Edwards, J., & Nykiforuk, C. (2010). Changes in BMI over 6 years: The role of demographic and neighborhood characteristics. *International Journal of Obesity*, 34, 1275–1283. doi:10.1038/ijo.2010.36
- Besser, L., & Dannenberg, A. (2005). Walking to public transit: Steps to help meet physical activity recommendations. *American Journal of Preventive Medicine*, 29(4), 273-280.
- Bickel, R. (2007). *Multilevel analysis for applied research: It's just regression!* New York: The Guilford Press.
- Blair, S., Cheng, Y., & Holder, S. (2001). Is physical activity or physical fitness more important in defining health benefits? *Medicine & Science in Sports & Exercise*, 33(6, Suppl.), S379 –S399.
- Bouchard, C., & Perusse, L. (1993). Genetics of obesity. *Annual Review Nutrition*, 13, 337-354.
- Bovens, A., Van Baak, M., Vrencken, J., Wijnen, J., Saris, W., & Verstappen, F. (1993). Physical activity, fitness, and selected risk factors for CHD in active men and women. *Medicine and Science in Sports and Exercise*, 25, 572–576.
- Bravata, D., Smith-Spangler, C., Sundaram, V., Gienger, A., Lin, N., Lewis, R., . . . Sirard, J. (2007). Using pedometers to increase physical activity and improve health: A systematic review. *The Journal of the American Medical Association*, 298(19), 2296-2304. doi:10.1001/jama.298.19.2296
- Brown, B., & Werner, C. (2007). A new rail stop: Tracking moderate physical activity bouts and ridership. *American Journal of Preventive Medicine*, 33(4), 306-309.
- Brown, W., Hockey, R., & Dobson, A. (2008). Physical activity, body mass index and health care costs in mid-age Australian women. *Australian and New Zealand Journal of Public Health*, 32(2), 150-155.
- Brownson, R., Hoehner, C., Day, K., Forsyth, A., & Sallis, J. (2009). Measuring the built environment for physical activity: State of the science. *American Journal of Preventive Medicine*, 36(4S), S99-S123. doi:10.1016/j.amepre.2009.01.005
- Burnett, K., & Farkas, G. (2009). Poverty and family structure effects on children's mathematics achievement: Estimates from random and fixed effects models. *The Social Science Journal*, 46, 297-318.
- Butler, G., Orpana, H., & Wiens, A. (2007). By your own two feet: Factors associated with active transportation in Canada. *Canadian Journal of Public Health*, 98(4), 259-264.

- Canada, S. (2007). National Population Health Survey - household component - longitudinal (NPHS). Retrieved from <http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SurvId=1824&InstaId=3358&SDDS=3225>
- Cao, X. (2009a). Disentangling the influence of neighborhood type and self-selection on driving behavior: An application of sample selection model. *Transportation*, 36(2), 207-222. doi:10.1007/s11116-009-9189-9
- Cao, X. (2009b). *Exploring causal effects of neighborhood type on travel behavior using stratification on the propensity score*. Paper presented at the Transportation Research Board 88th Annual meeting Washington, DC.
- Cao, X., Mokhtarian, P., & Handy, S. (2009). Examining the impacts of residential self-selection on travel behaviour: A focus on empirical findings. *Transport Reviews*, 29(3), 359-395. doi:10.1080/01441640802539195
- Car, L., Dunsiger, S., & Marcus, B. (2010). Validation of Walk Score for estimating access to walkable amenities. *British Journal of Sports Medicine*. doi:10.1136/bjsm.2009.069609
- Carlson, J., Saelens, B., Kerr, J., Schipperijn, J., Conway, T., Frank, L., . . . Sallis, J. (2015). Association between neighborhood walkability and GPS-measured walking, bicycling and vehicle time in adolescents. *Health & Place*, 32, 1-7. doi:10.1016/j.healthplace.2014.12.008. Epub 2015 Jan 9
- Cervero, R. (2001). Walk-and-ride: Factors influencing pedestrian access to transit. *Journal of Public Transportation*, 3(4), 1-23.
- Cervero, R., & Gorham, R. (1995). Commuting in transit versus automobile neighborhoods. *Journal of the American Planning Association*, 61, 210-225.
- Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D*, 2(3), 199-219.
- Cervero, R., & Radisch, C. (1996). Travel choices in pedestrian versus automobile oriented neighborhoods. *Transport Policy*, 3, 127-141.
- Chapleau, R. (2003). Measuring the internal quality of a CATI travel household survey. In P. Stopher & P. Jones (Eds.), *Transport Survey Quality and Innovation* (pp. 69-87). Kruger, South Africa: Pergamon.
- Chen, C., & Miller, W. (1999). Health effects of physical activity. *Health Reports*, 11(1), 21-30.

- Commission on social determinants of health. (2008). *Closing the gap in a generation. Health equity through action on the social determinants of health*. Retrieved from
- Cummins, S., Curtis, S., Diez Roux, A., & Macintyre, S. (2007). Understanding and representing 'place' in health research: A relational approach. *Social Science & Medicine*, 65, 1825-1838.
- Dasgupta, K., Joseph, L., Pilote, L., Strachan, I., Sigal, R., & Chan, C. (2010). Daily steps are low year-round and dip lower in fall/winter: findings from a longitudinal diabetes cohort. *Cardiovascular Diabetology*, 9.
- Diez Roux, A., & Mair, C. (2010). Neighbourhoods and health. *Annals of the New York Academy of Sciences*, 1186, 125-145.
- Duncan, D., Aldstadt, J., Whalen, J., Melly, S., & Gortmaker, S. (2011). Validation of Walk Score® for estimating neighborhood walkability: An analysis of four US metropolitan areas. *International Journal of Environmental Research and Public Health*, 8, 4160-4179. doi:doi:10.3390/ijerph8114160
- Egger, G., & Swinburn, B. (1997). An "ecological" approach to the obesity pandemic. *BMJ*, 315, 477-480.
- Eid, J., Overman, H., Puga, D., & Turner, M. (2008). Fat city: Questioning the relationship between urban sprawl and obesity. *Journal of Urban Economics*, 63(2), 385-404.
- Ekelund, U. (2012). Commentary: too much sitting-a public health threat. *International Journal of Epidemiology*, doi:10.1093/ije/dys128, 1-3.
- El-Geneidy, A., & Levinson, D. (2006). *Access to destinations: Development of accessibility measures*. Retrieved from Minneapolis, Minnesota, USA:
- El-Geneidy, A., Strathman, J., Kimpel, T., & Crout, D. (2006). The effects of bus stop consolidation on passenger activity and transit operations. *Transportation Research Record*, 1971, 32-41.
- El-Geneidy, A., Tétreault, P., & Surprenant-Legault, J. (2010). *Pedestrian access to transit: Identifying redundancies and gaps using variable service area analysis*. Paper presented at the 89th Transportation Research Board Annual Meeting, Washington D.C., USA.
- Eluru, N., Bhat, C., & Hensher, D. (2008). A mixed generalized ordered response model for examining pedestrian and bicyclist injury severity level in traffic crashes. *Accident Analysis & Prevention*, 40(3), 1033-1054.

- Evans, A. (1995). Reviews and commentary: Causation and disease: A chronological journey. *American Journal of Epidemiology*, 142(11), 1127-1135.
- Ewing, R. (2005). Can the physical environment determine physical activity levels? *American College of Sports Medicine*, 33(2), 69-75.
- Ewing, R. (2009). *Measuring the impact of urban form and transit access on mixed use site trip generation rates - Portland pilot study*. Retrieved from Washington, DC:
- Ewing, R., & Cervero, R. (2010). Travel and the built environment. *Journal of the American Planning Association*, 76(3), 265-294.
- Federal-Provincial/Territorial Advisory Committee on Fitness and Recreation. (1997). *A framework for action: Towards healthy, active living for Canadians*. Retrieved from Ottawa:
- Feeny, D., Garner, R., Bernier, J., Thompson, A., McFarland, B., Huguet, N., . . . Blanchard, C. (2014). Physical activity matters: Associations among body mass index, physical activity, and health-related quality of life trajectories over 10 years. *Journal of Physical Activity and Health*, 11(7), 1265-1275.
- Feng, J., Glass, T., Curriero, F., Stewart, W., & Schwartz, B. (2010). The built environment and obesity: A systematic review of the epidemiologic evidence. *Health & Place*, 16(2), 175-190.
- Fielding, G., Glauthier, R., & Lave, C. (1978). Performance indicators for transit management. *Transportation*, 7, 365-379.
- Finkelstein, E., Fiebelkorn, I., & Wang, G. (2003). National medical spending attributable to overweight and obesity: How much, and who's paying. *Health Affairs*, 22(1), 219-226.
- Forsyth, A., Oakes, J., Schmitz, K., & Hearst, M. (2007). Does residential density increase walking and other physical activity? *Urban Studies*, 44(4), 679-697.
- Frank, L., Andresen, M., & Schmid, T. (2004). Obesity relationships with community design, physical activity, and time spent in cars. *American Journal of Preventive Medicine*, 27(2), 87-96.
- Frank, L., Saelens, B., Powell, K., & Chapman, J. (2007). Stepping towards causation: Do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity? *Social Science & Medicine*, 65, 1898-1914.
- Frank, L., Sallis, J., Conway, T., Chapman, J., Saelens, B., & Bachman, W. (2006). Many pathways from land use to health: Associations between

- neighborhood walkability and active transportation, body mass index, and air quality. *Journal of American Planning Association*, 72, 75–87.
- Frank, L., Schmid, T., Sallis, J., Chapman, J., & Saelens, B. (2005). Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *American Journal of Preventive Medicine*, 2005(2S2), 117-125.
- Frees, E. (2004). *Longitudinal and panel data: Analysis and applications in the Social Sciences*. New York: Cambridge University Press.
- Frohlich, K., Ross, N., & Richmond, C. (2006). Health disparities in Canada today: Some evidence and a theoretical framework. *Health Policy*, 79(2-3), 132-143.
- Fruin, J. (1971). *Pedestrian planning and design*. New York: Metropolitan association of urban designers and environmental planners.
- Fujiwara, T., & Kawachi, I. (2009). Is education causally related to better health? A twin fixed-effects study in the USA. *International Journal of Epidemiology*, 38, 1310-1322.
- Gebel, K., Bauman, A., Sugiyama, T., & Owen, N. (2011). Mismatch between perceived and objectively assessed neighborhood walkability attributes: Prospective relationships with walking and weight gain. *Health & Place*, 17(2), 519-524. doi:10.1016/j.healthplace.2010.12.008
- Gordon-Larsen, P., Nelson, M., & Beam, K. (2005). Associations among active transportation, physical activity, and weight status in young adults. *Obesity Research*, 13(5), 868-875.
- Grasser, G., Van Dyck, D., Titze, S., & Stronegger, W. (2013). Objectively measured walkability and active transport and weight-related outcomes in adults: A systematic review. *International Journal of Public Health*, 58, 615-625. doi:10.1007/s00038-012-0435-0
- Gutiérrez, J., & García-Palomares, J. (2008). Distance-measure impacts on the calculation of transport service areas using GIS. *Environment and Planning B: Planning and Design*, 35, 480-503.
- Handy, S. (1993). Regional versus local accessibility: Implications for non-work travel. *Transportation Research Record*, 1400, 58-66.
- Handy, S. (1996a). Methodologies for exploring the link between urban form and travel behavior. *Transportation research Part D: Transport and Environment*, 1(2), 151-165.
- Handy, S. (1996b). Urban form and pedestrian choices: Study of Austin neighborhoods. *Transportation Research Record*(1552), 135–144.

- Handy, S. (2005). *Does the built environment influence physical activity? Examining the evidence. Critical assessment of the literature on the relationships among transportation, land use, and physical activity.* Retrieved from Washington DC:
- Handy, S., Boarnet, M., Ewing, R., & Killingsworth, R. (2002). How the built environment affects physical activity. *American Journal of Preventive Medicine*, 23(2), 64–73.
- Handy, S., Cao, X., & Mokhtarian, P. (2008). The causal influence of neighborhood design on physical activity within the neighborhood: Evidence from Northern California. *Americian Journal of Health Promotion*, 22(5), 350-358.
- Handy, S., & Clifton, K. (2001). Local shopping as a strategy for reducing automobile travel. *Transportation Research Part A*, 28, 317–346.
- Handy, S., & Mokhtarian, P. (2005). Which Comes First: The Neighbourhood or The Walking? *ACCESS Magazine*, 1, 16-21.
- Handy, S., & Niemeier, D. (1997). Measuring accessibility: An exploration of issues and alternatives. *Environment and Planning A*, 29(7), 1175-1194.
- Hannah, B., & Grant, S. (2008). Health associations with transport-related physical activity and motorized travel to destinations. *International Journal of Sustainable Transportation*, 2(2), 77-90.
- Hansen, W. (1959). How accessibility shapes land use. *Journal of American Institute of Planners*, 25(2), 73-76.
- Hassan, E. (2005). Recall bias can be a threat to retrospective and prospective research designs. *The Internet Journal of Epidemiology*, 3(2).
- Hayashi, T., Tsumura, K., Suematsu, C., Okada, K., Fujii, S., & Endo, G. (1999). Walking to work and the risk of hypertension in men: The Osaka Health Survey. *Annals of Internal Medicine*, 130, 21–26.
- Heath, G., Brownson, R., Kruger, J., Miles, R., Powell, K., Ramsey, L., & the Task Force on Community Preventive Services. (2006). The effectiveness of urban design and land use and transport policies and practices to increase physical activity: A systematic review. *Journal of Physical Activity and Health*, 3, 55-76.
- Hill, J., & Peters, J. (1998). Environmental contributions to the obesity epidemic. . *Science*, 280, 1371-1374.
- Hill, J., Wyatt, H., & Melanson, E. (2000). Genetic and environmental contributions to obesity. *The Medical Clinics of North America*, 84(2), 333-346.

- Hinde, S., & Dixon, J. (2005). Changing the obesogenic environment: Insights from a cultural economy of car reliance. *Transportation Research: Part D*, 10, 31-53.
- Hirsch, J., Diez Roux, A., Moore, K., Evenson, K., & Rodriguez, D. (2014). Change in walking and body mass index following residential relocation: The multi-ethnic study of atherosclerosis. *American Journal of Public Health* 104(3), e49-e56.
- Hoehner, C., Handy, S., Yan, Y., Blair, S., & Berrigan, D. (2011). Association between neighborhood walkability, cardiorespiratory fitness and body-mass index. *Social Science & Medicine*, 73(12), 1707-1716.
- Hollingworth, B., Mori, A., Cham, L., Passmore, D., Irwin, N., & Noxon, G. (2010). *Urban transportation indicators: Fourth Survey*. Retrieved from
- Hsiao, S., Lu, J., Sterling, J., & Weatherford, M. (1997). Use of Geographic Information System for analysis of transit pedestrian access. *Transportation Research Record*, 1604, 50-59.
- Hu, F., Sigal, R., Rich-Edwards, J., Colditz, G., Solomon, C., Willett, W., . . . Manson, J. (1999). Walking compared with vigorous physical activity and risk of type 2 diabetes in women: A prospective study. . *The Journal of the American Medical Association*, 282, 1433-1439.
- Hu, G., Pekkarinen, H., Hanninen, O., Tian, H., & Guo, Z. (2001). Relation between commuting, leisure time physical activity and serum lipids in a Chinese urban population. *Annals of Human Biology*, 28, 412–421.
- Hu, G., Pekkarinen, H., Hanninen, O., Yu, Z., Guo, Z., & Tian, H. (2002). Commuting, leisure-time physical activity, and cardiovascular risk factors in China. *Medicine and Science in Sports and Exercise*, 34, 234–238.
- Huot, S., Paradis, G., & Ledoux, M. (2004). Factors associated with overweight and obesity in Quebec adults. *International Journal of Obesity*, 38, 137-148.
- Iacono, M., Krizek, K., & El-Geneidy, A. (2010). Measuring non-motorized accessibility: Issues, alternatives, and execution. *Journal of Transport Geography*, 18, 133-140.
- Jakicic, J., & Gallagher, K. (2003). Exercise considerations for the sedentary, overweight adult. *Exercise and Sport Sciences Reviews*, 31(2), 91-95.
- Katzmarzyk, P. (2004). Physical activity levels of Canadian children and youth: Current issues and recommendations. *Canadian Journal of Diabetes*, 28(1), 67-78.
- Katzmarzyk, P., & Ardern, C. (2004). Overweight and obesity mortality trends in Canada, 1985-2005. *Canadian Journal of Public Health*, 95(1), 16-20.

- Katzmarzyk, P., Gledhill, N., & Shephard, R. (2000). The economic burden of physical inactivity in Canada. *Canadian Medical Association journal*, 163(11), 1435-1440.
- Kawachi, I., & Berkman, L. (Eds.). (2003). *Neighborhoods and health*. New York: Oxford University Press.
- Kearns, R. (1993). Place and health: towards a reformed medical geography. *Place and Health*, 45(2), 139-147.
- Kimpel, T., Dueker, K., & El-Geneidy, A. (2007). Using GIS to measure the effect of overlapping service areas on passenger boardings at bus stops. *Urban and Regional Information Systems Association Journal*, 19(1), 5-11.
- Kitamura, R., Mokhtarian, P., & Laidet, L. (1997). A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay area. *Transportation Research Part A*, 24, 125–158.
- Knoblauch, R., Pietrucha, M., & Nitzberg, M. (1996). Field studies of pedestrian walking speed and start-up time. *Transportation Research Record*, 1538, 27-38.
- Knuiman, M., Christian, H., Divitini, M., Foster, S., Bull, F., Badland, H., & Giles-Corti, B. (2014). A longitudinal analysis of the influence of the neighborhood built environment on walking for transportation. *American Journal of Epidemiology*, 180(5), 453-461.
- Kockelman, K. (1997). Travel behavior as function of accessibility, land use mixing, and land use balance: Evidence from San Francisco bay area. *Transportation Research Record*, 1607, 116-125.
- Krizek, K. (2000). Pretest-posttest strategy for researching neighborhood-scale urban form and travel behavior. *Transportation Research Record*, 1722, 48-55.
- Kuby, M., Barranda, A., & Upchurch, C. (2004). Factors influencing light rail station boardings in the United States. *Transportation Research Part A*, 38, 223-247.
- LaMonte, M., Blair, S., & Church, T. (2005). Physical activity and diabetes prevention. *Journal of Applied Physiology*, 99, 1205-1213.
- Larsen, J., El-Geneidy, A., & Yasmin, F. (2010). Beyond the quarter mile: Re-examining travel distances by active transportation. *Canadian Journal of Urban Research: Canadian Planning and Policy (supplement)*, 19(1), 70-88.

- Lavizzo-Mourey, R., & McGinnis, M. (2002). Making the Case for Active Living Communities. *American Journal of Public Health*, 93(9), 1386-1388. doi:doi: 10.2105/AJPH.93.9.1386
- Le Petit, C., & Berthelot, J. (2006). Obesity a growing issue. *Health Reports*, 17(3), 43-50.
- Lee, I., & Skerrett, P. (2001). Physical activity and all-cause mortality: What is the dose-response relation? *Medicine and Science in Sports and Exercise*, 33(6), S459-S471.
- Lee, I. M., & Buchner, D. M. (2008). The importance of walking to public health. *Medicine & Science in Sports & Exercise*, 40(7 Suppl.), S512-S518.
- Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A., & Hugo, G. (2007). Walkability of local communities: Using Geographic Information Systems to objectively assess relevant environmental attributes. *Health & Place*, 13, 111-122.
- Li, F., Harmer, P., Cardinal, B., Bosworth, M., Acock, A., Johnson-Shelton, D., & Moore, J. (2008). Built environment, adiposity, and physical activity in adults aged 50–75. *American Journal of Preventive Medicine*, 35(1), 38-46.
- Lindström, M. (2008). Means of transportation to work and overweight and obesity: A population-based study in southern Sweden. *Preventive Medicine*, 46 22–28.
- Little, R., & Rubin, D. (2002). *Statistical analysis with missing data*. (Second ed.). Hoboken, New Jersey: John Wiley & Sons, Inc.
- Lopez-Zetina, J., Lee, H., & Friis, R. (2006). The link between obesity and the built environment: Evidence from an ecological analysis of obesity and vehicle miles of travel in California. *Health & Place*, 12(4), 656-664.
- Loutzenheiser, D. (1997). Pedestrian access to transit: Modeling of walk trips and theory design and urban form determination around bay area rapid transit stations. *Transportation Research Record*, 1604, 40-49.
- MacDonald, J., Stokes, R., Cohen, D., Kofner, A., & Ridgeway, G. (2010). The effect of light rail transit on body mass index and physical activity. *American Journal of Preventive Medicine*, 39(2), 105-112.
- Macdonald, S., Reeder, B., Chen, B., & Despres, J. (1997). Obesity in Canada: A descriptive analysis. . *Canadian Medical Association journal*, 157(1).
- Macintyre, S., & Ellaway, A. (2003). Neighborhoods and health: An overview. In I. Kawachi & L. Berkman (Eds.), *Neighborhoods and Health*. New York: Oxford University Press.

- Macintyre, S., Ellaway, A., & Cummins, S. (2002). Place effects on health: How can we conceptualise, operationalise, and measure them? *Social Science & Medicine*, 55, 125-139.
- Mackenbach, J., Rutter, H., Compernelle, S., Glonti, K., Oppert, J.-M., Charreire, H., . . . Lakerveld, J. (2014). Obesogenic environments: A systematic review of the association between physical environment and adult weight status, the SPOTLIGHT project. *BMC Public Health*, 14(1), 233.
- Manaugh, K., & El-Geneidy, A. (2011). Validating walkability indices: How do different households respond to the walkability of their neighbourhood? *Transportation Research Part D: Transport and Environment*, 16(4), 309-315.
- Manaugh, K., & Kreider, T. (2013). What is mixed use? Presenting an interaction method for measuring land use mix. *The Journal of Transport and Land Use*, 6(1), 63-72.
- Manson, J., Greenland, P., LaCroix, A., Stefanick, M., Mouton, C., Oberman, A., . . . Siscovick, D. (2002). Walking compared with vigorous exercise for the prevention of cardiovascular events in women. *The New England Journal of Medicine*, 347(10), 716-726.
- Marmot, M. (1998). Improvement of social environment to improve health. *The Lancet*, 351, 57-60.
- McLeroy, K., Bibeau, D., Steckler, A., & Glanz, K. (1988). An ecological perspective on health promotion programs. *Health Education Behaviour*, 15, 351.
- Meade, M., & Earickson, R. (2000). *Medical geography*. New York: Guilford Press.
- Meyer, M. (1999). Demand management as an element of transportation policy: Using carrots and sticks to influence travel behavior. . *Transportation Research Part A: Policy and Practice*, 33(7-8), 575-599.
- Morency, C., Demers, M., & Lapierre, L. (2007). How many steps do you have in reserve: Some thoughts and measures regarding a healthier way to travel. *Transportation Research Record*(2002), 1-6.
- Morency, C., Trépanier, M., & Demers, M. (2011). Walking to transit: An unexpected source of physical activity. *Transport Policy*, 18(6), 800-806.
- Murray, A., & Wu, X. (2003). Accessibility tradeoffs in public transit planning. *Journal of Geographic Systems*, 5(1), 93-107.

- Neilson, G., & Fowler, W. (1972). Relation between transit ridership and walking distances in a low-density Florida retirement area. *Highway Research Record*(403), 26-34.
- Nelson, N., & Woods, C. (2009). Obesogenic environments: Are neighbourhood environments that limit physical activity obesogenic? *Health & Place*. doi:doi:10.1016/j.healthplace.2009.02.001
- O'Neill, W., Ramsey, D., & Chou, J. (1992). Analysis of transit service areas using Geographic Information Systems. *Transportation Research Record*, 1364, 131-139.
- Oreskovic, N., Charles, P., Shepherd, D., Nelson, K., & Bar, M. (2014). Attributes of form in the built environment that influence perceived walkability. *Journal of Architecture and Planning Research*, 31(3), 218-232.
- Owen, N., Humpel, N., Leslie, E., Bauman, A., & Sallis, J. (2004). Understanding environmental influences on walking: Review and research agenda. *American Journal of Preventive Medicine*, 27, 67-76.
- Papas, M., Alberg, A., Ewing, R., Helzlsouer, K., Gary, T., & Klassen, A. (2007). The built environment and obesity. *Epidemiological Reviews*, 29, 129–143.
- Pedišić, Ž., & Bauman, A. (2015). Accelerometer-based measures in physical activity surveillance: current practices and issues. *British Journal of Sports Medicine*, 49 219-223. doi:doi:10.1136/bjsports-2013-093407
- Peters, J. (2003). Combating obesity: Challenges and choices. *Obesity Research*, 11 (Suppl.), 7S-11S.
- Pikora, T., Giles-Corti, B., Bull, F., Jamrozik, K., & Donovan, R. (2003). Developing a framework for assessment of the environmental determinants of walking and cycling. *Social Science & Medicine*, 56, 1693-1703.
- Poston, W., & Foreyt, J. (1999). Obesity is an environmental issue. *Atherosclerosis*, 146, 201–209.
- Pouliou, T., Elliott, S., Paez, A., & Newbold, K. (2014). Building obesity in Canada: Understanding the individual- and neighbourhood-level determinants using a multi-level approach. *Geospatial Health*, 9(1), 44-55.
- Public Health Agency of Canada. (2008). *Canada's physical activity guide to healthy active living*. Ottawa.
- Ross, C., & Mirowsky, J. (2008). Neighbourhood socioeconomic status and health: Context or composition? *City & Community*, 7(2), 163-179.

- Ross, N. A., Tremblay, S., & Graham, K. (2004). Neighbourhood influences on health in Montréal, Canada. *Social Science & Medicine*, 59(7), 1485-1494
- Ross, N. A., Tremblay, S., Khan, S., Crouse, D., Tremblay, M., & Berthelot, J. (2007). Body mass index in urban Canada : Neighborhood and metropolitan area effects. *American Journal of public health*, 97(3), 500-508.
- Saelens, B., & Handy, S. (2008). Built environment correlates of walking: A review. *Medicine and Science in Sports and Exercise*, 40(7), 550-566.
- Saelens, B., Sallis, J., & Frank, L. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, 25(2), 80-91.
- Sallis, J., Frank, L., Saelens, B., Kraft, M., & Engelke, E. (2004). Active transportation and physical activity: Opportunities for collaboration on transportation and public health research. *Transportation Research Part A*, 38(4), 249–268.
- Sallis, J., Saelens, B., Frank, L., Conway, T., Slymen, D., Cain, K., . . . Kerr, J. (2009). Neighborhood built environment and income: Examining multiple health outcomes. *Social Science & Medicine*, 68(7), 1285-1293.
- Salvo, D., Reis, R., Stein, A., Rivera, J., Martorell, R., & Pratt, M. (2014). Characteristics of the built environment in relation to objectively measured physical activity among Mexican adults, 2011. *PREVENTING CHRONIC DISEASE*, 28(11), E147. doi:doi: 10.5888/pcd11.140047
- Sari, N. (2009). Physical inactivity and its impact on health care utilization. *Health Economics*, 18(8), 885-901.
- Schlossberg, M., Agrawal, A., Irvin, K., & Bekkouche, V. (2007). *How far, by which route, and why? A spatial analysis of pedestrian preference*. Retrieved from San José, CA:
- Siergrist, J. (2000). Place, social exchange and health: Proposed sociological framework. *Social Science & Medicine*, 51, 1283-1293.
- Singer, J., & Willet, J. (2003). *Applied Longitudinal data analysis: Modelling change and event occurrence*. New York: Oxford University Press, Inc.
- Smith, K., Brown, B., Yamada, I., Kowaleski-Jones, L., Zick, C., & Fan, J. (2008). Walkability and body mass index: Density, design, and new diversity measures. *American Journal of Preventive Medicine*, 35(3), 237-244.
- Statistics Canada. (2003, 2003). Illustrated glossary. Retrieved from http://geodepot.statcan.ca/Diss/Reference/COGG/Index_e.cfm

- Statistics Canada. (2009). *National Population Health Survey. Household component documentation for the derived variables and the constant longitudinal variables (specifications). Cycles 1 to 7 (1994/1995 to 2006/2007)*. Ottawa: Statistics Canada Retrieved from http://www23.statcan.gc.ca/imdb-bmdi/pub/document/3225_D10_T9_V3-eng.pdf.
- Statistics Canada. (2015a). CANSIM, table 105-0501: Body mass index, overweight or obese, self-reported, adult, by sex, provinces and territories (percent). Retrieved from <http://www.statcan.gc.ca/tables-tableaux/sum-som/101/cst01/health82b-eng.htm?sdi=body%20mass%20index>. Retrieved 14 July 2015, from Statistics Canada <http://www.statcan.gc.ca/tables-tableaux/sum-som/101/cst01/health82b-eng.htm?sdi=body%20mass%20index>
- Statistics Canada. (2015b). *Ethnic diversity and immigration*. Canada: Statistics Canada, Retrieved from <http://www.statcan.gc.ca/pub/11-402-x/2011000/chap/imm/imm-eng.htm>.
- Statistics Canada. (2015c). *Indicators of Well-being in Canada.*: Statistics Canada, Retrieved from <http://well-being.esdc.gc.ca/misme-iowb/.3ndic.1t.4r@-eng.jsp?iid=33>.
- Susser, M., & Susser, E. (1996). Choosing a future for epidemiology: I. eras and paradigms. *American Journal of Public Health*, 86(5), 668-673.
- Swinburn, B., Caterson, I., Seidell, J., & James, W. (2004). Diet, nutrition and the prevention of excess weight gain and obesity. *Public Health Nutrition*, 7((1A)), 123-146.
- Syme, L. (2000). Community participation, empowerment, and health. In M. Jamner & D. Stockols (Eds.), *Promoting human wellness: New frontiers for research, practice and policy* (pp. 78-98). Berkeley Los Angeles London: University of California Press.
- Tétreault, P., & El-Geneidy, A. (2010). Estimating bus run times for new limited-stop service using archived AVL and APC data. *Transportation Research Part A: Policy and Practice*, 44(6), 390-402.
- Thielman, J., Rosella, L., Copes, R., Lebenbaum, M., & Manson, H. (2015). Neighbourhood walkability: differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. *American Journal of Preventive Medecine*, 15. doi:doi: 10.1016/j.ypmed.2015.05.011.
- Tomer, A., & Kane, J. (2014). Most americans still driving, but new census data reveal shifts at the metro level. Retrieved from

http://www.brookings.edu/blogs/the-avenue/posts/2014/09/29-americans-driving-census-data-metro-tomer-kane#.VCq_FiZyIXc.mailto

- Torrance, G., Hooper, M., & Reeder, B. (2002). Trends in overweight and obesity among adults in Canada (1970 – 1992): Evidence from national surveys using measured height and weight. *International Journal of Obesity*, 26, 797-804.
- Transport Canada. (2005). *Moving on sustainable transportation program*. Retrieved from
- Tremblay, M., Katzmarzyk, P., & Willms, J. (2002). Temporal trends in overweight and obesity in Canada, 1981–1996. *International Journal of Obesity*, 26, 538-543.
- Tuckel, P., & Milczarski, W. (2015). Walk Score(TM), Perceived Neighborhood Walkability, and walking in the US. *American Journal of Health Behaviour*. doi:doi:10.5993/AJHB.39.2.11
- Tucker, P., & Gilliland, J. (2007). The effect of season and weather on physical activity: A systematic review. *Public Health*, 121(12), 909-922. doi:doi:10.1016/j.puhe.2007.04.009
- Twells, L., Gregory, D., Reddigan, J., & Midodzi, W. (2014). Current and predicted prevalence of obesity in Canada: A trend analysis. *Canadian Medical Association journal*, 2(1), E18-E26 doi:doi:10.9778/cmajo.20130016
- Van Dyck, D., Cardon, G., Deforche, B., Sallis, J., Owen, N., & De Bourdeaudhuij, I. (2010). Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. *Preventive Medicine*, 50(Suppl 1), S74-S79. doi:doi:10.1016/j.ypmed.2009.07.027
- Van Dyck, D., Deforche, B., Cardon, G., & Dr Bourdeaudhuij, I. (2009). Neighbourhood walkability and its particular importance for adults with a preference for passive transport. *Health & Place*, 15(2), 496-504.
- Veenstra, G., Luginaah, I., Wakefield, S., Birch, S., Eyles, J., & Elliott, S. (2005). Who you know, where you live: Social capital, neighbourhood and health. *Social Science & Medicine*, 60, 2799–2818.
- Vickerman, R. (1974). Accessibility, attraction and potential: A review of some concepts and their use in determining mobility. *Environment and Planning A*, 6, 675-691.
- Wachs, M., & Kumagai, T. (1973). Physical accessibility as a social indicator. *Socioeconomic Planning Science*, 7, 327-456.
- Wagner, A., Simon, C., Ducimetiere, P., Montaye, M., Bongard, V., Yarnell, J., . . . Arveiler, D. (2001). Leisure-time physical activity and regular

- walking or cycling to work are associated with adiposity and 5y weight gain in middle-aged men: The PRIME study. *International Journal of Obesity and Related Metabolic Disorders*, 25, 940–948.
- Walk Score®. (2013). Retrieved from <https://www.walkscore.com/professional/research.php>
- Warburton, D., Nicol, C., & Bredin, S. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association journal*, 174(6), 801-809.
- Wasfi, R., Ross, N., & El-Geneidy, A. (2013). Achieving recommended daily physical activity levels through commuting by public transportation: Unpacking individual and contextual influences. *Health and Place*, 23, 18-25. doi:10.1016/j.healthplace.2013.04.006
- Wei, M., Kampert, J., Barlow, C., Nichaman, M., Gibbons, L., Paffenbarger, R., & Blair, S. (1999a). Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight, and obese men. *JAMA*, 282(16), 1547-1553.
- Wei, M., Kampert, J., Barlow, C., Nichaman, M., Gibbons, L., Paffenbarger, R., & Blair, S. (1999b). Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight, and obese men. *The Journal of the American Medical Association*, 282(16), 1547-1553.
- Wharf-Higgins, J. (2002). *The Coalition for Active Living: Making the case for a crucial role for physical activity in the future of Canada's health care system*. Retrieved from Ottawa: <http://www.activeliving.ca/pdf/Romanowfinalreport.pdf>
- White, N. (1981). Modern health concepts. In N. White (Ed.), *The Health Conundrum*. Toronto: T.V Ontario Publications.
- Wilkinson, R., & Marmot, M. (Eds.). (2003). *Social determinants of health: The solid facts* (2nd ed.). Copenhagen: Denmark: World Health Organization.
- Winship, C., & Radbill, L. (1994). Sampling weights and regression analysis. *Sociological methods and research*, 23(2), 2.
- World Health Organization. (2003). *Global strategy on diet, physical activity and health: Chronic disease information sheets: physical activity*. Retrieved from Geneva: <http://www.who.int/dietphysicalactivity/publications/facts/pa/en/>
- World Health Organization. (2010a). The global forum on urbanization and health. Retrieved from http://www.who.int/topics/urban_health/kobecalltoaction

- World Health Organization. (2010b). *Global recommendations on physical activity for health*. Retrieved from Geneva:
- World Health Organization. (2011). Prevalence of insufficient physical activity. Adults aged 18+ years. *Global Health Observatory (GHO) data*. Retrieved from http://www.who.int/gho/ncd/risk_factors/physical_activity_text/en/
- Yang, Y., & Diez-Roux, A. (2012). Walking distance by trip purpose and population subgroups. *American Journal of Preventive Medicine*, 43(1), 11-19.
- Zhao, F., Chow, L.-F., Li, M.-T., Ubaka, I., & Gan, A. (2003). Forecasting transit walk accessibility: Regression model alternative to buffer. *Transportation Research Record*, 1835, 34-41.

APPENDIX 1: Built Environment Variables Computed

All the NPHS respondents addresses used in our analysis were geocoded. Around each respondent's postcode, a 400 meter buffer on the street network, and 800 meter buffer were computed in ArcGIS 10. Built environmental measures for every postal code were computed. These measures included population density, street connectivity (4-way intersections, connected node ratio, link node ratio, 1-way intersections and street density), land use mix (the entropy measure, and land use interaction measure). All the measures were computed for 1996 and 2006, except the land use mix was calculated for 2006, since we did not have land use historical data. Walk Score® data was obtained from walkscore.com, and linked to the GIS file. We ran correlations between street connectivity measures (1996, and 2006), and found that the two measures were highly correlated (Pearson correlation coefficient = 0.94; $p < .01$), indicating a relatively small change over the ten year period.

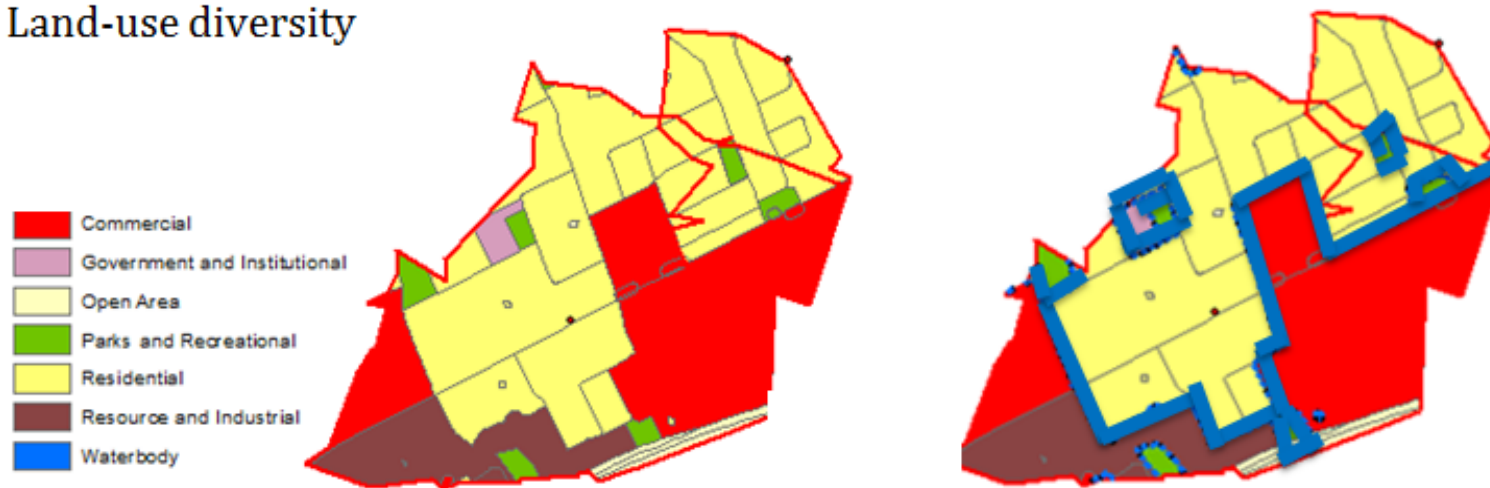
A correlation matrix between the different built environment measures was computed and tested on the utilitarian walking outcome. Table Appendix 1A presents the correlation matrix between the different built environment measures in 2006. The Walk Score® was computed for 2012. Figure Appendix 1A provides an example of built environment measures computed.

Table Appendix 1A: Correlation matrix between the built environment measures computed

	Link node ratio	Connected node ratio	Node density/ km	Percent of 4way intersections	Street density	Entropy measure	Interaction density 3 Categories	Interaction density (All categories)	Entropy 3 Categories	Walk Score®	Dwelling Density/ km
Connected node ratio	0.79										
Node density/ km	-0.07	0.19									
Percent of 4way intersections	0.62	0.42	0.19								
Street density	0.05	0.00	0.22	0.27							
Entropy measure	-0.01	0.01	-0.05	-0.00	-0.08						
Interaction density 3 Categories	0.27	0.30	0.37	0.46	0.27	0.33					
Interaction density (All categories)	-0.23	-0.35	-0.10	-0.06	0.63	0.06	0.023				
Entropy 3 categories	0.19	0.21	0.15	0.34	0.10	0.51	0.63	0.01			
Walk Score®	0.29	0.34	0.37	0.50	0.24	0.11	0.64	-0.10	0.48		
Dwelling density/km	0.27	0.27	0.27	0.40	0.21	0.11	0.58	-0.03	0.36	0.57	
Population density/km	0.23	0.25	0.25	0.32	0.17	0.07	0.52	-0.04	0.30	0.53	0.96

Note: All correlation estimates are statistically significant at the 95% confidence level.

Land-use diversity



$$\text{Entropy} = \text{LUM} = - \sum \frac{p_i \ln p_i}{\ln n}$$

$$\text{Land use Interaction Density} = \frac{\text{Interaction Length}}{\text{Buffer Area}}$$

Street design (street connectivity)

$$\text{Percent of 4 way intersections} = \frac{\text{Number of 4 way intersections}}{\text{Total number of nodes}}$$

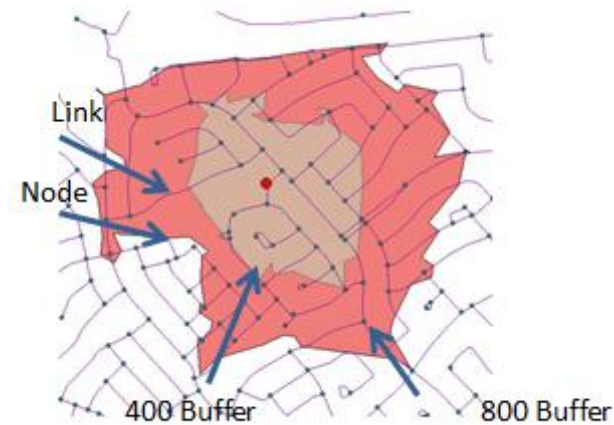


Figure Appendix 1A: Example of built environment measures computed

APPENDIX 2: Attrition Analysis of NPHS

Table Appendix 2A: Summary Statistics of Utilitarian Walking (Ut_Walking), NPHS, Cycles 1 to 3 (1994-1998)

Summary statistics utilitarian walking of overall sample at Cycle 1				Summary statistics at Cycle 1 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 2				Summary statistics at Cycle 1 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 2			
Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.
1	1192	39.39	39.39	1	1086	39.42	39.42	1	106	39.11	39.11
2	519	17.15	56.54	2	478	17.35	56.77	2	41	15.13	54.24
3	785	25.94	82.49	3	712	25.84	82.61	3	73	26.94	81.18
4	530	17.51	100.00	4	479	17.39	100.00	4	51	18.82	100.00
Total	3,026	100.00		Total	2,755	100.00		Total	271	100.00	
Summary statistics utilitarian walking of overall sample at Cycle 2				Summary statistics at Cycle 2 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 3				Summary statistics at Cycle 2 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 3			
Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.
1	1127	39.98	39.98	1	1065	40.25	40.25	1.00	62	35.84	35.84
2	468	16.60	56.58	2	444	16.78	57.03	2.00	24	13.87	49.71
3	761	27.00	83.58	3	713	26.95	83.98	3.00	48	27.75	77.46
4	463	16.42	100.00	4	424	16.02	100.00	4.00	39	22.54	100.00
Total	2,819	100.00		Total	2,646	100.00		Total	173	100.00	
Summary statistics utilitarian walking of overall sample at Cycle 3				Summary statistics at Cycle 3 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 4				Summary statistics at Cycle 3 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 4			
Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.
1	1069	42.27	42.27	1	995	42.14	42.14	1	74	44.05	44.05
2	378	14.95	57.22	2	354	14.99	57.14	2	24	14.29	58.33
3	662	26.18	83.39	3	624	26.43	83.57	3	38	22.62	80.95
4	420	16.61	100.00	4	388	16.43	100.00	4	32	19.05	100.00
Total	2,529	100.00		Total	2,361	100.00		Total	168	100.00	

Table Appendix 2B: Summary Statistics of Utilitarian Walking (Ut_Walking), NPHS, Cycles 4 to 6 (2000-2004)

Summary statistics utilitarian walking of overall sample at Cycle 4				Summary statistics at Cycle 4 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 5				Summary statistics at Cycle 4 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 5			
Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.
1	844	36.54	36.54	1	790	36.61	36.61	1	54	35.53	35.53
2	349	15.11	51.65	2	322	14.92	51.53	2	27	17.76	53.29
3	666	28.83	80.48	3	628	29.10	80.63	3	38	25.00	78.29
4	451	19.52	100.00	4	418	19.37	100.00	4	33	21.71	100.00
Total	2,310	100.00		Total	2,158	100.00		Total	152	100.00	
Summary statistics utilitarian walking of overall sample at Cycle 5				Summary statistics at Cycle 5 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 6				Summary statistics at Cycle 5 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 6			
Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.
1	696	32.77	32.77	1	644	32.44	32.44	1	52	37.41	37.41
2	323	15.21	47.98	2	299	15.06	47.51	2	24	17.27	54.68
3	667	31.40	79.38	3	634	31.94	79.45	3	33	23.74	78.42
4	438	20.62	100.00	4	408	20.55	100.00	4	30	21.58	100.00
Total	2,124	100.00		Total	1,985	100.00		Total	139	100.00	
Summary statistics utilitarian walking of overall sample at Cycle 6				Summary statistics at Cycle 6 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 7				Summary statistics at Cycle 6 of utilitarian walking for the remaining sample that were not lost due to attrition at Cycle 7			
Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.	Ut_Walking	Freq.	Percent	Cum.
1	716	35.82	35.820	1	658	36.00	36.00	1	58	33.92	33.92
2	218	10.91	46.720	2	199	10.89	46.88	2	19	11.11	45.03
3	641	32.07	78.790	3	589	32.22	79.10	3	52	30.41	75.44
4	424	21.21	100.000	4	382	20.90	100.00	4	42	24.56	100.00
Total	1,999	100.00		Total	1,828	100.00		Total	171	100.00	

Table Appendix 2C: Summary Statistics of Health Utility Index (HUI), NPHS, Cycles 1 to 6 (1994-2004)

Health Utility Index						
Variable	Obs	Mean	Std. Err.	[95% Conf. Interval]		
HUI	3133	0.89	0.00	0.88	0.89	Summary statistics of HUI overall sample at Cycle 1
HUI	2856	0.89	0.00	0.88	0.89	Summary statistics at Cycle 1 of HUI for the remaining sample that was not lost due to attrition at Cycle 2
HUI	277	0.89	0.01	0.87	1.00	Summary statistics at Cycle 1 of HUI for the sample that was lost due to attrition at Cycle 2
HUI	2836	0.92	0.00	0.91	0.92	Summary statistics of HUI overall sample at Cycle 2
HUI	2659	0.92	0.00	0.91	0.92	Summary statistics at Cycle 2 of HUI for the remaining sample that were not lost due to attrition at Cycle 3
HUI	177	0.92	0.01	0.90	0.95	Summary statistics at Cycle 2 of HUI for the sample that was lost due to attrition at Cycle 3
HUI	2550	0.91	0.00	0.90	0.92	Summary statistics of HUI overall sample at Cycle 3
HUI	2380	0.91	0.00	0.90	0.92	Summary statistics at Cycle 3 of HUI for the remaining sample that were not lost due to attrition at Cycle 4
HUI	170	0.91	0.01	0.89	0.93	Summary statistics at Cycle 3 of HUI for the sample that was lost due to attrition at Cycle 4
HUI	2348	0.91	0.00	0.90	0.92	Summary statistics of HUI overall sample at Cycle 4
HUI	2189	0.91	0.00	0.90	0.92	Summary statistics at Cycle 4 of HUI for the remaining sample that were not lost due to attrition at Cycle 5
HUI	159	0.90	0.01	0.88	0.93	Summary statistics at Cycle 4 of HUI for the sample that was lost due to attrition at Cycle 5
HUI	2174	0.90	0.00	0.89	0.90	Summary statistics of HUI overall sample at Cycle 5
HUI	2022	0.90	0.00	0.89	0.91	Summary statistics at Cycle 5 of HUI for the remaining sample that were not lost due to attrition at Cycle 6
HUI	152	0.86	0.02	0.82	0.90	Summary statistics at Cycle 5 of HUI for the sample that was lost due to attrition at Cycle 6
HUI	2017	0.90	0.00	0.89	0.90	Summary statistics of HUI overall sample at Cycle 6
HUI	1844	0.89	0.00	0.89	0.90	Summary statistics at Cycle 6 of HUI for the remaining sample that were not lost due to attrition at Cycle 7
HUI	173	0.90	0.01	0.88	0.92	Summary statistics at Cycle 6 of HUI for the sample that was lost due to attrition at Cycle 7

Table Appendix 2D: Summary Statistics of Body Mass Index (BMI), NPHS, Cycles 1 to 6 (1994-2004)

BMI (Not stratified yet by gender)						
Variable	Obs	Mean	Std.Err.	[95%Conf.Interval]		Condition
BMI	3073	24.98	0.08	24.82	25.14	Summary statistics of BMI overall sample at Cycle 1
BMI	2802	25.06	0.09	24.89	25.23	Summary statistics at Cycle 1 of BMI for the remaining sample that was not lost due to attrition at Cycle 2
BMI	271	24.13	0.26	23.62	24.64	Summary statistics at Cycle 1 of BMI for the sample that was lost due to attrition at Cycle 2
BMI	2767	25.32	0.08	25.15	25.48	Summary statistics of BMI overall sample at Cycle 2
BMI	2593	25.39	0.09	25.22	25.56	Summary statistics at Cycle 2 of BMI for the remaining sample that were not lost due to attrition at Cycle 3
BMI	174	24.24	0.32	23.60	24.88	Summary statistics at Cycle 2 of BMI for the sample that was lost due to attrition at Cycle 3
BMI	2514	25.79	0.09	25.60	25.97	Summary statistics of BMI overall sample at Cycle 3
BMI	2348	25.84	0.10	25.65	26.03	Summary statistics at Cycle 3 of BMI for the remaining sample that were not lost due to attrition at Cycle 4
BMI	166	25.02	0.31	24.42	25.63	Summary statistics at Cycle 3 of BMI for the sample that was lost due to attrition at Cycle 4
BMI	2314	26.18	0.10	25.98	26.38	Summary statistics of BMI overall sample at Cycle 4
BMI	2156	26.19	0.11	25.98	26.39	Summary statistics at Cycle 4 of BMI for the remaining sample that were not lost due to attrition at Cycle 5
BMI	158	26.07	0.40	25.28	26.86	Summary statistics at Cycle 4 of BMI for the sample that was lost due to attrition at Cycle 5
BMI	2114	26.53	0.11	26.32	26.74	Summary statistics of BMI overall sample at Cycle 5
BMI	1964	26.58	0.11	26.36	26.80	Summary statistics at Cycle 5 of BMI for the remaining sample that were not lost due to attrition at Cycle 6
BMI	150	25.88	0.41	25.07	26.69	Summary statistics at Cycle 5 of BMI for the sample that was lost due to attrition at Cycle 6
BMI	1959	26.69	0.11	26.46	26.91	Summary statistics of BMI overall sample at Cycle 6
BMI	1790	26.72	0.12	26.49	26.95	Summary statistics at Cycle 6 of BMI for the remaining sample that were not lost due to attrition at Cycle 7
BMI	169	26.37	0.41	25.56	27.18	Summary statistics at Cycle 6 of BMI for the sample that was lost due to attrition at Cycle 7

Table Appendix 2E: Summary Statistics of Energy Expenditure (EE), NPHS, Cycles 1 to 6 (1994-2004)

Energy Expenditure						
Variable	Obs	Mean	Std.Err.	[95% Conf.Interval]	Condition	
EE	3026	1.66	0.04	1.59 1.73	Summary statistics of EE overall sample at Cycle 1	
EE	2755	1.66	0.04	1.58 1.73	Summary statistics at Cycle 1 of EE for the remaining sample that was not lost due to attrition at Cycle 2	
EE	271	1.68	0.11	1.46 1.90	Summary statistics at Cycle 1 of EE for the sample that was lost due to attrition at Cycle 2	
EE	2821	1.78	0.04	1.70 1.85	Summary statistics of BMI overall sample at Cycle 2	
EE	2648	1.78	0.04	1.70 1.85	Summary statistics at Cycle 2 of EE for the remaining sample that were not lost due to attrition at Cycle 3	
EE	173	1.77	0.15	1.49 2.06	Summary statistics at Cycle 2 of EE for the sample that was lost due to attrition at Cycle 3	
EE	2536	1.86	0.04	1.79 1.93	Summary statistics of BMI overall sample at Cycle 3	
EE	2366	1.86	0.04	1.78 1.93	Summary statistics at Cycle 3 of EE for the remaining sample that were not lost due to attrition at Cycle 4	
EE	170	1.92	0.15	1.62 2.22	Summary statistics at Cycle 3 of EE for the sample that was lost due to attrition at Cycle 4	
EE	2313	1.717	0.03	1.65 1.78	Summary statistics of BMI overall sample at Cycle 4	
EE	2161	1.72	0.04	1.65 1.79	Summary statistics at Cycle 4 of EE for the remaining sample that were not lost due to attrition at Cycle 5	
EE	152	1.61	0.15	1.31 1.90	Summary statistics at Cycle 4 of EE for the sample that was lost due to attrition at Cycle 5	
EE	2135	2.02	0.04	1.94 2.10	Summary statistics of BMI overall sample at Cycle 5	
EE	1994	2.04	0.04	1.96 2.12	Summary statistics at Cycle 5 of EE for the remaining sample that were not lost due to attrition at Cycle 6	
EE	141	1.69	0.12	1.45 1.92	Summary statistics at Cycle 5 of EE for the sample that was lost due to attrition at Cycle 6	
EE	2002	1.96	0.04	1.88 2.04	Summary statistics of BMI overall sample at Cycle 6	
EE	1831	1.96	0.04	1.88 2.04	Summary statistics at Cycle 6 of EE for the remaining sample that were not lost due to attrition at Cycle 7	
EE	171	2.01	0.16	1.69 2.32	Summary statistics at Cycle 6 of EE for the sample that was lost due to attrition at Cycle 7	

APPENDIX 3: The Rationale behind Reporting Unweighted Regression Models

The use of sampling weights:

A common methodological issue researchers face in social sciences is the decision whether or not to use sampling weights in their analyses (Winship & Radbill, 1994). Sampling weights are used as an adjustment for misrepresentation of certain groups of people. This misrepresentation could be due to survey sampling designs, or response patterns, which results in having a sample that is not randomly drawn from the population. Most of the surveys used in the social sciences have complex sampling designs, including the National Population Health Survey used in the utilitarian walking analysis and BMI trajectory analysis. Adjustments become critical if we want to calculate descriptive statistics for a given population and the distribution of the sample used does not represent the distribution of the population. In this case, the sampling weights will basically adjust for under-representation or over-representation of certain groups based on population auxiliary variables that are used to calculate the sampling weights. The National Population Health Survey uses age, sex, and province from the 2006 Canadian Census as their auxiliary variables to calculate their adjustment sampling weights (Statistics Canada, 2009)

The decision whether or not to use sampling weights with regression analyses is not straightforward, and has been debated in the literature (Winship & Radbill, 1994). Some researchers suggest applying sampling weights, others argue that sampling weights can impose more bias, increasing the standard error (Winship & Radbill, 1994). It is recommended, as good practice, to run the regression analyses with and without sampling weights and compare the estimates. If the estimates are consistent (stable) between the weighted and unweighted outputs, then it is more efficient and recommended to report the un-weighted regression model since it will have smaller standard errors (Winship & Radbill,

1994). If the coefficient estimates are substantially different, there could be several potential problems, including misspecification of the model, or a problem of endogenous sampling (i.e., the sample selection is directly correlated with the dependent variable).

In this dissertation, regression models were computed twice, using sampling weights, and without sampling weights, and compared to each other. Un-weighted regression estimates were chosen to be reported in the second and third manuscripts since estimates were stable across the models. The unweighted estimates were advantageous due to their smaller standard errors (see Table Appendix 3A for a comparison between BMI trajectory models of weighted and un-weighted estimates).

Table Appendix 3A: Men BMI random coefficient and fixed effects estimates, NPHS (1994-2006)

BMI	Unweighted random coefficient estimates		Weighted random coefficient estimates		Unweighted fixed effects estimates		Weighted fixed effects estimates	
	Coef.	Robust Std.Err.	Coef.	Robust Std.Err.	Coef.	Robust Std.Err.	Coef.	Robust Std.Err.
Time	0.13***	0.01	0.13***	0.01	0.13***	0.01	0.13***	0.01
Age centered around baseline mean age (AGEC)	0.06***	0.01	0.09***	0.013	-----	-----	-----	-----
Baseline Walk Score® quartile (ref. baseline WSQ1)								
Baseline WSQ2	0.31	0.29	0.51	0.33	-----	-----	-----	-----
Baseline WSQ3	0.23	0.32	0.23	0.35	-----	-----	-----	-----
Baseline WSQ4	-0.40	0.31	-0.47	0.33	-----	-----	-----	-----
Utilitarian Walking (ref. no utilitarian walking)								
Low utilitarian walking	0.04	0.06	0.03	0.07	0.04	0.06	0.02	0.07
Moderate utilitarian walking	-0.08	0.05	-0.09	0.06	-0.09	0.05	-0.10	0.07
High utilitarian walking	-0.11*	0.06	-0.11*	0.06	-0.14**	0.06	-0.17**	0.07
Change in Walk Score® quartile (ref. same WSQ)								
Moved one Walk Score® quartile higher	0.10	0.26	0.11	0.31	0.03	0.21	0.07	0.24
Moved two or three Walk Score® quartiles higher	-1.02***	0.36	-1.13***	0.40	-0.86**	0.30	-1.09***	0.35
Moved one Walk Score® quartiles lower	0.19	0.31	0.41	0.35	-0.09	0.14	-0.08	0.23
Moved two or three Walk Score® quartiles lower	0.45**	0.23	0.44**	0.28	-0.59***	0.17	-0.60**	0.31
Leisure time physical activity (ref. inactive)								
Moderately active at leisure time	-0.11	0.05	-0.07	0.060	-0.11*	0.05	-0.08	0.06
Active at leisure time	-0.17***	0.06	-0.16**	0.07	-0.19***	0.06	-0.18**	0.08
Smoking status (ref. never smoker)								
Former Smoker	0.15	0.10	0.20	0.13	0.19	0.14	0.19	0.14
Current Smoker	-0.42***	0.13	-0.44**	0.18	-0.51**	0.21	-0.51**	0.21
Marital status (ref. married)								
Single	-0.45***	0.11	-0.51***	0.13	-0.55***	0.16	-0.55***	0.16
Divorced	-0.21*	0.12	-0.24*	0.13	-0.15*	0.15	-0.15*	0.15
Education level (ref. completed post-secondary education)								
Did not complete post-secondary education	-0.04	0.10	0.00	0.12	0.20	0.15	0.20	0.15
Immigration status (ref. not recent immigrants)								
Recent immigrant	-1.11***	0.25	-1.14***	0.27	-----	-----	-----	-----
Constant	26.42	0.23	26.26	0.27	25.97	0.14	25.97	0.14

APPENDIX 4: Binary Mixed Effects Logistic Regressions of Utilitarian Walking for Overall Sample

Table Appendix 4A: Odds of utilitarian walking, NPHS (1994-2006)

Dependent Variable	(Moderate or high utilitarian walking per week)
Reference: utilitarian walking less than an hour a week	Odds Ratio [95% Conf. Interval]
Good perceived health (ref. poor health)	1.09 [0.88, 1.34]
Active in leisure time (ref. inactive)	1.10** [0.99, 1.23]
Proportion of cumulative exposure time (PCET) to neighbourhoods Walk Score® quartiles (WSQ) (ref. PCET WSQ1)	
PCET to WSQ2	1.84*** [1.10, 3.10]
PCET to WSQ3	1.75*** [0.98, 3.14]
PCET to WSQ4	1.95*** [1.04, 3.69]
Time: (ref. Cycle 1: 1994)	
Cycle 2: 1996	1.02 [0.88, 1.19]
Cycle 3: 1998	0.98 [0.84, 1.15]
Cycle 4: 2000	1.34 [1.15, 1.56]
Cycle 5: 2002	1.53 [1.31, 1.79]
Cycle 6: 2004	1.64 [1.40, 1.91]
Cycle 7: 2006	2.14 [1.82, 2.51]

Table Appendix 4B: Men utilitarian walking fixed effects estimates with population weights and bootstrap weights, NPHS (1994-2006)

BMI	Weighted estimates ⁸	fixed effects	Weighted estimates ⁹	fixed effects
	Coef.	95% C.I.	Coef.	95% C.I.
Time	0.13***	[0.11, 0.15]	0.13***	[0.11, 0.15]
Age centered around baseline mean age	-----	-----	-----	-----
Baseline Walk Score® quartile (<i>ref. baseline WSQ1</i>)				
Baseline WSQ2	-----	-----	-----	-----
Baseline WSQ3	-----	-----	-----	-----
Baseline WSQ4	-----	-----	-----	-----
Change in Walk Score® quartile (<i>ref. same WSQ</i>)				
Moved one Walk Score® quartile higher	0.07	[-0.41, 0.55]	0.07	[-0.43, 0.57]
Moved two or three Walk Score® quartiles higher	-1.09***	[-1.77, -0.41]	-1.09***	[-1.77, -0.41]
Moved one Walk Score® quartiles lower	-0.08	[-0.53, 0.37]	-0.08	[-0.53, 0.37]
Moved two or three Walk Score® quartiles lower	0.60*	[-0.02, 1.22]	0.60*	[-0.04, 1.23]
Utilitarian Walking (<i>ref. no utilitarian walking</i>)				
Low utilitarian walking	0.02	[-0.12, 0.16]	0.02	[-0.12, 0.16]
moderate utilitarian walking	-0.10	[-0.23, 0.04]	-0.10	[-0.24, 0.05]
High utilitarian walking	-0.17**	[-0.31, -0.03]	-0.17**	[-0.31, -0.02]
Leisure time physical activity (<i>ref. inactive</i>)				
Moderately active in leisure time	-0.08	[-0.20, 0.05]	-0.08	[-0.20, 0.04]
Active in leisure time	-0.18**	[-0.34, -0.03]	-0.18**	[-0.33, -0.04]
Smoking status (<i>ref. never smoker</i>)				
Former Smoker	0.19	[-0.09, 0.47]	0.19	[-0.09, 0.47]
Current Smoker	-0.51**	[-0.93, -0.09]	-0.51**	[-0.91, -0.11]
Marital status (<i>ref. married</i>)				
Single	-0.55***	[-0.86, -0.24]	-0.55***	[-0.88, -0.22]
Divorced	-0.15*	[-0.45, 0.15]	-0.15*	[-0.47, 0.17]
Education level (<i>ref. completed post-secondary education</i>)				
Did not complete post-secondary education	0.20	[-0.09, 0.50]	0.20	[-0.08, 0.48]
Recent immigrant (<i>ref. non-recent immigrants</i>)	-----	-----	-----	-----
Constant	26.16***	[25.97, 26.36]	26.16***	[25.60, 26.32]

⁸ Weights included population weights, NPHS (1994-2006)

⁹ Weights included population weights and bootstrap weights, NPHS (1994-2006)

APPENDIX 5: Females BMI Random Effects and Fixed Effects Models

Table Appendix 5A: Females BMI random effects and fixed effects models, NPHS (1994-2006)

BMI	Unweighted random coefficient estimates		Weighted random coefficient estimates		Unweighted fixed effects estimates		Weighted fixed effects estimates	
	Coef.	Robust Std.Err	Coef.	Robust Std.Err	Coef.	Robust Std.Err	Coef.	Robust Std.Err
Time	0.13***	0.01	0.13***	0.01	0.129***	0.007	0.129	0.01
Age centered around baseline mean age (AGEC)	0.09***	0.01	0.10***	0.02	-----	-----	-----	-----
Baseline Walk Score® quartile (ref. baseline WSQ1)								
Baseline WSQ2	-0.26	0.36	-0.25	0.39	-----	-----	-----	-----
Baseline WSQ3	-0.40	0.39	-0.61	0.42	-----	-----	-----	-----
Baseline WSQ4	-0.33	0.38	-0.08	0.43	-----	-----	-----	-----
Utilitarian Walking (ref. no utilitarian walking)								
Low utilitarian walking	0.02	0.07	-0.08	0.07	0.02	0.08	-0.10	0.08
moderate utilitarian walking	0.05	0.06	0.00	0.06	0.05	0.06	-0.00	0.0
High utilitarian walking	0.02	0.07	-0.03	0.09	0.02	0.07	-0.04	0.09
Change in Walk Score® quartile (ref. same WSQ)								
Moved one Walk Score® quartile higher	0.06	0.29	-0.12	0.35	0.13	0.26	-0.10	0.32
Moved two or three Walk Score® quartiles higher	-0.66	0.46	-0.46	0.62	-0.76**	0.38	-0.35	0.55
Moved one Walk Score® quartiles lower	0.68	0.36	0.57	0.40	0.65	0.17	0.57	0.23
Moved two or three Walk Score® quartiles lower	0.01	0.25	0.16	0.34	-0.02	0.20	0.15	0.29
Leisure time physical activity (ref. inactive)								
Moderately active in leisure time	-0.17***	0.05	-0.11*	0.06	-0.18***	0.06	-0.10***	0.06
Active in leisure time	-0.32***	0.07	-0.28***	0.09	-0.31***	0.08	-0.25***	0.09
Smoking status (ref. never smoker)								
Former smoker	0.08	0.100	0.06	0.11	0.04***	0.13	-0.01	0.13
Current smoker	-0.79**	0.15	-0.79***	0.17	-0.94	0.17	-0.97	0.2
Marital status (ref. married)								
Single	-0.38**	0.17	-0.25	0.17	-0.58***	0.13	-0.34	0.19
Divorced	-0.09	0.14	-0.16	0.17	-0.28***	0.12	-0.27***	0.18
Education level (ref. completed post-secondary education)								
Did not complete post-secondary education	-0.16	0.12	-0.26	0.15	-0.018	0.13	-0.01*	0.18
Immigration status (ref. not recent immigrant)								
Recent immigrant	-1.09***	0.27	-0.62***	0.31	-----	-----	-----	-----
Have children (yes/no)	-0.57***	0.18	-0.72***	0.18	-0.632	0.150	-0.671**	0.24
Constant	25.50	0.30	25.32	0.34	25.222	0.124	24.975	0.14

Table Appendix 5A, Continued

Random effects parameters	Unweighted random coefficient estimates		Weighted random coefficient estimates		UnWeighted fixed effects estimates	Weighted fixed effects estimates
	Estimate	[95%C.I.]	Estimate	[95%C.I.]	Estimate	Estimate
Standard deviation (AGEC)	0.20	[0.17,0.24]	0.17	[0.15, 0.21]		
Standard deviation (constant)	4.53	[4.24, 4.84]	4.22	[3.96, 4.49]	4.77	4.77
Correlation (AGEC, constant)	-.030	[-0.18, 0.12]	0.07	[-0.08, 0.21]		
Standard deviation (Residual)	1.68	[1.56, 1.81]	1.65	[1.50, 1.81]	1.81	1.81
Intra class correlation	0.88	0.87			0.87	0.87