Exploring the association between rail transit investments and utilitarian walking in urban-dwelling Canadians

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Abstract

Background: Public transit, especially rail transit, shows promise as an intervention to increase utilitarian walking at the population level. Cross-sectional studies have shown that individuals who use public transit walk 8 to 24 minutes more per day than those who do not (Rissel et al., 2012). Previous research has also demonstrated that rail transit is a type of transit individuals will walk long distances for (Wasfi et al., 2013). However, to our knowledge, no longitudinal study examining long-term effects of public rail transit exposure on utilitarian walking has been carried out.

Goal: A retrospective cohort study was performed to investigate how investments in public transit in urban areas in Canada influenced utilitarian walking (i.e., walking for a specific purpose such as going to work or school or shopping) in adults. The study had two objectives: (1) to identify and geocode new rail transportation infrastructure in urban Canada between 1994 and 2010 and link this information to respondent information from the National Population Health Survey (NPHS), a longitudinal health survey of more than 17,000 Canadians; and 2) to characterize the utilitarian walking profiles of NPHS respondents who were exposed to rail transit investment within walking distances of their home neighbourhoods.

Methods: Data came from the Canadian National Population Health Survey, a biennial survey carried out between 1994 and 2010. Using local transit maps, new rail stations (light rail transit, subway and commuter rail) built in major Canadian cities during the time of the survey were identified. A geographic information system (GIS) was used to identify six digit postal codes located less than 2,000 meters from each new station; these postal codes were matched with

NPHS participants' postal codes. Levels of utilitarian walking were compared over time (before and after new stations opened) in individuals living 2,000 meters or less from new rail transit. Distance from the station was used as a measure of exposure to new transit. A mixed-effect logistic regression model compared the odds of walking one or more hours per week when exposed to a new station compared with not being exposed (i.e. living more than 2,000 meters from the new station within a Census Metropolitan Area (CMA)). For respondents who were exposed to transit, a sensitivity analysis comparing levels of utilitarian walking at different distances from the station (0-800 meters, 801-1,000 meters, 1,001-1,500 meters and 1,501-2,000 meters) was carried out.

Results: Between 1994 and 2010, 84 new rail stations were built within 2,000 meters of NPHS participants' households in the cities of Toronto, Ottawa, Montreal, Vancouver, Calgary and Edmonton. A total of 5,428 NPHS participants lived in a CMA where new stations had been built. Of these, 414 lived within 2,000 meters of a new station and were deemed exposed to new stations, while 5,014 lived more than 2,000 meters from a new station and were deemed unexposed. There was an increase of approximately 3% in the proportion of respondents reporting one or more hours of utilitarian walking per week after exposure to new rail transit, although this increase was not statistically significant. Individuals living within 2,000 meters from a new transit investment had 20% higher odds of engaging in one or more hours of utilitarian walking per week than individuals who lived more than 2,000 meters from new urban transit investments (univariate regression: OR 1.19, 95% Confidence Interval (CI) (1.00, 1.41)). The relationship between utilitarian walking and exposure to new transit was no longer significant when adjusted for neighborhood walkability (multivariate regression adjusting for

age, sex, education level, self-rated health, physical activity level in leisure time and neighborhood walkability: OR 1.18, 95% CI 0.99, 1.40). Within those exposed to a new station, those living closest to the new rail transit investments (i.e., ≤ 800m) showed the largest increase in levels of utilitarian walking, but this difference did not reach statistical significance.

Conclusions: There were modest detectable increases in utilitarian walking profiles of those exposed to new rail transit investment in Canada between 1994 and 2010. Longitudinal evidence generally supports cross-sectional research findings and provides further support for the physical activity benefits of public transportation.

Résumé

Mise en contexte: Le transport en commun, plus spécifiquement le rail, est une intervention qui a le potentiel d'augmenter la marche à des fins utilitaires à l'échelle de la population. Des études transversales ont trouvé que les individus qui empruntent le transport en commun marchent entre 8 et 24 minutes de plus par jour que ceux qui ne l'empruntent pas (Rissel et al., 2012). Des études antérieures ont aussi démontré que le rail est un type de transport en commun pour lequel les gens sont prêts à marcher de longues distances (Wasfi et al., 2013). Toutefois, à notre connaissance, aucune étude longitudinale n'a été entreprise afin d'examiner les effets à long terme de l'exposition au rail sur la marche à des fins utilitaires.

But: Une étude de cohorte rétrospective a été entreprise afin d'examiner comment des investissements au niveau des infrastructures de transport en commun en milieu urbain peuvent influencer la marche à des fins utilitaires (c'est- à-dire, la marche ayant pour but de se rendre au travail, à l'école ou pour faire des courses) chez les adultes. Cette étude avait deux objectifs: (1) identifier et géocoder les nouvelles infrastructures de rail à travers les principaux centres urbains canadiens entre 1994 et 2010 et associer cette information aux données des participants de l'Enquête nationale sur la santé de la population (ENSP), une enquête longitudinale sur la santé de plus de 17000 Canadiens, et 2) caractériser les profils de marche à des fins utilitaires des participants de l'ENSP ayant été exposés à un investissement en transport en commun dans leur quartier.

Méthode: Nos données provenaient de l'Enquête nationale sur la santé de la population canadienne, une enquête entreprise de façon biennale entre 1994 et 2010. Des cartes locales

des transports en commun ont été utilisées pour identifier les nouvelles stations de rail (rail léger, métro et train de banlieue) implantées dans les grandes villes canadiennes durant l'enquête. Un système d'information géographique (SIG) a été utilisé pour identifier les codes postaux à six caractères localisés à moins de 2000 mètres de chaque nouvelle station. Ces codes postaux ont ensuite été appariés aux codes postaux des participants de l'ENSP. Le niveau de marche à des fins utilitaires a été comparé au fil du temps (avant et après l'ouverture de nouvelles stations) auprès d'individus vivant à 2000 mètres ou moins d'une nouvelle station de rail. La distance à laquelle les participants habitaient d'une station a été utilisée pour mesurer leur exposition aux nouvelles infrastructures de transport en commun. Un modèle avec une régression logistique à effet aléatoire a été utilisé pour comparer la chance d'effectuer une heure ou plus de marche à des fins utilitaires par semaine chez les individus exposés à une nouvelle station (individus vivant à moins de 2000 mètres d'une nouvelle station) avec celle chez les individus non-exposés à une nouvelle station (individus vivant à plus de 2000 mètres d'une nouvelle station dans des régions métropolitaines de recensement (RMR)). Chez les individus ayant été exposés à une nouvelle station, le niveau de marche à des fins utilitaires a été comparé chez des individus vivant à différentes distances de la station (0-800 mètres, 801-1000 mètres, 1001-1500 mètres et 1501-2000 mètres).

Résultats: De 1994 à 2010, 84 stations ont été implantées à moins de 2000 mètres des domiciles des participants à l'ENSP dans les villes de Toronto, Ottawa, Montréal , Vancouver, Calgary et Edmonton. Au total, 5428 participants de l'ENSP vivaient dans une RCR où de nouvelles stations ont été érigées. Parmi ceux-ci, 414 vivaient à moins de 2000 mètres d'une nouvelle station et 5014 vivaient à plus de 2000 mètres d'une nouvelle station. Une augmentation d'environ 3% de la proportion des participants rapportant une heure ou plus de marche à des fins utilitaires par semaine a été observée après l'ouverture de nouvelles stations quoique cette augmentation n'était pas statistiquement significative. Les individus vivant à moins de 2000 mètres d'une nouvelle station avaient 20% plus de chance de faire une heure ou plus de marche à fins utilitaires par semaine que les individus vivant à plus de 2000 mètres de la nouvelle station (régression univariée: RC 1.19, 95% intervalle de confiance (IC) 1.00, 1.41). La relation entre la marche à des fins utilitaires et l'exposition à une nouvelle station n'était plus significative lorsqu'ajustée pour la marchabilité du quartier (régression multivariée ajustée pour l'âge, le sexe, le niveau d'éducation, l'état de santé autodéclaré, le niveau d'activité physique lors des temps libres et le niveau de marchabilité du quartier: RC 1.18, 95% IC (0.99, 1.40)). Chez les individus exposés à une nouvelle station, ceux vivant le plus proche de la nouvelle station (c.-à-d. ≤ 800m) ont connu la plus importante augmentation du niveau de marche à des fins utilitaires, mais cette différence n'était pas statistiquement significative.

Conclusion: Une augmentation modeste de la marche à fins utilitaires a été détectée chez les individus exposés à de nouveaux investissements dans les infrastructures de transport en commun au Canada entre 1994 et 2010. De façon générale, ces trouvailles longitudinales appuient les constatations des études transversales et supportent l'idée que le transport en commun a un effet positif sur l'activité physique.

Dedication

This thesis is dedicated to my family and friends.

Your unconditional support has given me the courage and strength to overcome difficulties and to reach for my wildest dreams. Thank you for your love and for being there for me.

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Contribution of Authors

Nancy A. Ross, PhD

- is a Professor in the Department of Geography and an Associate member in the Department of Epidemiology at McGill University.
- Supervised the thesis
- Dr. Ross oversaw all aspects of the thesis and manuscript preparation, including the development of the methods, the interpretation of the results, and the editing of the final written material.

Sidonie Penicaud

- Cleaned the data
- Created outcome and exposure variables
- Ran the analysis
- Interpreted the results
- Wrote the thesis

Rania Wasfi

- Post-doctoral student at the School of Public Health of the University of Montreal and completed her PhD with Dr Ross
- Provided the steps to clean the data
- Generated Geographic Information Systems (GIS) files for all stations that would be then linked with the NPHS dataset
- Suggested the statistical methods for the analysis of the data

Katelyn Moyer

- Student doing Honor’s Thesis with Dr. Ross as part of her bachelor’s degree in the Department of Geography
- Surveyed to find public transit investments in Canada from mid-1990s to mid-2,000s
- Extracted postal codes for all stations built during that time
- Create files to be used in Geographic Information Systems (GIS)

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- Provided the data

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Statistics Canada and the Canadian Research Data Centre Network (CRDCN) requests that researchers publishing findings from the Research Data Program (RDC) include the following notice: "This research was supported by funds to the Canadian Research Data Centre Network (CRDCN) from the Social Sciences and Humanities Research Council (SSHRC), the Canadian Institute for Health Research (CIHR), the Canadian Foundation for Innovation (CFI), and Statistics Canada. Although the research and analysis are based on data from Statistics Canada, the opinions expressed do not represent the views of Statistics Canada."

Research Ethics

Statistics Canada granted permission to use the data through the Quebec Interuniversity Centre for Social Statistics (QICSS) (Contract number: 15-SSH-MCG-4430). This permission includes an oath of confidentiality which strictly protects the confidentiality of respondents and as such no additional ethics approval is required.

Research involving Forward Sortation Area (FSA) geography (i.e., postal codes) must include the following statement:

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"The attached custom data provided in the thesis tables at the FSA level is provided for use in accordance with the terms and conditions of the Statistics Canada Open Licence Agreement hereby attached."

List of Abbreviations

BMI Body Mass Index

CMA Census Metropolitan Area

CI Confidence Interval

GIS Geographic Information System

GPS Global Positioning System

NPHS National Population Health Survey

OR Odds Ratio

PA Physical Activity

QICSS Quebec Inter-University Center for Social Statistics

RR Risk Ratio

UW Utilitarian Walking

List of Tables

List of Figures

Table of Contents

Chapter 1: Introduction

Objectives

The ultimate goal of this thesis is to explore how we can design the environment we live in to make us healthier. This retrospective cohort study is a natural experiment that capitalizes on investments in public transit infrastructure to study how they affect physical activity. This thesis wishes to determine if new transit investments are associated with changes in the level of utilitarian or purposeful walking.

The specific objectives of this thesis are:

1) To identify and geocode new rail transportation infrastructure in urban Canada between 1994 and 2010 and link this information to respondent information on the National Population Health Survey, a longitudinal health survey of more than 17,000 Canadians.
2) To characterize the utilitarian walking profiles of NPHS respondents who were exposed to rail transit investment within walking distance of their home.

The overarching hypothesis of the thesis is that rail transit investment would be associated with an increase in the levels of utilitarian walking of individuals living within walking distance of a new station.

Important definitions

The outcome of interest of this thesis is utilitarian walking, a particular form of physical activity. Below are important definitions that contrast and clarify the meaning of different terms related to utilitarian walking and physical activity that are used frequently in this thesis.

Physical activity can be defined as “bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure” (Caspersen et al., 1985)

Utilitarian walking can be defined as walking done for “useful” purposes such as going to work or school, or going shopping. Utilitarian walking can also be referred to as walking for transportation. Utilitarian walking is a form of active transportation.

Active transportation consists of “any form of human-powered transportation: walking, cycling, using a wheelchair, in-line skating or skateboarding” (Public Health Agency of Canada, 2014).

Leisure walking is walking that is done exclusively for “recreation, health or fitness” (Sugiyama et al., 2010).

The **total amount of walking** done by individuals is thought to be a sum of their utilitarian walking and leisure walking.

Rationale

Transportation is an important determinant of health as several aspects of our health can be influenced by transportation (American Public Health Association, 2010; Litman, 2015). For example, emissions from private vehicles can increase pollution levels which can in turn be associated with the exacerbation of respiratory diseases such as asthma. Collisions between motor vehicles and pedestrians can lead to trauma and death. Individuals who live near highways can be exposed to noise levels that can interrupt sleep and increase stress levels. Individuals who use private vehicles as their main mode of transportation may walk less and be more prone to obesity and cardiovascular disease. Because transportation affects health in so many ways, the World Health Organization has claimed that transportation is one of the top ten most important determinants of health (World Health Organization, 2003). Learning more about the relationship between transportation and health may help us modify certain aspects of transportation infrastructure to improve health.

One of the ways transportation can affect health is by influencing routine types of daily physical activity. There are many ways that transportation can influence physical activity and different modes of transportation seem to influence physical activity in different ways. People who drive motorized vehicles tend to walk less and engage in less physical activity than their counterparts who use public transit and other modes of active transportation, such as walking, biking or other types of human powered transportation. In a cross-sectional survey using self-reported walking levels comparing the use of different modes of transport on physical activity, individuals using private vehicle were physically active 10.0 minutes/day, while those who used public transport for 35.2 minutes/day and walkers and cyclists 38.3 minutes/day (Beavis et al., 2014). There also appears to be an inverse relationship between car ownership and physical activity. The availability of motorized vehicles is associated with a decrease in the proportion of individuals walking to work (McKenzie, 2014). When no vehicle was available in a household, 14.8% of individuals walked to work. When one vehicle was available, 3.7% walked to work and 1.5% when two vehicles were available (McKenzie, 2014). Car ownership is also associated with fewer minutes of physical activity. Individuals who own a vehicle carry out less moderate to vigorous physical activity per day than those who do not own a vehicle (46.6 minutes, 95% CI 41.86, 51.24) versus 20.4 minutes (95% CI 14.69, 26.1) respectively (Shoham et al., 2015).

Furthermore, when trips are done by walking, biking or public transit, individuals are more likely to walk more steps and carry out more minutes of moderate to vigorous physical activity (Chaix et al., 2014).

In North America, the car is the main mode of transportation. In Canada, approximately 80% of individuals use motorized vehicles to commute to work (Statistics Canada, 2011b). Concurrently, Canadians are not physically active enough. Canadians spend most of their awake time being sedentary (68% of men and 69% of women) (Colley et al., 2011). Few Canadian adults (17% of men, 14% of women) meet standard clinical guidelines of 150 minutes of moderate physical activity per week (Colley et al., 2011).

These very low levels of physical activity have an immense influence on health. Physical inactivity is one of the top four risk factors leading to non-communicable diseases (also known as chronic diseases), such as cardiovascular disease, diabetes and certain cancers (World Health Organization, 2014). Physical inactivity is associated with metabolic changes such as increases in blood pressure, body weight, serum glucose levels and serum lipid levels. All of these physiological changes are precursors to non-communicable disease. Each year, physical inactivity results in 3.2 million deaths and 69.3 million Disability Adjusted Life Years (World Health Organization, 2014).

Conversely, physical activity, even of moderate intensity and of short duration (like walking to a transit stop) can lead to better health. In individuals who do not engage in any physical activity, incorporating small amounts of moderate physical activity into their day can decrease the risk of death and certain chronic diseases. Walking two or more hours per week or

1.5 to 3.2 km/day while controlling for other types of physical activity is associated with a decrease in all-cause mortality (Physical Activity Guidelines Advisory Committee, 2008). There is a dose-response relationship between walking and mortality. Increase in the intensity and duration of walking results in a greater decrease in mortality (Kelly et al., 2014).

Large cohort studies have shown that walking 1 to 2 hours per week is associated with fewer cardiovascular events, such as myocardial infarctions, compared to not walking at all (RR=0.75, 95% CI 0.63, 0.89 (Manson et al., 2002), RR=0.70, 95% CI 0.51, 0.95 (Manson et al., 1999) , and RR=0.49, 95% CI 0.28, 0.86 (Lee et al., 2001)). As with all-cause mortality, there is a dose-response relationship between the amount and intensity of physical activity and the prevention of cardiovascular events. High levels of physical activity prevent more events than moderate levels of physical activity and moderate levels of physical activity prevent more events than light levels of physical activity (Physical Activity Guidelines Advisory Committee, 2008, pp. G2-G13).

Walking can also help prevent diabetes. A recent meta-analysis study found that low intensity physical activity and walking are both associated with a lower incidence of type 2 diabetes (Aune et al., 2015). A large cohort study found that individuals who engaged in low levels of walking (2.1 to 4.6 METs per hour which correspond to 1 to 2 hours of slow walking (Harvard Women's Health Watch, 2009) were associated with fewer new cases of diabetes than those who were not physically active (RR=0.84, 95% CI 0.72, 0.97) (Hu et al., 1999).

Walking does not only have positive benefits on physical health; it may also improve mental disorders such as anxiety and depression. Walking three times per week was found to be associated with a decrease in anxiety symptoms in individuals with panic disorder compared to those who took placebo (Broocks et al., 1998). A systematic review looked at the relationship between physical activity and depression (Mammen et al., 2013). While not all studies included in the review found a decrease in depression related to physical activity, most found that walking 150 minutes per week was associated with a lower incidence of depression.

Beyond the fact that walking is associated with a decrease in the incidence of several chronic diseases and improvement in mental health, there are several other reasons why walking should be considered as an intervention to help increase physical activity in the population (Mackett et al., 2011). Walking is a common activity. It is easily accessible because it does not require specific equipment or facilities (Lee et al., 2008). Furthermore, walking can be carried out by individuals from all walks of life, independent of their socioeconomic status, their cultural background or their age (Lee et al., 2008). Walking provides an easy way to incorporate physical activity into a daily routine that does not impinge on work time or leisure time (Reynolds et al., 2014). Walking may also be particularly well-suited as an intervention to increase physical activity in individuals who are sedentary. Sedentary individuals may dislike exercise or be intimidated by physical activity. If, however, sedentary individuals do not perceive walking as exercise, they may be more willing to walk than to engage in physical exercise (Zunft et al., 1999).

If we wish to increase walking in whole populations, we must look to interventions that have the potential to influence the walking behaviour of large groups of people. Public transit can be a way to increase utilitarian walking at the population level. There seems to be a natural association between public transit use and walking. Most public transit trips begin and end with walking (Boone-Heinonen et al., 2009). Walking has been objectively recorded via GPS and accelerometers in 95% of trips using public transit (Brown et al., 2015). Moreover, public transit is the most frequent destination for active travel such as walking and biking (Day 2014).

Another way that public transit may lead to increased walking is that individuals who take public transit may use their car less. For example, Lachapelle et al. (2012) found that 60% of those who commuted to work by walking, biking or public transit engaged in a walk trip, compared to 30% of individuals who used their car or carpooled. Doing short trips by foot rather than by car has the potential of adding 2,660 steps per person per day which corresponds to 25% of recommended daily physical activity (Morency et al., 2011). A small number of steps done day after day for many years could lead to a substantial improvement in physical activity and, in turn, in multiple physical and mental health outcomes. Public transit has the potential to reach a large number of people and has long term effects on levels of physical activity at the population level (Day et al., 2014).

This chapter presented the overall aim, objectives and overarching hypothesis behind this thesis. It further introduced the relationships between transportation, physical activity and health and underlined the importance of transport as a determinant of health. Transportation is an important determinant of health because it acts on a multitude of aspects of health from air pollution to road trauma as well as individual behaviors such as physical activity. Different modes of transportation may affect our levels of overall physical activity in different ways. In the current global context of high levels of physical inactivity and the rise in non-communicable diseases, understanding the features in our environment that encourage us to be physically active is crucial to create effective population level interventions to increase physical activity and improve health.

Overview of thesis chapters

This thesis consists of five chapters. Chapter One is an introduction which provides the objectives of the thesis. This chapter also introduces the reader to the links that exist between transportation, physical activity and health. Chapter Two consists of a brief descriptive portrayal of public transit in Canada and is followed by a literature review that aims to uncover what is already known about the influences of new public transit investment on utilitarian walking. Chapter Three details the methods of this study, explaining the approach involved in identifying commuter rail investment using geographic information systems (GIS), the linkage of this information to NPHS respondents and the development of statistical models to address the thesis objectives. Chapter Four reports descriptive results of commuter rail investment during the study period. Chapter Four also reports results of multivariate models of utilitarian walking associated with rail investment that account for key individual characteristics (i.e., age, sex, education level, leisure time physical activity and self-rated health) and the overall walking-friendliness or 'walkability' of respondents' home neighbourhoods. These models also take into consideration the non-independence problem of repeated measures taken from the same individual over time. Chapter Five, the final chapter, provides the substantive, methodological and policy contributions of the thesis and discusses limitations of the research.

Chapter 2: Overview of public transit in Canada and literature review

This chapter provides the background for this study and is divided into two parts. The first part of this chapter describes public transit in Canada. It discusses how many people use public transit in Canada, describes the public transit infrastructure that is present in different Canadian cities and assesses Canadians' accessibility to public transit. The second part of this chapter consists of a literature review focusing on the relationship between public transit use and utilitarian walking. This section looks at systematic reviews, natural experiments and longitudinal studies that have tried to answer the question: What happens to utilitarian walking when a new rail station opens in a neighborhood? Current gaps and limitations of the current literature will be highlighted.

Overview of public transit in Canada

Modes of transport in Canada

Most Canadians rely on their private vehicle to commute to work. In 2011, 15.4 million Canadians commuted to work. Of these, 74.0% drove to work and 5.6% were passengers in a motorized vehicle. A smaller proportion of Canadians engage in more physically active modes during their daily commute: 12% used public transit, 5.7% walked and 1.2% cycled to work (Statistics Canada, 2011b). In another study, it was estimated that 15.2% of Canadians used public transit to get to work, 5.7% walk, and 1.4% cycle (Hollingworth et al., 2010).The amount of individuals who use public transit varies in different cities across Canada, ranging from 20% in the Toronto and Montreal areas and dipping to as low as 5% in smaller urban areas (Hollingworth et al., 2010).

Around the world, there is an important amount of variation in the number of individuals who use public transit and engage in other forms of active travel, such as walking or cycling. In the United States, the American Community Survey (2008-2012) found that 5% of Americans used public transit to get to work while 86% used a motorized vehicle (McKenzie, 2014). The Land Transport Authority Academy (2014) in Singapore published a report on transportation mode breakdown in different cities across the world. They found that some cities use public transit and active transit to a much greater extent: For example, in Berlin, Germany, 26% use public transport, 29% walk, 13% cycle and 32% use a private vehicle. An extreme example is Hong Kong, where 81% of survey takers reported using public transit.

Individuals use public transit for purposes other than commuting to work. Using data from the Households and Environment Study carried out by Statistics Canada, Munro (2007) found that 16% of the study participants used public transit exclusively to travel to work, 37% used it both for work and non-work travel and 47% used it for non-work travel alone. Transit data from the U.S. National Household Travel Survey of 2001 and 2009 showed that 43.7% of participants used public transit to commute to work and 34.1% used it for non-work related purposes (15.2% to do errands, 13.4% to engage in social and recreational activities and 5.5% to go to school, daycare or religious activities) (Freeland et al., 2013). While trips for shopping or leisure may involve fewer steps than trips used for commuting to work (Morency et al., 2011) including data on non-work journeys could dramatically increase the measure of prevalence of public transit use in Canada.

Types of public transit infrastructure in Canada

Several modes of public transit exist in Canada. The Urban Transit Task Force (2010) reports that buses are the most prevalent, with number reaching 15,222 buses in 2008. Subways are present in Montreal and Toronto. Light Rail Transit is found in Calgary and Edmonton (221 LRT cars), Toronto (31 LRT cars) and Ottawa (3 LRT cars). Metro Vancouver has an Automated Light Rapid Transit system called the SkyTrain (210 cars) that includes portions of the tracks which are on elevated structures and others that are underground like a traditional subway. The SkyTrain has been referred to as an Automated Light Rapid Transit (ALRT) and alternatively as an Intermediate Capacity Transit System (ICTS), an Automated Light Metro (ALM) and an Advanced Rapid Transit (ART) (Zweisystem, 2008). ALRT differs from LRT as it may be able to transport a heavier passenger load but it is more costly. Streetcars operate only in Toronto. Commuter Rail is found in Canada's three largest metropolitan areas: Greater Montreal (205 rail cars), Greater Toronto/Hamilton (495 rail cars) and Metro Vancouver (37 rail cars). Ferries are present in Halifax and Vancouver (Urban Transit Task Force, 2010). For Canadian public transit riders, the bus is the most popular transit mode, transporting 63.5% of all commuters. One quarter (25%) of individuals using public transit travel by subway or elevated rail, 11.2% use the commuter train and 0.3% ride ferries (Statistics Canada, National Household Survey, 2011b).

Ridership and accessibility to public transit

Not all Canadians have access to public transit. In 2008, 22 million Canadians (approximately 66%) had access to public transit (Canadian Urban Transit Association, 2010; Munro, 2007). Munro (2007) defined access as public transit that is available within five minutes from participants' homes either by foot or by car. Access to public transit varies between provinces as well as between rural areas and urban centres. In census metropolitan areas (CMAs) 85% of households have access to nearby public transit compared to only 32% of non-CMA households (Munro, 2007). Defining accessibility as easy access by car may overestimate access to public transit, as it restricts public transit use to car users. Montreal is estimated to be the city with most individuals living within one kilometer of rapid transit (37%) followed closely by Toronto (34%). Ottawa (28%), Calgary (21%) and Vancouver (19%) had fewer individuals living in such close proximity to rapid transit (Pembina Institute, 2014). Accessibility increases the chances an individual will choose to travel using public transit (Djurhuus et al., 2014). However, in some circumstances, such a train travel, people are willing to walk long distances to public transportation (Wasfi et al., 2013). It is possible that increasing access to public transit would be associated with an increase in public transit use.

In summary, most Canadians use their car as their main mode of travel. While levels of public transit use are higher in Canada than in the United States, they are much lower than in European countries. A variety of public transit modes exist in Canada and the modes vary in different cities. A substantial number of Canadians use rail transit. A high proportion of Canadians are considered to have access to public transit but this accessibility may be overestimated and does not address other barriers such as the need for a motorized vehicle to access public transit stations which, in turn, may lower ridership. The fact that other countries have higher levels of public transit ridership suggests that public transit infrastructure and organization in Canada may need to be optimized.

Literature review

While the previous section provided background information about the state of public transit infrastructure in Canada, this section will try to better understand the relationship between public transit use and the behaviors of transit users, more specifically, what is currently known about how transit use influences walking. The next section will describe the knowledge base on this topic has emerged from studies using different designs, namely systematic reviews, cross-sectional studies as well as natural experiments such as pre-post studies and longitudinal studies. Natural experiments will be defined and the reasons natural experiments may be well suited to better understand the relationship between public transit and utilitarian walking will be discussed.

Systematic reviews and cross-sectional studies

The current literature looking at the relationship between public transit and walking seems to indicate that public transit use leads to an increase in walking. Two recent systematic reviews looking at the relationship between public transit and walking have been carried out (Hutchinson et al., 2015; Rissel et al., 2012). Hutchinson's group is based at the University of York in the United Kingdom and Rissel's group is based at the University of Sydney in Australia.

In their systematic review, **Rissel et al. (2012)** found 27 studies focusing on physical activity and public transport published between 2002 and 2012. Nine of these studies reported objective measures for physical activity such as number of steps as measured by pedometers or mean daily minutes of moderate physical activity as measure by accelerometers. Of these nine studies, eight were classified as cross-sectional and one as quasi-experimental by the authors. Within these studies, individuals using public transit walked a minimum of 8 minutes more per day than those who did not use public transit (Lachapelle et al., 2011). Most studies reported an increase of 12 to 15 minutes of walking time associated to public transit use. One study in the review found that 29% of subjects were more likely to meet the physical activity guideline of walking 30 minutes per day by walking to public transit stops (Besser et al., 2005).

Hutchinson et al. (2015) carried out a scoping review examining the relationship between the environment and health behaviors. The review included one study published in 1991 and with the remaining studies ranging from 2003 to 2013. Seventeen studies focused on the relationship between physical activity and public transit use. Of these, one was a before-after study and the other 16 were cross-sectional. Five of the studies used objective measures. Hutchinson's review had nine studies in common with Rissel (2012). The results found by Hutchinson (2015) are similar to those found by Rissel (2012). Hutchinson (2015) reported that 16 of the 17 studies found a positive association between public transit use and physical activity, be it an increase in the time spent walking, an increase in the amount moderate exercise or an increase in the distance walked. Public transit use was associated with an 8 to 10 minute increase in daily walking. Three out of five studies found that public transit allowed individuals to meet daily physical activity requirements.

Since the publication of the systematic reviews, new cross-sectional studies have been published (Bopp et al., 2015; Chaix et al., 2014; Freeland et al., 2013; Mansfield et al., 2016; Saelens et al., 2014; Sallis et al., 2016). These studies also find a positive relationship between public transit use and physical activity. Moreover, some new studies were able to better characterize certain aspects of the relationship between public transit and physical activity, providing evidence, for example, of a dose-response relationship between public transit use and physical activity (Saelens et al., 2014). Individuals who use public transit more frequently carry out more physical activity than individuals who do not use transit at all (transit use <30% of days=average of 2.3 minutes more of physical activity per day (95% CI 1.3, 3.3), transit use 31-59% of days=6.5 minutes (95% CI 5.4, 7.6), transit use >60% if days=14.8 minutes (95% CI 13.7, 15.9) (Saelens et al., 2014). Another interesting finding from recent cross-sectional research is that time walked to transit varied by transit mode (Freeland et al., 2013; Wasfi et al., 2013). Individuals engaging in trips by commuter train walked the most (34.59 to 49.91 minutes), followed by those who used buses serving peripheral areas (25.38 to 40.7 minutes) and those who used the subway (19.55 to 34.87 minutes). Those walking the least were those travelling by city bus (11.65 to 26.96) or suburban bus (15.56 and 30.97 minutes) (Wasfi et al., 2013). Individuals living in an urban area of greater than a million people with a rail system were 72% more likely to walk 30 minutes per day to access transit (AOR =1.72, p=0.01) than those living in a city of a similar size with only a bus system (Freeland et al., 2013). Rail transit, the focus of this thesis, appears to be particularly effective at motivating walking behaviour.

Most of the studies looking at the relationship between public transit use and physical activity have been cross-sectional. Cross-sectional studies may be prone to certain biases. For example, individuals who prefer to use public transit and to walk for utilitarian purposes may be more likely to live in a neighborhood with good access to public transit (Mokhtarian et al., 2008). This could result in the individuals selected for the studies to walk more than the general population and for the effect of being exposed to public transit on walking to be overestimated. A way to control for selection bias is to conduct a cohort study where the amount of physical activity is measured before and after new public transit infrastructure is built in a neighborhood. This kind of natural experiment can help elucidate what happens when a new transit investment is made in a neighborhood.

’Natural’ Experiments

Natural experiments are studies that take advantage of population-level environmental change to explore the effect of the environmental exposure on a certain outcome. For example, the opening of new transit stations can be used to examine the effect of transit on utilitarian walking. Natural experiments are a type of observational study. They are also referred to as quasi-experimental studies. Their main feature is that “exposure to the event or intervention of interest has not been manipulated by the researcher” (Craig et al., 2012). In a natural experiment, the researcher cannot control who is exposed to the intervention, rather researchers capitalize in the natural variation of the exposure within a population (Petticrew et al., 2005). Compared to experimental studies, natural experiments are more vulnerable to bias and confounding (Craig et al., 2012). Randomized studies randomly assign subjects to the exposure and control groups which, in ideal circumstances, results in an equal distribution of confounders in both groups and results in the effect of confounders being cancelled out (Rothman, 2012). Conversely, in natural experiments, the experimental and control groups may differ according to certain characteristics that influence the likelihood of the outcome. Careful consideration of how the data are collected, analysed and interpreted can help take these limitations into account (Craig et al., 2012; Petticrew et al., 2005). Despite these limitations, natural experiments can be used to study phenomena that cannot be studied experimentally for practical or ethical reasons (Craig, 2012). Moreover, while natural experiments may not be able to establish causality, they can help to identify effective interventions that have the potential to improve the population's health (Petticrew et al., 2005).

Two types of natural experiments have been carried out to look at the relationship between public transit use and utilitarian walking. The first type is pre-post studies. Researchers measure levels of utilitarian walking before and after a new station is opened. The second type is longitudinal studies that capitalize on natural variations in access to public transit, either through participants living at different distances from public transit stops or moving to a new neighborhood that differs in public transit access when compared to their old neighborhood.

Pre-post studies

Very few studies have used natural experiments to look at the relationship between public transit use and walking. Studies have looked at the effect of new light rail transit (LRT) stations (Brown et al., 2015; MacDonald et al., 2010), bus rapid transit (BRT) (Day et al., 2014) and the opening of a busway (Ogilvie et al., 2016). This section will focus on the results of the studies looking at new LRT stations as this thesis focuses on rail transport.

Two main groups have looked at the effect of new LRT stations on physical activity: Brown and MacDonald. In both cases, the research was carried out in the United States. Brown's group carried out a total of five studies. Two of these looked at the opening of one LRT station between two other stops in fall 2005 (Brown et al., 2007, 2008) and two focused on the opening of five LRT stations in April 2013, both times in Salt Lake City, Utah (Brown et al., 2015; Miller et al., 2015). MacDonald et al. (2010) looked at the opening of an LRT line (the number of stations was not specified) in Charlotte, North Carolina in November 2007. All employed a pre-post design measuring physical activity outcomes before and after the stations opened.

Brown et al. (2007) wished to determine if opening a new LRT stop led to more individuals riding the LRT and more bouts of moderate intensity physical activity (≥ 3 METs). They contacted adults living within 0.5 miles (805 meters) of the new LRT station. At baseline, 102 participants were recruited in the summer of 2005 and 51 remained in the summer of 2006 after the opening of the LRT station. Public transit use was determined through self-reported number of LRT trips the participant carried out in the previous two weeks. Physical activity was defined as bouts of 8 minutes or more of moderate physical activity as determined by an accelerometer. The researchers measured the number of physical activity bouts associated with LRT use. Results found that 50% of the participants were riding the LRT before the new LRT station was built. This increased to 69% six months after the station was built. Individuals who rode the LRT were more likely to engage in more bouts per hour of physical activity when compared to individuals who did not ride the LRT both before (Beta=0.32, p=0.03) and after the LRT was built (Beta=0.57, p=0.00). Level of moderate physical activity associated to LRT use before the new LRT station was built predicted moderate physical activity bouts after the station was built.

Brown et al. (2008) used the same sample of participants to observe the relationship between LRT ridership and several outcomes: physical activity, obesity, car ridership and leisure time walking. Participants were divided into ridership groups based on whether they rode the LRT at time 1 (before the LRT station was built) and at time 2 (after the LRT station was built).

At time 2, 47 participants remained and had sufficient accelerometer data. Of these, 11 were new riders, in that they had not ridden the LRT at time 1 but did at time 2. Twenty-two were continuing riders and had ridden the LRT at time 1 and time 2. Fifteen were considered non-riders, and had either never ridden the LRT at time 1 and time 2, or ridden the LRT at time 1 and stopped ridding at time 2 (these numbers add up to 48 instead of 47 but this is what is stated in the paper). Multivariate analyses looking at the effect of ridership group (non-rider, new rider and continuing rider) and survey time (before and after new LRT station) on outcomes such as obese status (yes/no), number of bouts of moderate physical activity per hour and number of car rides in the last two weeks. They found an effect of ridership group (non-rider, new rider and continuing rider) and no effect of pre-LRT versus post-LRT station exposure for obesity ($F (2, 23)=4.80$, $p=0.01$), physical activity ($F (2, 23)=3.89$, $p=0.03$), and car rides ($F (2, 23)=6.44$, $p=0.00$). In an analysis contrasting LRT riders and non-riders, new LRT riders were less likely to be obese and more likely to do more physical activity than non-riders. Moreover, continuing LRT riders were the least obese and did the greatest amount of physical activity compared to new riders and non-riders.

Brown et al. (2015) wished to determine if exposure to new LRT stations led to changes in physical activity and BMI. They recruited subjects living within 2 kilometers of five new LRT stations. 939 subjects participated in the study and provided data from March to December 2012 before the stations were built. 614 participants remained after the station was built and were surveyed from May to November 2013. Of these, 537 had valid GPS data. Exposure to LRT was determined using GPS with subjects deemed exposed to transit if the GPS trip crossed a 40 meter buffer around the center of the street that contained the five stations. Physical activity was defined as counts per minutes (cpm) captured by the accelerometer. As in the 2008 study, subjects were divided into never riders (n=393), former riders (n=41), new riders (n=52) and continuing riders (n=51). When comparing levels of physical activity before and after the new LRT station within ridership groups, never riders (11.9 cpm change) and new riders (47 cpm) had an increase in physical activity while former riders (-43 cpm) and continuing riders (-14 cpm) had a decrease in physical activity. Absolute amounts of physical activity at time 2 appear to be higher for continuing riders (376.93 cpm ± SE 23.18) and new riders (381.04 cpm ± SE 23.73) when compared to never riders (320.33 cpm ± SE 7.11) and former riders (317.96 cpm ± SE 25.73). These measures were not compared formally with one another in the study. Moreover, never riders, former riders and continuing riders had an increase in BMI (0.19 ± SE 0.09 , 0.92 ± SE 0.24, 0.53 ± SE 0.37 respectively) while new riders had a decrease in BMI (–0.29 ± SE 0.30).

Miller et al. (2015) studied 537 subjects living within 2 kilometers of five new LRT stations whose data had previously been analysed by Brown et al. (2015). Exposure to public transit was defined as riding the bus, the LRT or the commuter train at least once during GPS wear time. Physical activity was time spent with accelerometer measures ≥ 1,000 cpm lasting for 5 or more minutes. Findings were similar to Brown et al. (2015). There was no significant change in the level of physical activity of individuals who were never riders or continuing riders. Conversely, individuals who were new riders saw a significant increase in their level of physical activity while those who were former riders saw a significant decrease in their level of physical activity. They also found that on average transit users carry out more overall physical activity on days when they take public transit as opposed to days when they do not (19.65 minutes, (95%

CI 17.28, 22.02) versus 9.59 minutes, (95% CI 7.97, 11.21). On public transit days, increases in physical activity appear to be due to physical activity accrued during transit while leisure time physical activity remained unchanged.

MacDonald et al. (2010) carried out phone sampling of individuals living within a 1 mile radius (1.6 km) of an LRT line before the LRT opened (July 2006-February 2007, n=839) and after (March 2008-July 2008, n=498). After the station was built, 26 subjects (5.2% of the post-LRT sample) used the LRT to commute to work daily on work days. Controls were 275 subjects who worked, but did not use the LRT to commute to work. Due to the imbalance between the number of subjects in the exposed group and the control group, propensity score weighting was used to select controls that had similar baseline characteristics to the exposed group to decrease the chance that difference in the group's characteristics other than the exposure of interest could lead to the observed effect. Daily LRT use was associated with a decrease in self-reported BMI and a lower chance of having a BMI > 30. No significant difference in the odds of meeting physical activity guidelines for self-reported moderate physical activity such as walking (30 minutes per day, 5 days a week) or vigorous physical activity (20 minutes per day, 3 days per week) were reported.

To summarize the findings of the pre-post studies, most studies find that LRT riders complete more physical activity than non-riders (Brown, 2007, Brown 2008, Brown 2015, Miller 2015). However, MacDonald (2010) was unable to find a change in physical activity levels related to LRT use. Switching from not using public transit to LRT use seems to result in an increase in physical activity (Brown 2008, Brown 2015, Miller, 2015), while switching from LRT to not using public transit results in a decrease in physical activity. Higher levels of physical activity found in LRT riders are maintained through time (Brown 2008, Brown 2015, Miller 2015). Furthermore, it is encouraging that the increase in physical activity in LRT riders is due to public transit use and not to an increase of leisure time physical activity and that it is tied to days where public transit is used (Miller 2015).

The pre-post studies done to date have some important limitations. Overall the studies have very small numbers of participants making it difficult to detect change in utilitarian walking. The sample sizes for these studies ranged from 11 to 52 individuals and non-rider control groups ranged from 15 to 393 individuals. The small number of individuals switching to public transit after the station was built may have made it more difficult to detect changes in utilitarian walking before and after the station opened (Brown et al., 2008; Brown et al., 2015). Another limitation of these studies is that subjects are typically only followed for a short amount of time after the station is opened. Data collection occurred within one to nine months after the opening of the station. It is possible that with a longer follow up time, more people could decide to switch to public transit and that the effect on physical activity levels within the population may be more pronounced. Finally, the way physical activity tends to be measured in this body of research may hamper detection of behaviour change. MacDonald (2010) may not have found an effect on physical activity because of the measure of physical activity (individuals walking 30 minutes per day, 5 days a week) was overly ambitious. It is possible that public transit use may help some but not all individuals to meet physical activity guidelines and there may be health benefits from walking even if physical activity guidelines are not reached.

Longitudinal studies

Three longitudinal studies have looked at utilitarian walking in relationship to exposure to public transit (Coogan et al., 2009; Hirsch et al., 2014; Knuiman et al., 2014). The main goal of all three studies was to look at the relationship between the built environment and walking, with access to public transit being one of the components being evaluated in the built environment. These three studies are different from research in this thesis as they evaluate the effect of transit that is already present in the environment rather than explore the effect of a new transit station on utilitarian walking. Two studies looked at the difference in utilitarian walking in individuals living at different distances from public transit (Hirsch, 2014; Coogan, 2009). One study looked at changes in utilitarian walking following subjects' move to a new neighborhood that varied in level of public transit access compared to the old neighborhood (Knuiman et al., 2014).

Hirsch et al. (2014) followed a cohort of 6814 adults at baseline for twelve years in six cities in the United States as part of the Multi-Ethnic Study of Atherosclerosis (MESA). Exposure to public transit was defined as distance to the nearest bus stop (in miles) from the participant's household. Distance between the household and the bus stop was established using GIS. Their outcome was the number of minutes of walking done for transportation per week over the last month. They found that an increase in the distance between the household and the nearest bus stop resulted in a decrease in the time spent utilitarian walking.

Coogan et al. (2009) reported results from the Black Women's Health Study, which was a prospective cohort study of 59,000 African-American women aged 21-69 years in the USA followed biennially from 1995-2001. They looked at the amount of utilitarian walking (>5 hours per week in the last year versus <5 hours per week in the last year) in relation to the shortest distance (from 0 to 97 miles) between participants' homes and public transit stops (subway, train or ferry). They also looked at the relationship between utilitarian walking and bus availability. Bus availability was defined as the number of miles of bus routes within a 0.5 mile (0.8 km) radius around the participants' homes. Individuals who lived within 0 to 0.4 miles (0.65 km) from a public transit stop were significantly more likely to do five hours or more of utilitarian walking per week than those who lived further away from transit stops. There was a positive trend between bus availability and utilitarian walking but it did not reach statistical significance.

Knuiman et al. (2014) followed the Residential Environments (RESIDE) cohort (N=1813 at baseline) over seven years in Perth, Australia. Individuals were followed before and after they moved to 73 new housing developments. Exposure to public transit was defined as the number of bus stops and the presence of railway stations (yes/no) within a 1,600 meter radius from participant's household. The outcome was self-reported utilitarian walking over a week (none versus at least 15 minutes). After moving to the new housing developments, participants had fewer bus stops and train stations within the 1,600 meter radius around their home. This decrease in 'exposure' to public transit was associated with a decrease in utilitarian walking. Conversely, having a railway station near one's home was associated with a greater amount of utilitarian walking (OR 1.34, 95% CI 1.00, 1.81) when adjusting for several covariates.

Longitudinal studies appear to find a dose-response relationship between the distance individuals live to a public transit station and the level of utilitarian walking (Coogan et al., 2009; Hirsch et al., 2014). This finding is similar to the one reported by a cross-sectional study previously mentioned (Saelens et al., 2014). While most pre-post studies had found that exposure to a new station resulted in an increase in utilitarian walking, the longitudinal study of Knuiman et al. (2014) found that a decrease in the number of stations was associated to a decrease in utilitarian walking.

Summary of current knowledge on public transit use and utilitarian walking

This chapter reviewed the state of public transit in Canada as well as the literature on public transit use and utilitarian walking. It showed that while most large Canadian cities have public transit infrastructure, public transit uptake in Canada is far from optimal: only a small proportion of Canadians use public transit on a regular basis. In turn, the literature review shows that increases in public transit use may have the potential to increase the population's physical activity levels by increasing daily levels of utilitarian walking. Individuals who use public transit do more utilitarian walking than those who do not use public transit. The literature also points to factors that may influence use of public transit. Distance between households and stations may influence public transit use and in turn levels of utilitarian walking. Individuals who live close to a public transit station are more likely to increase their level of utilitarian walking than those who live further away. Making public transit more accessible by increasing the number of public transit stations may reduce the distance individuals need to walk to public transit and make it more likely that individuals will use public transit more regularly. Conversely, it is possible that increasing the density of public transit stations could lower overall utilitarian walking as the distance walked to access stations could decrease. Studies looking at the effect of a new station opening in a neighborhood have found that a small proportion of the population will start using public transit. These new public transit users will engage in more utilitarian walking than individuals who did not switch to using public transit. The type of public transit may also influence use. Individuals appear to be willing to walk greater distances to rail transit compared to bus transit.

In summary, the current literature indicates that public transit use appears to be linked to an increase in utilitarian walking and that new stations seem to be associated with an increase in the use of public transit. Within a short time after a new transit station opens, a certain segment of the individuals living close to that station become new public transit users. Individuals living close to a station are more likely to engage in more utilitarian walking that those who live further away.

Current knowledge gaps addressed by this study

There are many elements about the relationship between public transit and utilitarian walking that remain unknown. This thesis tries to shed light on long term effects of new transit on utilitarian walking to understand the influences of new transit and distance to transit stations on utilitarian walking and to detect more subtle patterns of change in levels of utilitarian walking related to transit use.

Only pre-post studies have looked at the effect of the opening of a new station on utilitarian walking. In these studies, follow up occurred less than a year after a new stations had been opened. This study uses a longitudinal design to measure levels of utilitarian walking at multiple time points over several years after a new station opens. This allows for an appreciation of the long term effect of a new station on levels of utilitarian walking.

Previous studies have usually focused on one measure of exposure to public transit within their study: for example, the distance lived from a public transit station (Coogan et al., 2009; Hirsch et al., 2014), the opening of a new station in a neighborhood (MacDonald et al., 2010) or individuals moving from a neighborhood with more or less public transit station than their past neighborhood (Knuiman et al., 2014). This thesis considers both the increased access to public transit due to the opening of a new station and the effect of the distance lived from the station. It is possible that the opening of a new station and the distance lived from a station may lead to different levels of change in utilitarian walking. For example, the opening of a new station could lead to a 15% increase in utilitarian walking when compared to utilitarian walking levels before the station opened, while living at 800 meters compared to 1,000 meters from a new station may increase utilitarian walking by 5%.

To date, there has been only one longitudinal study that has looked at the relationship between the distance lived from a rail station and utilitarian walking levels (Coogan et al., 2009). Coogan et al. (2009) looked at whether living near a rail station led to more individuals engaging in five hours or more of utilitarian walking per week. This thesis focuses on smaller time intervals for utilitarian walking (less than one hour versus more than one hour) which may allow for the detection of more subtle changes in utilitarian walking patterns in relation to the distance lived from a public transit station.

Finally, this thesis is the first study to look at the effect of new commuter rail transit on utilitarian walking on such a large scale. Pre-post studies looking at new stations have focused on a set of stations in one city with very small sample sizes. Two longitudinal studies looked at the change in utilitarian walking within different US cities, but looked solely at bus stops (Hirsch et al., 2014) or at existing rail stops (Coogan et al., 2009). This study focuses on a large number of stations opened in several cities across Canada in a many different neighborhoods. It looks at the effect of new rail transit on utilitarian walking in a variety of different settings and could lead to more generalizable findings.

Chapter 3: Methods

This chapter describes the methods used to carry out this study. First, the dataset used in this study is discussed and details regarding the selection criteria of subjects included in the study are provided. Second, the method used to measure the outcome – utilitarian walking – is outlined. Third, the steps used to determine exposure to new rail transit stations is detailed: this spans from identifying new public transit investments in Canada to identifying subjects living close to new stations and methods used to quantify what this thesis terms 'exposure' to new transit in those respondents. Fourth, covariates that were potential confounders of public transit use and utilitarian walking are listed and defined. These covariates were subsequently used in the statistical analyses. The final part of the chapter explains the multivariate statistical analyses.

Data

The data used for this study come from the National Population Health Survey (NPHS). The NPHS is a longitudinal survey that was carried out by Statistics Canada to learn more about the health of Canadians (Statistics Canada, 2012). The household component was a closed cohort survey that followed the same 17,276 persons every two years from 1994/1995 to 2010/2011 for a total of nine cycles. Survey participants consisted of individuals of all ages from the ten Canadian provinces. It excluded individuals living on Indian Reserves and Crown Lands as well as residents of health institutions. Participants were selected using a two-stage sample design. First, clusters were selected within urban areas and rural areas. Thereafter, dwellings were selected within the clusters. Finally, one member from each household was chosen to be the longitudinal survey respondent (For more details, see Statistics Canada, 2012). Data collection was carried out by a computer assisted telephone interview system. Great attention was given to collecting high quality data. Threats to data quality such as sampling error and non-sampling error (response rates, refusal rates, unable to trace rates, attrition rates and "don't know" rates) were monitored and used to improve data collections in later cycles (Statistics Canada, 2010). The NPHS had an excellent response rate ranging from 83.6% in cycle 1 to 69.7% in cycle 9 (Statistics Canada, 2012). Indeed the high quality longitudinal health data of the NPHS may be difficult to achieve again given that land-line based telephone sampling frames are no longer reliable given the decline in land-line use in favour of cellular phones. Access to the data was granted by the Social Sciences and Humanities Research Council of Canada (#15-SSH-MCG-4430). Analyses were performed at the McGill-Concordia Quebec Inter-University Center for Social Statistics (QICSS) located on the McGill University campus.

Subject selection

Participants lived in urban areas where transit investments had occurred during the period of the survey. Participants were considered to be 'exposed' to rail transit if they lived within walking distance of a new rail transit investment (2,000 meters or less). Data from the US 2001 National Household Travel Survey suggested that 90% of individuals who walk from their home to public transit live within 27.5 minutes (2,500 meters if walking 5.47 km/hour (Knoblauch et al., 1996) of a transit station (Besser et al., 2005). The 2,000 meter distance was also used in a recent study looking at utilitarian walking and the opening of new LRT stations (Brown et al., 2015). Participants were considered 'unexposed' if they lived in one of the six Census Metropolitan Areas (CMA) where transit investments had occurred, but lived beyond 2,000 metres from a new station. A CMA consists of "one or more neighboring municipalities situated around a core. A census metropolitan area must have a total population of at least 100,000 of which 50,000 or more live in the core" (Statistics Canada, 2011a). Analyses were restricted to individuals over the age of 18 as utilitarian walking patterns may be different in children as compared to adults.

Outcome: Utilitarian walking

The NPHS survey included one question about utilitarian walking. This question was asked to all participants at each survey wave. Participants were asked: "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?" Possible answers were: none, less than 1 hour, from 1 to 5 hours, from 6 to 10 hours, from 11 to 20 hours and more than 20 hours. Since few respondents walked more than 11 hours per week, the six categories were collapsed into four categories: (1) none: 0 hours per week (2) low: less than one hour per week, (3) moderate: 1-5 hours per week and (4) high: 6 or more hours per week. To carry out logistic regressions, the outcome was made binary to compare participants who walked less than 1 hour compared to those who walked 1 hour or more per week.

Exposure measures

Identifying public transit investments

Six Canadian CMAs "received" rail transit investments during the time period when the NPHS survey was being carried out (from 1994 and 2010). These cities were : Montreal, Ottawa, Toronto, Calgary, Edmonton and Vancouver (Canadian Urban Transit Association, 2013; Pembina Institute, 2014). These cities received a variety of rail transit investments such as subways, light rail, advanced rapid transit (also known as the Vancouver SkyTrain) and commuter trains. An undergraduate student (Katelyn Moyer) searched the literature and the internet to identify stations that had opened between 1994 and 2010. Thereafter, the street addresses of each of the new stations were obtained via local transit company websites and Google maps.

Identifying subjects living close to a station: Buffer area around station

Once new stations were identified, the location of each station was geocoded by obtaining the latitude and the longitude coordinates of each station using Google maps. The geocoded addresses were imported into ArcGIS, a Geographic Information Systems (GIS). Each station appeared as a point on the city map. Different size network buffers with different radii (800 meters, 1,000 meters, 1,500 meters and 2,000 meters) were created around each station centroid and saved in buffer shapefiles. The sizes of buffer area radii were based on the potential distances individuals may be willing to walk to get to a public transit station were created around each station following the street network (Besser et al., 2005; Wasfi et al., 2013).

Shapefiles containing six digit Canadian postal code maps were overlaid onto the buffer shapefiles. Postal codes were included if they fit completely within the buffers around each station. Shapefiles containing the list of postal codes associated with the buffers around each station were converted to database format and then to CSV format so that they could imported into Stata 14.1 (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP.), the program used for the statistical analysis. Station postal codes were matched to the NPHS participants' six digit household postal codes by merging the file containing the station postal codes and other information about the stations with the NPHS data file in Stata.

Exposure to a new transit investment

To capture the longitudinal nature of the data, exposure of participants was compared over time (Figure 1). Levels of utilitarian walking were compared for participants living within walking distance of the new stations (≤2,000 meters) before versus after a new station opened. This mimicked a pre-post design. This measure of transit exposure was underpowered to detect changes in utilitarian walking. At that point, it was decided to capitalize on the geographic information available and participants were compared based on distance lived from the station. Distance was used as a measurement of exposure to transit (exposed versus not exposed). Finally, a sensitivity analysis was carried out to explore the relationship between proximity to transit (800 meters, 1,000 meters, 1,500 meters or 2,000 meters) and utilitarian walking. The following paragraphs will detail how each measure of exposure was created.

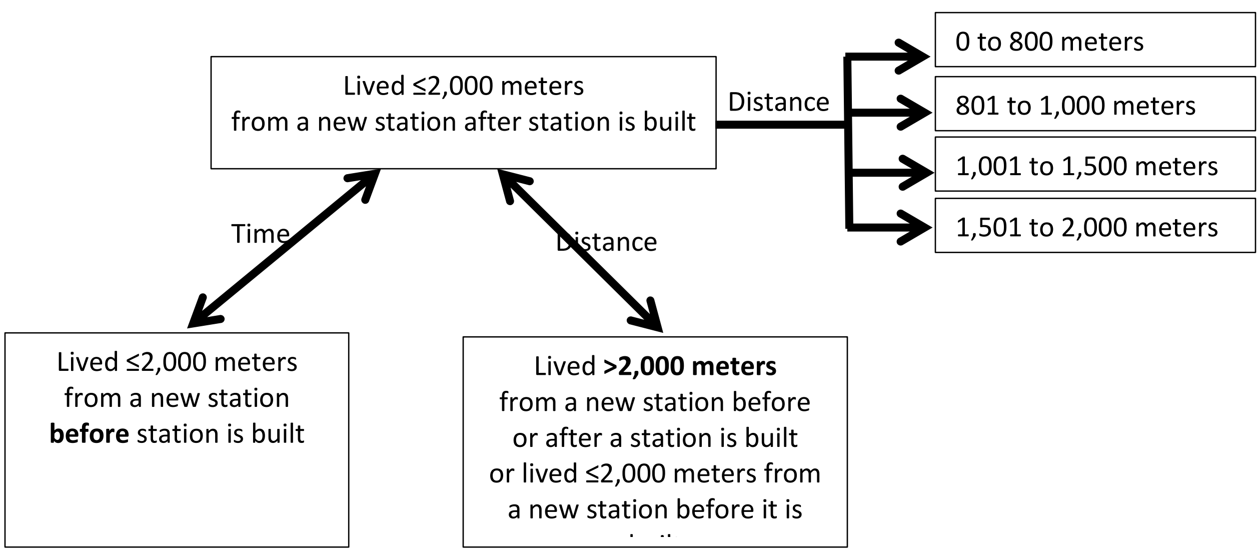

Figure 1: Different measures of exposure to new rail transit

Respondents pre and post new rail transit investment

Participants living 2,000 meters or less from a new station before or after it opened were selected. A variable identifying whether individuals living 2000 meters or less from a new station before or after the new station opened was created (Table 1). In the context of this study, participants were considered to live in a neighborhood that had received transit if they lived 2000 meters or less from a new station. Participants living 2000 meters or less from new station before it opened were compared to those living 2000 meters or less from a new station after it opened. To be included, individuals could have lived 2000- meters or less from a new station before it opened, after it opened or both before and after. Due to some individuals moving during the study, some individuals could move away from a neighborhood before a new station was built or move to a neighborhood with a new station after it was built. To try to limit selection bias related to individuals moving to a neighborhood because it had received a new station, a subsample of individuals that were non-movers (i.e. lived in a neighborhood within 2000 meters of a new station both before and a new station was built) was created. Levels of utilitarian of non-movers were compared before and after a new station opened in their neighborhood.

Participant ID	Survey wave	Participant postal code	Postal code within 2,000 meter radius of new station	Survey Year	Year new station opened	Years before and after station opens	Exposure to new station
1	1	A	.	1994	.	.	.
1	2	A	.	1996	.	.	.
1	3	B	B	1998	2002	-4	0
1	4	B	B	2000	2002	-2	0
1	5	B	B	2002	2002	0	1
1	6	B	B	2004	2002	2	1
1	7	C	.	2006	.	.	.
1	8	C	.	2008	.	.	.
1	9	C	.	2010	.	.	.

Table 1: Example of the creation of pre-post exposure variable for one survey respondent

First, postal codes within 2,000 meters of new stations were matched to participants' postal codes. In this example, the participants only lived in a neighborhood that received transit in the survey waves 3 to 6, when living at postal code B. Then the variable "years before and after station opens" was calculated by subtracting the year the new station opened from the survey year. If the "year before and after the stations" was a negative number, "exposure to a new station" was coded "0", if it was a positive number, " exposure to a new station" was coded "1". "0" corresponded to time spent in the neighborhood before the station opened and "1" corresponded to time spent in the neighborhood after the station opened.

Respondents 'exposed' to new rail transit investment and those unexposed

Participants were considered exposed to rail transit if they lived 2,000 meters or less from a new station after it was built. Participants were considered unexposed to transit if they lived in a CMA that received a new station and lived more than 2,000 meters from a new station before or after a new station was built. Participants who lived 2,000 meters or less from a new station before it was built were considered unexposed to transit and were included in the unexposed group.

Sensitivity analysis: Respondents 'exposed' to new rail transit investment by distance from new station

To study the effect of different walking distances to a new station, participants living 2,000 meters or less from a new station after it opened (exposed group) were divided into different subgroups: lived 0 to 800 meters from the new station, lived 801 to 1,000 metres from the new station, lived 1,001 to 1,500 metres from the new station or lived 1,501 to 2,000 meters from the new station.

Covariates: Potential confounders of walking and public transit use

Age, sex, level of education, leisure time physical activity, self-perceived health and neighbourhood walkability were included as potential determinants of walking and public transit use. These determinants had previously been used in a study by Wasfi et al. (2013) that also made use of NPHS respondents to look at the relationship between neighbourhood walkability and utilitarian walking. It is likely that the same variables may influence public transit use and utilitarian walking. All these covariates had been measured through questions asked in the NPHS.

Education level was defined as having post-secondary education or not at the first wave of the survey. Leisure time physical activity was determined by using a composite variable called the Physical Activity Index calculated by Statistics Canada (2009). The Physical Activity Index uses total daily energy expenditure to categorize respondents as inactive (0 to <1.5 kcal/kg/day), moderately physically active (1.5 to <3.0 kcal/kg/day) or physically active (>3.0 kcal/kg/day). To determine the total energy expenditure of each respondent, the respondent is asked whether they have participated in a range of leisure time physical activities such as different types of sports and physical activities (e.g., gardening, fishing). Then, they were asked to specify how many times in the last three months they participated in this activity and how long (1 to 15 minutes, 16 to 30 minutes, 31 to 60 minutes or more than one hour). The total daily energy expenditure (EE) associated with each leisure time physical activity was calculated by looking at the number of times a respondent engaged in a physical activity over the last 12 months (Ni), the average duration of the activity (Di), and the energy cost associated of the activity (kcal/kg/year). All physical activities were summed up and divided by 365 to obtain daily values. Formula: EE (kcal/kg/day) = Sum of ((N^i *D^i * MET value) / 365).

In their assessment of their health status, respondents were asked the following question: “In general, would you say that your health is excellent, very good, good, fair or poor?” This variable was collapsed to form two categories: Excellent or very good health versus good, fair or poor health.

The WalkScore® was used as a neighbourhood level determinant of walking (neighbourhood walkability). The WalkScore® is a measure of how much the built environment is suitable (facilitates or hinders) for utilitarian walking. It is measured by analysing multiple routes to nearby amenities such as businesses, parks, schools, etc. (WalkScore, 2016). Points are awarded based on the distance to amenities belonging to different categories. Amenities within a 5 minute walk (0.4 km) are awarded the most points. The number of points awarded for an amenity decreases with distance with amenities beyond a 30 minute walk (1.6 km) awarded no points. Other characteristics of the built environment such as population density, block length and intersection density are included in the WalkScore®. The total score ranges from 0 to 100. The 2012 WalkScore® was used for all survey cycles. To ensure that the 2012 WalksScore® could be used as an approximation of neighbourhood walkability for the timespan of the NPHS from 1994 to 2010, Wasfi et al. (2016) compared the 2012 WalksScore® to earlier measures of the built environment correlated with the WalksScore® such as street connectivity and population density in 1994 and 1996 using street network and Census data. The 2012 WalkScore® was highly corrected to the 1994 and 1996 measures of the built environment (Pearson correlation coefficient = 0.94; $P < .01$) (Wasfi et al., 2016). In this light of these findings, it appears that neighbourhood characteristics used to compute the WalksScore® change slowly in time, and that the 2012 WalkScore® could be used for analysis within the timespan of the NPHS.

The WalkScore® was collapsed into two categories: high walkability (≥70) versus moderate to low walkability (< 70). A neighbourhood with a WalkScore® greater than 70 is considered to be very walk-friendly and the type of neighbourhood one might be able to live in without needing a car for routine daily activities.

Statistical analysis

The statistical analysis of the data involved descriptive statistics and logistic regression modelling of longitudinal data. Analyses were conducted using Stata 14.1 (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP).

Since participants were followed longitudinally they had repeated measures for the outcome and covariates. To present descriptive statistics, the first measure of outcome and covariates for each subject was reported. For participants exposed to transit (lived ≤ 2000 meters from a new station), this corresponded to the first year they were exposed to a new station after it was built. For participants not exposed to transit (lived > 2000 meters from a new station), this corresponded to the first year they lived in a CMA that would receive transit during the duration of the NPHS, and could be before or after the station was built.

Random effects multivariate logistic regressions, accounting for the nesting of multiple responses over time from the same individuals, were carried out (Stata 14.1, xtmixed command) in keeping with the thesis objective to assess the relationship between utilitarian walking and exposure to public transit while accounting for age, sex, education level, self-perceived health, leisure time physical activity and neighborhood walkability.

Chapter 4: Results

Description of sample selection

The initial cohort of the NPHS consisted of 17,276 individuals. Over the course of the survey, 5,925 participants lived in a CMA where a new station was built. Within this sample, 5,766 participants were 18 years of age or older. Of these, 5,428 participants reported their level of utilitarian walking; 414 of these participants lived within 2,000 meters of a new station after it was built and 485 participants lived within 2,000 meters of a new station before it was built (Figure 2). Of these 899 participants who lived less than 2,000 meters from a station before or after it opened, 221 lived in the neighborhood both before and after the station opened.

5,014 participants were considered unexposed to new public transit as they lived more than 2000 meters from a new station before or after it was built in a CMA that received new transit or lived less than 2,000 meters from a station before it was built.

Of the 414 participants who lived less than 2,000 meters from a new station after it was built, 72 lived 0 to 800 meters from the station, 36 lived 801 to 1,000 meters from the station, 135 lived 1,001 to 1,500 meters from the station and 171 lived 1,501 to 2,000 meters from the station.

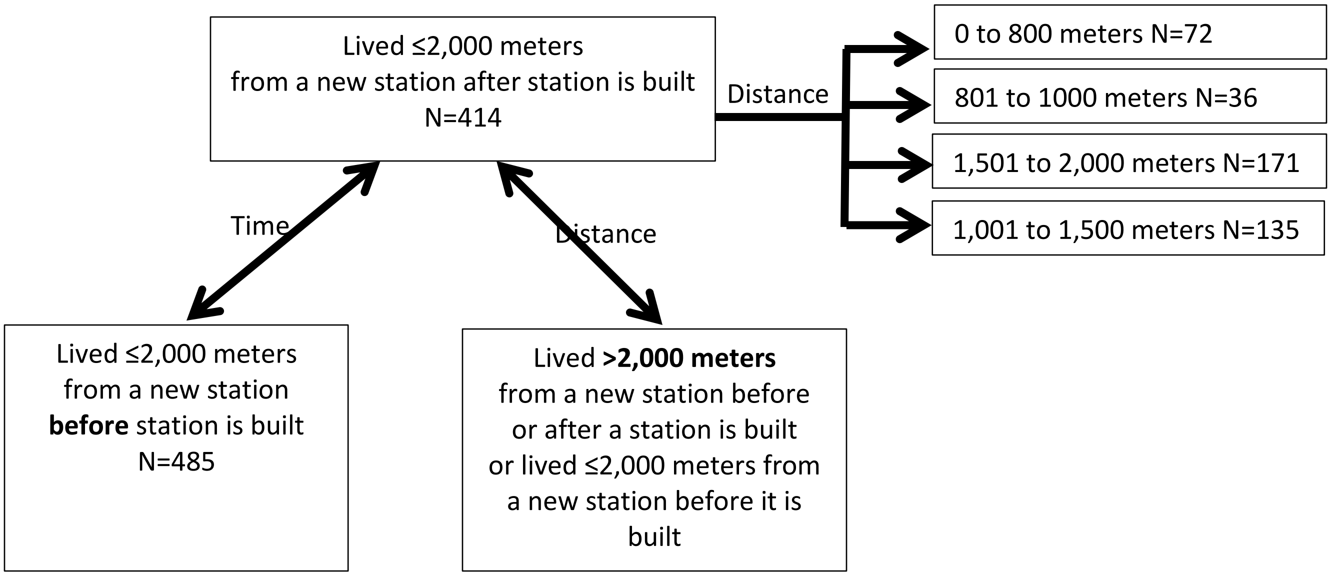

Figure 2: Sample description

Descriptive Statistics

Public transit investments

Over the course of the NPHS from 1994 to 2010, 84 new stations opened within 2,000 meters of survey participants' homes. Most stations opened in the later part of the survey starting in 2000 (Figure 3). By the end of the survey, there were 23 new stations built in Quebec, 22 in Ontario, 12 in Alberta and 27 in British Columbia (Table 2). Across Canada, 27 Advanced Rapid Transit (SkyTrain) stations were built, 16 LRT stations, 9 subway stations and 32 commuter train stations (Table 2). The mean WalkScore® of neighbourhoods within 2,000 meters of a new station was 60.54 (SD 22.84). 36.90 % of the stations were located in moderate-high to high WalkScore® areas (WalkScore® ≥ 70). Since stations were mostly built in the second half of the survey, most participants were exposed to a new station for some but not all cycles of the survey. Participants were not all exposed to new stations for the same length of time. Participants lived in a neighborhood with a new station between one to eight years. 65.70% of participants lived in a neighborhood with a new station for one year (Table 3).

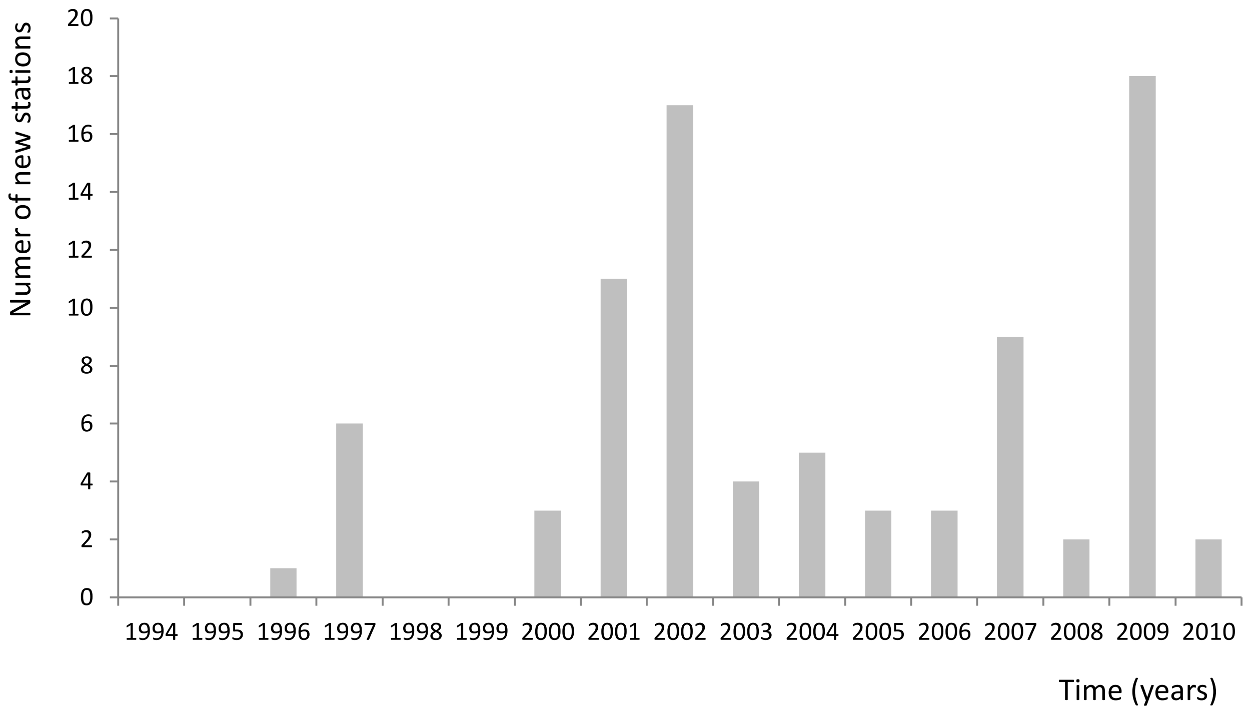

Figure 3: Frequency of new public transit stations built between 1994 and 2010 within 2,000 meters of NPHS participants' homes (N=84)

Province	Total number of new stations by province	Transit mode			
		Advanced Rapid Transit	Light Rail Transit	Subway	Commuter train
Quebec	23	0	0	3	20
Ontario	22	0	4	6	12
Alberta	12	0	12	0	0
British Columbia	27	27	0	0	0
Total	84	27	16	9	32

Table 2: Stations opened within 2,000 meters of participants' home between 1994-2010 across provinces and for different rail transit modes (N=84)

Time exposed to transit (years)	Number of unique participants	% of participants
1	272	65.70
2	75	18.12
3	32	7.73
4	20	4.83
5 to 8*	15	3.62
Total	414	100.00

Table 3: Number of years of exposure to a new station in individuals living ≤ 2,000 meters from a station (N=414)

*Categories collapsed due to small cell size to protect participant confidentiality as required by Statistics Canada

Pre-post descriptives: Utilitarian walking before and after new stations opened

Participants living in a neighborhood that received transit (lived within 2,000 meters from a new station) before a new station opened were compared to participants living in the same neighborhood after the station opened. The proportion of individuals engaging in one or more hours of utilitarian walking per week appeared to increase after the station was built (before: 53.20%, 95% CI 48.73, 57.62, after: 55.56%, 95% CI 50.71, 60.30) (Figure 4). In a subsample looking at only at non-movers (i.e. individuals who lived in a neighborhood that received transit both before and after the new station opened), the proportion of individuals engaging in one or more hours of utilitarian walking per week also appeared to increase after the station opened (before: 52.94%, 95% CI 46.30, 59.48, after: 56.11%, 95% CI 49.45, 62.56) (Figure 5).

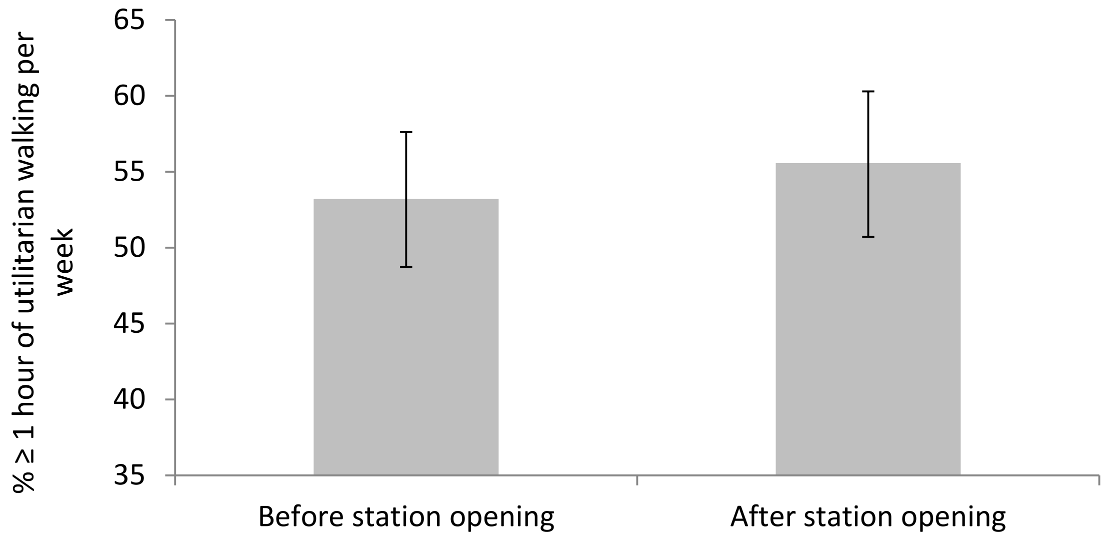

Figure 4: Proportion of participants reporting an hour or more of utilitarian walking before and after the opening of new transit stations for individuals living ≤ 2,000 meters from the new station (N=899)

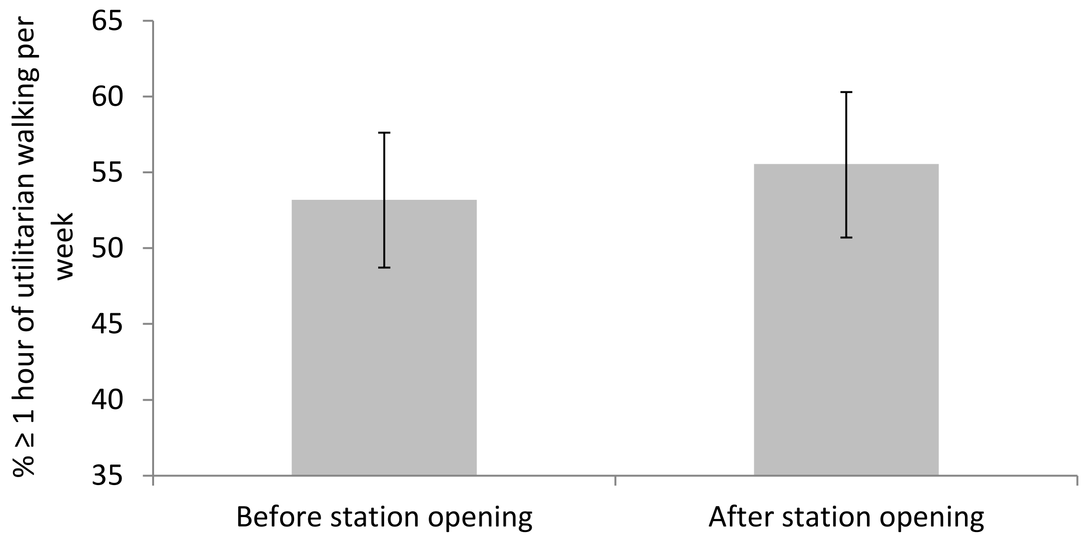

Figure 5: Proportion of non-movers reporting an hour or more of utilitarian walking before and after the opening of new transit stations for individuals living ≤ 2,000 meters from the new station (N=221)

Contrasting baseline characteristics for respondents 'exposed' to new rail transit investment and those unexposed

Baseline characteristics were obtained for participants living in a CMA that had received a public transit investment during the NPHS. These characteristics are contrasted for individuals that were exposed (lived ≤ 2,000 meters from a new station) and unexposed (lived > 2,000 meters from a new station) to new transit (Table 4).

Participants who were exposed to new transit had a mean age of 44.60 years (SD 18.47) (Table 4). 44.93% were males. 51.69% had completed post-secondary education. Slightly more than half reported that their health was excellent or very good (55.56%). 27.29% were considered active in their leisure time. 45.17% lived in a neighborhood with a high WalkScore®. 55.56% reported one hour or more of utilitarian walking each week after the station was opened.

Participants who were not exposed to transit had different characteristics than those that were exposed to transit (Table 4). Participants not exposed to new transit were younger (mean age 40.19 years (SD 18.19)). Fewer completed post-secondary education (34.38%). More reported being in excellent or very good health (64%). Less were active in their leisure time (22.90%). A smaller proportion lived in highly walkable neighborhoods (37.34%). Participants who were not exposed to a new station were engaged in one of more hour of utilitarian walking (49.22%, 95% CI 47.84, 50.60) to a lesser extent than those who were exposed to a new station (55.56%, 95% CI 50.77, 60.35) (Figure 6).

	Live ≤ 2,000 meters from the new station N=414		Live >2,000 meters from the new station N=5,014		Live in a CMA with a new station N=5,428	
	Mean	SD	Mean	SD	Mean	SD
Age	44.60	18.47	40.19	18.19	40.53	18.24
	n	%	n	%	n	%
Male	186	44.93	2,277	45.41	2,463	45.38
Completed post-secondary education	214 ƚ	51.69	1,724 ƚ	34.38	1,938 ƚ	35.70
Physically active in leisure time	113	27.29	1,148	22.90	1,261	23.23
Excellent/very good perceived health	230	55.56	3,197	63.76	3,427	63.14
Highly walkable neighborhood: WalkScore® ≥ 70	187ƚ	45.17	1,872 ƚ	37.34	2,059 ƚ	37.93
≥ 1 hour of utilitarian walking per week	230	55.56	2,468	49.22	2,698	49.71

Table 4: Baseline characteristics¥ of National Population Health Survey participants who lived in Census Metropolitan Areas where a new transit station was built and for whom utilitarian walking data was available (N=5,428)

¥ For participants exposed to transit, baseline corresponds to the first year they were exposed to a new station after it was built. For participants not exposed to transit, baseline corresponds to the first year they lived in a CMA that would receive transit during the duration of the NPHS, and could be before or after the station was built.
ƚ Totals for education and WalkScore® were slightly different because of missing observations:
Education: N=5,396, ≤2,000 meters=410 and >2,000 meters=4,986
WalkScore® ≥ 70: N=5,158, ≤2,000 meters=414 and >2,000 meters=4,744

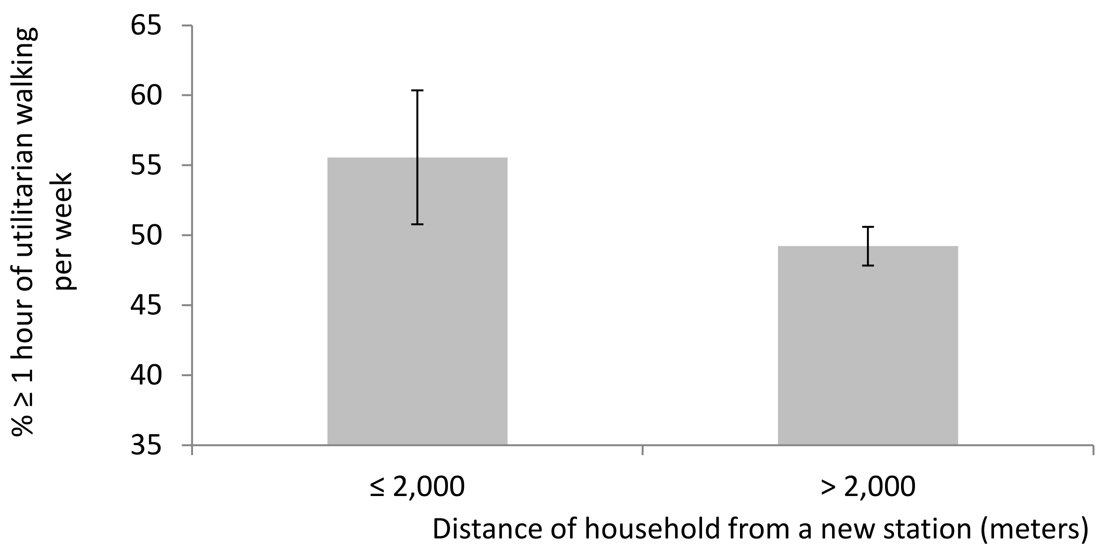

Figure 6: Proportion of participants reporting an hour or more of utilitarian walking in relation to distance lived from the station for individuals living ≤ 2,000 or > 2,000 meters from the new station (N=5,428)

Contrasting baseline characteristics for respondents 'exposed' and 'unexposed' to public transit who engaged in high levels of utilitarian walking

Levels of utilitarian walking were affected by time, participant characteristics and neighborhood WalkScore® (Table 5). A secular trend was observed for utilitarian walking levels. With the passing of time, participants reported higher levels of utilitarian walking (Figure 7). In the first survey wave, 45.58% of participants living in a CMA that received transit reported one or more hours of utilitarian walking per week. In the last survey wave, 64.95% reported one of more hours of utilitarian walking per week. In wave 9, individuals exposed transit reported lower levels of utilitarian walking (60.64% walk an hour or more) than those not exposed to transit (69.00% walk an hour or more). The percent increase in utilitarian walking with time was similar in the participants exposed to transit (60.64-39.22=21.42%) and those unexposed to transit (69.00-46.62=22.38%).

Time spent utilitarian walking appeared to decrease with age (Figure 8); 61.99% of individuals 18 to 24 years old reported one or more of utilitarian walking per week compared to 43.45% of individuals that were 55-64 year olds and 33.77% of individuals 75 years or older. Across age groups, participants who were exposed to transit were more likely to engage in one hour or more of utilitarian walking per week than those not exposed to transit.

Men were less likely to report one or more hours of utilitarian walking per week (45.59%) than women (53.12%), irrespective of exposure to a transit station. Individuals who had completed post-secondary education were slightly less likely to engage in one or more hours of utilitarian walking per week (48.35%) than those who had not (50.40%), irrespective of exposure to a transit station. Individuals who were physically active in their leisure time were more likely to engage in one or more hours of utilitarian walking per week (57.10% versus 47.47%) as were individuals who perceived themselves as having excellent or very good health (52% versus 46%) or lived in a highly walkable neighborhood (53.57% versus 46.89%).

Proportion engaging in ≥ 1 hour utilitarian walking per week		Live in CMA ≤ 2,000 meters from a new station N=414		Live > 2,000 meters from a new station N=5,014		Live in a CMA that received a station N=5,428	
Overall		230	55.56%	2468	49.22%	2698	49.71%
Survey wave	1					1,558	45.58
	2					193	44.57
	3					154	50.49
	4	20*	39.22*	2011*	46.62*	126	60.29
	5	64	58.18	109	65.66	173	62.68
	6	29	52.73	96	64.86	125	61.58
	7	32	62.75	107	64.46	139	64.06
	8	28	52.83	76	63.33	104	60.12
	9	57	60.64	69	69.00	126	64.95
Age (years)	18-24	43	67.19	730	61.71	773	61.99
	25-34	42	53.85	596	51.96	638	52.08
	35-44	50	53.76	409	44.07	459	44.96
	45-54	27	44.26	286	43.80	313	43.84
	55-64	28	60.87	181	41.61	209	43.45
	65-74	23	58.97	180	45.45	203	46.67
	75+	17	51.52	86	31.62	103	33.77
Sex	Men	102	54.84	1,021	44.84	1,123	45.59
	Women	128	56.14	1,447	52.87	1,575	53.12
Completed post-secondary education	Yes	116	54.21	821	47.62	937	48.35
	No	112	57.14	1,631	50.00	1,743	50.40
Physically active in leisure time	Yes	69	61.06	651	56.71	720	57.10
	No	161	53.49	1,817	47.00	1,978	47.47
Excellent/very good perceived health	Yes	129	56.09	1,657	51.83	1,786	52.12
	No	101	54.89	811	44.63	912	45.58
Highly walkable neighborhood: WalkScore® ≥ 70	Yes	106	56.68	997	53.26	1,103	53.57
	No	124	54.63	1,329	46.27	1,453	46.89

Table 5: Proportion of participants living in a CMA with a new station engaging in an hour or more of utilitarian walking per week in relation to multiple covariates (N=5,428)

*Data from survey waves 1-4 was collapsed due to small cell size to protect participant confidentiality as required by Statistics Canada

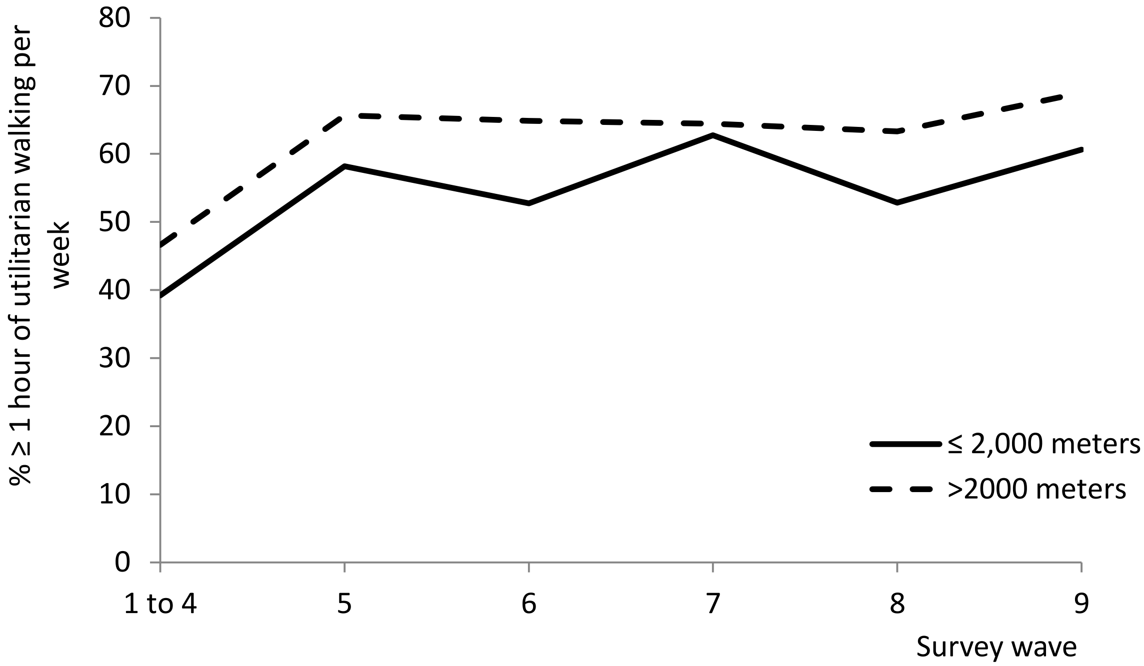

Figure 7: Proportion of participants engaging in one or more hours of utilitarian walking per week in relation to survey wave if living ≤ or > than 2,000 meters from a new station (N=5,428)

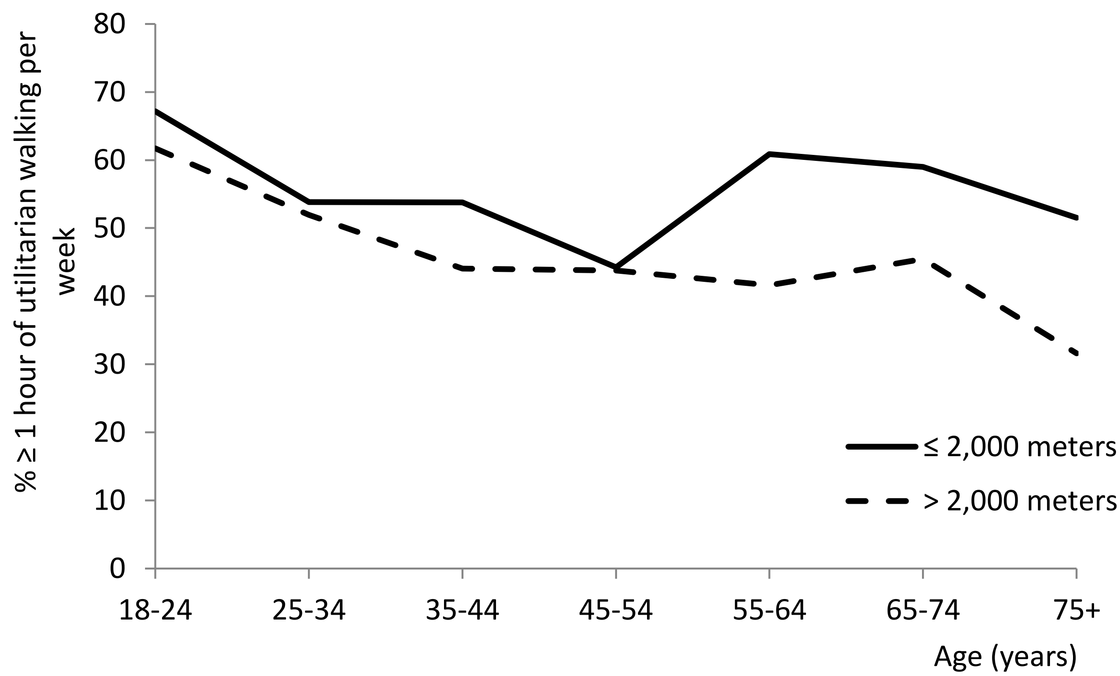

Figure 8: Proportion of participants engaging in one hour or more of utilitarian walking per week in relation to age if living ≤ or > than 2,000 meters from a new station (N=5,428)

Logistic regression analysis: Utilitarian walking in respondents 'exposed' to new rail transit investment and those unexposed

A univariate logistic regression showed the odds of engaging in one or more hours of utilitarian walking per week were 19% greater in participants living within 2,000 meters of a new station stations when compared to participants living more than 2,000 meters from the station (OR 1.19, 95% CI 1.00, 1.41) (Table 6). A multivariate logistic regression model adjusting for age, gender, completed post-secondary education, leisure time physical activity level and self-rated health also reached significance (OR 1.22, 95% CI 1.03, 1.44) (Table 6, model 2). Adding neighborhood WalkScore® to this model led to a similar trend although it no longer reached traditional statistical significance (OR 1.18, 95% CI 1.00, 1.40) (Table 6, model 3).

An increase of one year in age was associated with a 1% decrease in the odds of reporting more than one hour of utilitarian walking per week when all other covariates were held constant (OR 0.99, 95% CI 0.99, 0.99) (Table 6, model 3). If age increased by ten years, the odds of engaging in one or more hours of utilitarian walking per week decreased by 10%. Females had significantly higher odds (41%) than males of engaging in one or more hours of utilitarian walking per week with all other covariates held constant (OR 0.71 95% CI 0.65, 0.77) where 1/0.71=1.41). Being active in leisure time (OR 1.37, 95% CI 1.27, 1.47) and reporting excellent or very good perceived health (OR 1.17, 95% CI 1.09, 1.24) were associated with a greater odds of reporting one or more hours of utilitarian walking per week when controlling for all other covariates. Individuals living in a highly walkable neighborhood (WalkScore®≥ 70) had 54% greater odds than those with a less walkable neighborhood (WalkScore® < 70) of reporting one or more hours of utilitarian walking per week when adjusted for the other covariates (OR 1.54, 95% CI 1.44, 1.66). The education level of respondents did not appear to influence the level of utilitarian walking (OR 1.06, 95% CI 0.98, 1.14).

Dependent variable: ≥ 1 hour utilitarian walking per week	Univariate model N=5,428 OR (95% CI)	Multivariate model 1 N=5,428 OR (95%CI)	Multivariate model 2 N=5,411 OR (95%CI)	Multivariate model 3 N=5,269 OR (95%CI)
Constant	1.07* (1.02, 1.11)	1.30* (1.23, 1.38)	1.10* (1.02, 1.18)	0.92* (0.85, 1.00)
Live ≤ 2,000 meters from a station	1.19* (1.00,1.41)ł	1.23* (1.04,1.45)	1.22* (1.03, 1.44)	1.18 (1.00, 1.40)ł
Age centered at 40		0.99* (0.99, 0.99)	0.99* (0.99,0.99)	0.99* (0.99, 0.99)
Male		0.72* (0.67, 0.78)	0.70* (0.65, 0.76)	0.71* (0.65, 0.77)
Completed post-secondary education			1.06 (0.98, 1.14)	1.06 (0.98, 1.14)
Active in leisure time			1.35* (1.26, 1.45)	1.37* (1.27, 1.47)
Excellent/very good perceived health			1.15* (1.08, 1.23)	1.17* (1.09, 1.24)
Highly walkable neighborhood (WalkScore® ≥ 70)				1.54* (1.44, 1.66)

Table 6: Odds of reporting ≥ 1 hour of utilitarian walking per week if exposed versus not exposed to a new station

Model 1: Adjusted for age and sex
Model 2: Adjusted for age, sex, education level and leisure time physical activity
Model 3: Adjusted for age, sex, education level, leisure time physical activity and neighborhood WalkScore®
*Reached statistical significance ($p<0.05$)
ł The 95% CI for live ≤ 2,000 meters from a station in univariate model ranged from 1.003 to 1.407 while in model 3 it ranged from 0.998 to 1.403

Sensitivity analysis: Utilitarian walking in respondents 'exposed' to new rail transit investment by distance from new station

Participants exposed to a new station (lived ≤ 2,000 meters from a new station) were divided into subgroups based on the distance they lived from the new station. 72 individuals lived within 0-800 meters from the station, 36 lived between 801-1,000 meters, 135 lived 1,001-1,500 meters and 171 lived 1,501-2,000 meters from a new station. Individuals living the closest to a new station (0-800 meters) engaged in the highest levels of utilitarian walking (61.11%, 95% CI 49.84, 72.36) (Figure 9) while individuals living further from the station engaged in lower levels of utilitarian walking (801-1,000 meters: 52.78%, 95%CI 36.47, 69.09, 1,001-1,500 meters: 52.59%, 95% CI 44.17, 61.01, 1,501-2,000 meters: 56.14%, 95% CI 48.70, 63.58) (Figure 9).

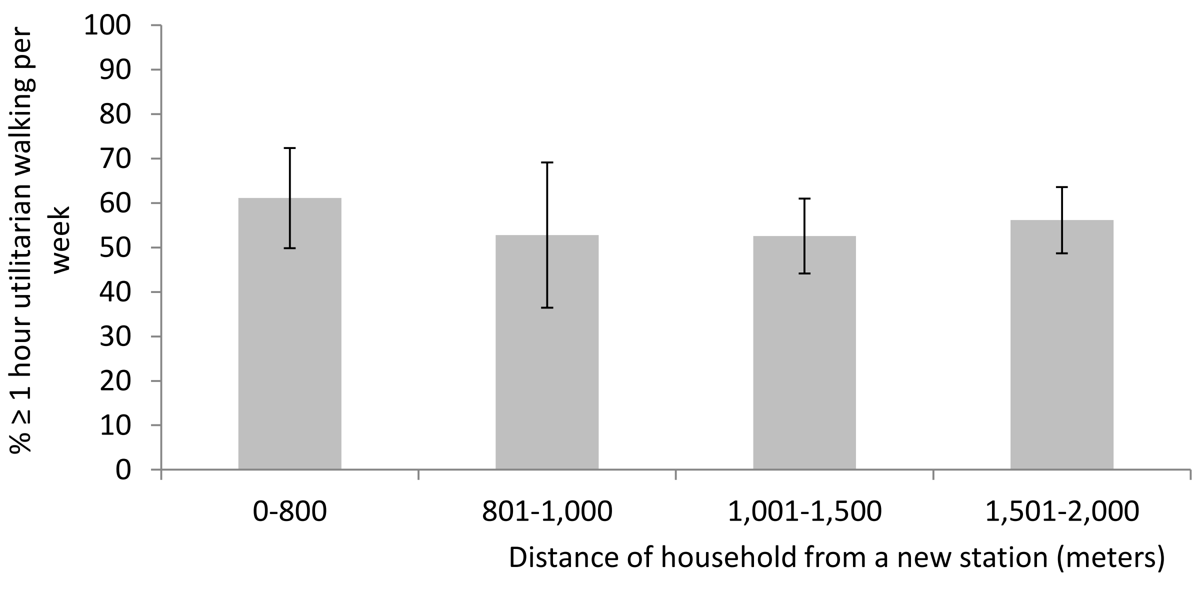

Figure 9: Proportion of participants reporting an hour or more of utilitarian walking in relation to distance lived from the station for individuals living ≤ 2,000 meters from the new station (N=414)

Chapter 5: Discussion

This chapter will compare and contrast the substantive findings of this study with regards to what is currently known about the relationship between public transit and utilitarian walking in the scientific literature. It will highlight important strengths and limitations of the study as well as the methodological contributions of the thesis. Finally, this chapter will discuss policy contributions of the thesis and suggest potential directions for future research.

Substantive contributions

This study was carried out to shed light on the relationship between utilitarian walking and improved access to public transit. More precisely, it sought to answer the following question: Would the opening of a new station in a neighborhood be associated with an increase in utilitarian walking in individuals living close to the station after it opened?

During the span of the survey from 1994 to 2010, 84 new stations opened in six major Canadian cities within 2,000 meters of NPHS participants' homes. There was an approximate 3% increase in the proportion of individuals who reported engaging in one or more hours of utilitarian walking per week after new stations opened, although this change did not reach significance. The odds of engaging in one or more hours of utilitarian walking per week was 20% greater in individuals exposed to a new station (living ≤ 2,000 meters from a new station) than in individuals who were not exposed to a new station (living > 2,000 meters from a new station), but was no longer significant when adjusted for neighborhood walkability. Importantly, during the span of the study, utilitarian walking increased by approximately 20% across the study period independent of exposure to new transit. Finally, there was a modest signal that individuals living the closest to the station appeared to engage in the most utilitarian walking but this difference did not reach statistical significance.

Utilitarian walking before and after new stations opened

This study found a small increase in levels of reported utilitarian walking after new stations opened. This finding is consistent with that of most pre-post studies done in the past (Brown et al., 2007; Brown et al., 2015) although a study had reported no changes in utilitarian walking after the opening of a new station (MacDonald et al., 2010).

There are several reasons that the effect of a new station on levels of utilitarian walking may have been underestimated. First, participants self-reported their level of walking. Self-reporting may result in participants overestimating or underestimating their level of utilitarian walking. However, one might expect this information bias to be non-differential with regards to exposure status. In other words, participants who are exposed to a new station will be as inaccurate in their reported level of utilitarian walking as those who are not exposed to a new station. This would bias the odds ratio of the model towards the null, because non-differential information bias tends to dilute the effect of the exposure on the outcome if the exposure is dichotomous (Rothman, 2012, pp. 134-135). Second, the utilitarian walking measure in this study may not have been precise enough to detect small changes in utilitarian walking that may have occurred in response to transit investment. In the survey, when participants were asked about the time they spent engaging in utilitarian walking per week, they were given pre-specified categories to choose from (none, less than 1 hour, from 1 to 5 hours, from 6 to 10 hours, from 11 to 20 hours and more than 20 hours). The amount of utilitarian walking due associated to walking to a new station can be estimated. Under ideal conditions, individuals would walk the distance between their home and the station twice a day for five days a week and walk an average walking speed of 5.47 km/hour (Knoblauch et al., 1996). If they lived 800 meters from the station, this would result in 1h27 minutes of utilitarian walking per week due to the walking to the station (800 meters * 5.47km/hour *2 times per day * 5 days per week = 87 minutes). Using the same calculation, living 1,000 meters from the station and using transit five days per week would result in 1h50 minutes of utilitarian walking, living 1,500 meters from the station would result in 2h45 minutes of utilitarian walking and living 2,000 meters from the station would result in 3h39 minutes of utilitarian walking. Because some of the categories of utilitarian walking span over 5 hours, it is possible that individuals who increased or decreased the time they spent doing utilitarian walking would fall within the same category and that the change would go unnoticed.

A subsample consisting of non-movers (i.e. participants who lived in a neighborhood that received transit both before and after a new station opened) was used to explore the effect of the new station on utilitarian walking in a way that was devoid of selection bias. More individuals appeared to be engaging in higher levels of utilitarian walking after the station opened, although the change was not statistically significant. The proportion of individuals engaging in one or more hours of utilitarian walking before and after the station opened were very similar to those found in the larger sample that included individuals that lived in a neighborhood that received public transit either before, after, or before and after a new station opened. These similar results appear to indicate that selection bias was not a major analytical concern of the study.

Utilitarian walking in respondents 'exposed' to new rail transit investment and those unexposed

Individuals living close to the new station (≤ 2,000 meters) had significantly higher odds of engaging in one or more hours of utilitarian walking per week than individuals living far from a new station (>2,000 meters). This relationship remained significant when adjusted for potential confounders of utilitarian walking and public transit use such as age, sex, education level, leisure time physical activity level and self-perceived health, but was no longer significant when neighborhood WalkScore® was added along with the other previously mentioned covariates.

The finding that individuals who live within 2,000 meters of a new station are at higher odds of engaging in one hour or more of utilitarian walking per week than those who do not live within 2,000 meters of a new station is consistent with results from previous cross-sectional studies showing that individuals using public transit tend to walk between eight and fifteen minutes more per day that those who do not use public transit (Hutchinson et al., 2015; Miller et al., 2015; Rissel et al., 2012). These findings are also in keeping with results of previous pre-post studies showing a proportion of the population will start using public transit after the opening of a new station (Brown et al., 2007; Brown et al., 2015; MacDonald et al., 2010). New transit users engage in more utilitarian walking than individuals who did not switch to using public transit (Brown et al., 2015). This finding complements the longitudinal study carried out by Knuiman et al. (2014) that found that a decrease in the number of rail stops within 1,600 meters of participants' homes led to a decrease in levels of utilitarian walking. In this way, the results of this study are consistent with the idea that populations proximal to a new transit investment will see an increase in their levels of utilitarian walking.

There are several possible explanations for the greater amount of utilitarian walking carried out by individuals exposed to new stations compared to those who were not exposed to new station in this study. The increase in utilitarian walking may be due to shifts in modes of transit from private automobile to public transportation. While mode shift is a plausible explanation for the detected increase in utilitarian walking, it was not measured in the thesis. As public transit use was not directly measured, it was not possible to determine how many participants that were exposed to new stations switched from car use to public transit. Previous studies have shown that 5% (MacDonald, 2010) to 23% (Brown et al., 2008) switched from car use to public transit use within six to twelve months of a new public transit station opening. In other words, this means that most individuals in past studies never switch to riding public transit. Furthermore, it is impossible to know if individuals who switched to using public transit soon after a station was built maintained public transit use through time. For example, Brown et al. (2015) found that in a sample of individuals exposed to a new station, some individuals switched from car use to public transit use (9.7%=52/537), but a substantial proportion switched from public transit use to car use (7.6%=41/537). A more important increase in utilitarian walking may have been detected if this study had been able to isolate individuals who switched to using public transit regularly and compared them to individuals who did not. However, by considering the whole population, this study gives a good estimate of the impact of building new public transit stations on utilitarian walking at the population level. This study measures effectiveness: the change in the level of utilitarian walking under ordinary circumstances where only a segment of the population uses public transit, rather than its efficacy: the change in the level of utilitarian walking that can be expected under ideal conditions where all individuals switch to using public transit after a public transit station opens.

In addition to mode shift, other factors could have resulted in the increase in utilitarian walking in individuals exposed to new stations. Walkability of neighborhoods appeared to be an important determinant of utilitarian walking in this study. The inclusion of the WalkScore® variable to the model rendered the influence of exposure to new rail transit non-significant, which seemed to indicate that the characteristics of the neighborhood where a station is built may influence the number of individuals who choose to walk to new public transit stations (Renne et al., 2013). Furthermore, since the purpose of the utilitarian walking trips was not measured in this study, it cannot be ruled out that the observed increase in utilitarian walking may have been the result of a general overall increase in walking to local amenities over time rather than the result of increase walking to the new public transit stations.

The change in utilitarian walking associated with exposure to a new station may also be influenced by a more global change in levels of utilitarian walking within the Canadian population. In this study, descriptive statistics showed a 20% increase in utilitarian walking in the study sample from 1994 to 2010, both in individuals exposed and not exposed to new stations. While the effect of time no doubt influenced levels of utilitarian walking in the NPHS sample, it was not possible to include survey waves as a covariate in the model due to low cell counts for individuals exposed to a new station. The low cell counts were the result of most new stations being built during the latter stages of the survey. However, the logistic regression models did take into account repeated measures within subjects. This strong secular trend made it difficult to detect the potentially weaker signal of increased levels of walking associated with transit investment. The increase in utilitarian walking could reflect a secular trend towards increased favourability of walking purposefully to destinations that in the past might have been accessed by private automobile.

The increase in utilitarian walking found in this study is more important than the one observed by Statistics Canada (2014). They reported a 5% increase in individuals engaging in more than 6 hours of utilitarian walking per week between 1996 and 2005. Utilitarian walking trends are less clear in the United States. The United States National Household Travel Survey reports a decrease (1%) in the proportion of individuals walking to work between 1990 and 2009 (Santos et al., 2011). This 1% decrease was also observed in data from the US Census and in the American Community Survey (Alliance for biking and walking, 2014). Utilitarian walking for family and personal errands appears to have increased slightly (3%) during the same period (Santos et al., 2011).

The secular increase in reported utilitarian walking detected in this study could be due to a change in how participants report utilitarian walking due to an increase social desirability of this activity or due to a real increase in utilitarian walking. The 1990s and 2000s saw an important shift in how physical activity was defined and promoted at the population level. From the 1970s to the 1990s, the population was encouraged to engage in vigorous physical activity during their leisure time to increase their physical fitness (Lee et al., 2008; Sallis, 2009). The

1990s saw a shift away from the promotion of vigorous physical activity towards moderate physical activity, with the goal to improve health (Lee et al., 2008). In 1996, the Surgeon General of the United States issued the report entitled “Physical Activity and Health” that suggested that lifestyle activities such as walking, gardening and biking could be beneficial for health (Orleans et al., 2009; U.S. department of health and human services, 1996). This shift towards promoting active lifestyle and utilitarian walking could have resulted in individuals engaging in or reporting higher levels of utilitarian walking.

While the past paragraphs focused on potential causes for the increase in utilitarian walking detected in this study, the following paragraphs examine other covariates, such as exposure to pre-existing public transit, car ownership and season, that have the potential to influence utilitarian walking and public transit use and may have been interesting to include in the statistical models.

This study did not take into account the potential effect of public transit infrastructure present before new stations were built on levels of utilitarian walking. A source of bias in the study comes from the assumption that individuals who were unexposed to a new station did not have as much access to public transit as individuals living near a new transit station. However, it is possible that the unexposed respondents had access to older public transit stations even if they did not live near a new station. That said, changes in utilitarian walking are potentially more likely with exposure to a new investment. Furthermore, if it is assumed that individuals who were not exposed to a new station use public transit and that this results in an increase in their utilitarian walking, this would diminish the differences in levels of utilitarian walking between the control group and the exposed group, biasing the results towards the null.

Another limitation is that the NPHS lacked information about car ownership and car use. These are important confounders of the utilitarian walking and public transit use relationship. Car ownership is inversely associated with walking (Shoham et al., 2015). Adjusting for car ownership and transit use could have helped explain patterns of utilitarian walking.

The season the survey was carried out for each participant and hence the utilitarian walking tied to that season was not included as a covariate in the model. Past studies have shown that fall and winter are associated with a decrease in the amount of utilitarian walking by a mean of 750 steps per day (Dasgupta et al., 2010; Tudor-Locke et al., 2004). This would be the equivalent of a decrease of 33 minutes of utilitarian walking per week in fall and winter (750 steps corresponds to approximately 600 meters * 5.47km/hour * 5 days per week = 33 minutes) (Knoblauch et al., 1996; Tudor-Locke et al., 2004). The fact that seasonality was not taken into account in the model is unlikely to affect the results as the difference in 33 minutes per week would most likely fall within the same category of utilitarian walking variable.

While this study had limitations inherent to its design, it remains a rich source of information about the potential impact of new transit station on utilitarian walking. A strength of this natural experiment is its external validity (Petticrew et al., 2005). The effect of new transit was assessed across different cities and provinces of Canada over several years, making the findings more generalizable across Canada than a local study occurring in one city or over a short time frame.

Sensitivity analysis: Utilitarian walking in respondents 'exposed' to new rail transit investment by distance from new station

The sensitivity analysis found that individuals living the closest (≤ 800 meters) from the station appeared to engage in the most utilitarian walking. This signal was small and therefore, the effect of distance on utilitarian walking levels was not modelled further. It would be expected that walking shorter distances would require less effort and time than walking longer distances and could be perceived as more feasible and acceptable by participants. Past studies have found that individuals living closer to public transit were more likely to walk and that the likelihood of walking to transit decreases with distance to transit. A study of 3,312 transit users (bus or train) in the cross-sectional 2001 U.S. National Household Travel Survey showed that 50% of respondents walked 8 minutes or less (approximately 730 meters if walking at an average speed of 5.47 km/hour (Knoblauch et al., 1996) from origin point to public transit; 75% walked 15 minutes or less (approximately 1,370 meters; 90% walked 27.5 minutes or less (2,507 meters) (Besser et al., 2005). Similar results were found in a study using subjects from the 2009 National Household Travel Survey by the same group (Freeland et al., 2013). In their longitudinal study, Hirsch et al. (2014) found that living at a greater distance from a bus stop was inversely related to time spent doing utilitarian walking. Another longitudinal study found an increase in utilitarian walking in individuals living within 0 to 0.4 miles (0 to 0.64 km) from a transit stop (train, subway or ferry), but not if living at greater distances (Coogan et al., 2009).

It is possible that a difference in utilitarian walking existed between participants living at different distances from the station, but that it was not detectable with the NPHS' sample size. While the subgroups living a different distances from the station ranged between 80 and 200 individuals, it is likely that only a small proportion of these individuals switched to using public transit when the stations opened.

Methodological contributions

This study was the first to look at the effect of new rail stations on utilitarian walking in such a large cohort over such a long time period. Such a study may be impossible to replicate due to the transition from landlines to cellular phones which leads to frequent changes in phone numbers and unlisted numbers and makes keeping in contact with individuals over long timespans very difficult. Furthermore, this study offers a unique methodological contribution to the literature by retrospectively linking GIS-based data of station location and participants' household location within a longitudinal cohort.

Policy contributions

This study was able to show a link between new public transit stations and increases in utilitarian walking levels in individuals living close to the station. Investment in public transit holds promise to increase physical activity and health at the population level. Rail infrastructure has benefits beyond the potential to increase physical activity in populations. Decreased road trauma and air pollution are potential co-benefits of public transit use (Litman, 2015). Transit ridership appears to be on the rise (Urban Transit Task Force, 2010) and recent investments by the Canadian government of 3.4 billion in the spring 2016 may increase ridership even more (Owram, 2016). This potential revival of public transit underlines the importance of doing more research to better understand the impact of public transit on physical activity and health, such as the long term impact of public transit use on health. For example, future studies could examine the relationship between the number of years of public transit ridership and BMI, dyslipidemia, hypertension or blood sugar levels. Furthermore, more research should be done to understand and address individual and environmental barriers to transit use and to create a supportive built environment around stations that encourages individuals to take public transit (Kesten et al., 2015; Renne et al., 2013). Studying the impact of measures that make car use less attractive, such as road congestion charges, should also be pursued (Henriksson et al., 2011). Future multidisciplinary collaboration between the fields of public health and urban planning may allow us to design efficient public transit that will lead to significant increase in physical activity and health within populations.

Conclusion

This retrospective cohort study was a natural experiment that wished to determine if exposure to new rail transit stations resulted in a change in utilitarian walking. To explore this question, utilitarian walking patterns of NPHS respondents living within walking distance of new rail transportation infrastructure built in urban Canada between 1994 and 2010 was used. It was found that the opening of a new station appeared to be associated with a 3% increase in the proportion of individuals that engaged in one hour or more of utilitarian walking, however this trend did not reach significance. Individuals exposed to a new station (lived ≤ 2,000 meters from a new station) were 20% more likely to engage in one or more hours of utilitarian walking that those who were not exposed to a new station (lived > 2,000 meters from a new station). The relationship between exposure to a new station and utilitarian walking did not remain significant when adjusted for neighborhood walkability. In addition to the increase in utilitarian walking associated to exposure to new stations, this study detected secular increase of 20% during the timespan of the survey. Finally, a sensitivity analysis exploring utilitarian walking in relation to the distance lived from a new station found that individuals who lived ≤ 800 meters from a new station did the most utilitarian walking, although this did not reach statistical significance.

This work contributes to the public health and urban planning literatures. This was the first longitudinal study looking at the effect of new public transit stations on utilitarian walking and it offers insight on the impact of new public transit stations on utilitarian walking. It provided an example of a creative use of GIS applied to a retrospective longitudinal dataset. GIS enabled participants of the NPHS survey to be retrospectively matched with a list of new rail stations that had been opened in Canada.

Further longitudinal research on public transit use and utilitarian walking would be beneficial to better understand the relationship between the distance lived from a station and time spent exposed to transit on utilitarian walking while taking into account frequency and duration of public transit use and car use. A better understanding of the impact of public transit and other forms of transportation on physical activity is key to building built environments that support the health of present and future populations.

References

Alliance for biking and walking. (2014). *Bicycling and walking in the united states: 2014 benchmarking report*. Retrieved from http://www.bikewalkalliance.org/storage/documents/reports/2014BenchmarkingReport.pdf

American Public Health Association. (2010). *The Hidden Health Costs of Transportation*. Retrieved from https://www.apha.org/publications-and-periodicals/reports-and-issue-briefs/transportation

Aune, D., Norat, T., Leitzmann, M., Tonstad, S., & Vatten, L. J. (2015). Physical activity and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis. *Eur J Epidemiol, 30*(7), 529-542.

Beavis, M. J., & Moodie, M. (2014). Incidental physical activity in Melbourne, Australia: health and economic impacts of mode of transport and suburban location. *Health Promotion Journal of Australia, 25*, 174-181.

Besser, L. M., & Dannenberg, A. L. (2005). Walking to public transit: steps to help meet physical activity recommendations. *American Journal of Preventive Medicine, 29*(4), 273-280.

Boone-Heinonen, J., Evenson, K. R., Taber, D. R., & Gordon-Larsen, P. (2009). Walking for prevention of cardiovascular disease in men and women: a systematic review of observational studies. *Obes Rev, 10*(2), 204-217.

Bopp, M., Gayah, V. V., & Campbell, M. E. (2015). Examining the link between public transit use and active commuting. *International Journal of Environmental Research and Public Health, 12*(4), 4256-4274.

Broocks, A., Bandelow, B., Pekrun, G., George, A., Meyer, T., Bartmann, U., Hillmer-Vogel, U., & Ruther, E. (1998). Comparison of aerobic exercise, clomipramine, and placebo in the treatment of panic disorder. *Am J Psychiatry, 155*(5), 603-609. doi:10.1176/ajp.155.5.603

Brown, B. B., & Werner, C. M. (2007). A new rail stop: tracking moderate physical activity bouts and ridership. *American Journal of Preventive Medicine, 33*(4), 306-309.

Brown, B. B., & Werner, C. M. (2008). Before and After a New Light Rail Stop: Resident Attitudes, Travel Behavior, and Obesity. *Journal of the American Planning Association, 75*(1), 5-12.

Brown, B. B., Werner, C. M., Tribby, C. P., Miller, H. J., & Smith, K. R. (2015). Transit Use, Physical Activity, and Body Mass Index Changes: Objective Measures Associated With Complete Street Light-Rail Construction. *American Journal of Public Health, 105*(7), 1468-1474.

Canadian Urban Transit Association. (2010). Measuring Success: The Economic Impact of Transit Investment in Canada. *Issue Paper 35*.

Canadian Urban Transit Association. (2013). *Federal, Provincial & Territorial Public Transit Funding Programs In Canada*. Retrieved from cutaactu.ca

Caspersen, C., Powell, K., & Christenson, G. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep, 100*(2), 126-131.

Chaix, B., Kestens, Y., Duncan, S., Merrien, C., Thierry, B., Pannier, B., Brondeel, R., Lewin, A., Karusisi, N., Perchoux, C., Thomas, F., & Meline, J. (2014). Active transportation and public transportation use to achieve physical activity recommendations? A combined GPS, accelerometer, and mobility survey study. *International Journal of Behavioral Nutrition and Physical Activity, 11*(1). doi:http://dx.doi.org/10.1186/s12966-014-0124-x

Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., & Tremblay, M. S. (2011). Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian health measures survey. . *Health Reports, 22*(1), 1-9.

Coogan, P. F., White, L. F., Adler, T. J., Hathaway, K. M., Palmer, J. R., & Rosenberg, L. (2009). Prospective study of urban form and physical activity in the Black Women's Health Study. *Am J Epidemiol, 170*(9), 1105-1117. doi:10.1093/aje/kwp264

Craig, P., Cooper, C., Gunnell, D., Haw, S., Lawson, K., Macintyre, S., Ogilvie, D., Petticrew, M., Reeves, B., Sutton, M., & Thompson, S. (2012). Using natural experiments to evaluate population health interventions: new MRC guidance. *Journal of Epidemiology & Community Health, 66*(12), 1182-1186.

Dasgupta, K., Joseph, L., Pilote, L., Strachan, I., Sigal, R. J., & Chan, C. (2010). Daily steps are low year-round and dip lower in fall/winter: findings from a longitudinal diabetes cohort. *Cardiovascular diabetology, 9*.

Day, K., Loh, L., Ruff, R. R., Rosenblum, R., Fischer, S., & Lee, K. K. (2014). Does Bus Rapid Transit promote walking? An examination of New York City's Select Bus Service. *Journal of Physical Activity & Health, 11*(8), 1512-1516. doi:http://dx.doi.org/10.1123/jpah.2012-0382

Djurhuus, S., Hansen, H. S., Aadahl, M., & Glumer, C. (2014). The association between access to public transportation and self-reported active commuting. *International Journal of*

Environmental Research & Public Health [Electronic Resource], 11(12), 12632-12651. doi:http://dx.doi.org/10.3390/ijerph111212632

Freeland, A. L., Banerjee, S. N., Dannenberg, A. L., & Wendel, A. M. (2013). Walking associated with public transit: moving toward increased physical activity in the United States. *American Journal of Public Health, 103*(3), 536-542. doi:http://dx.doi.org/10.2105/AJPH.2012.300912

Harvard Women's Health Watch. (2009). MET-hour equivalents of various physical activities. Retrieved from http://www.health.harvard.edu/staying-healthy/met-hour-equivalents-of-various-physical-activities

Henriksson, G., Hagman, O., & Andréasson, H. (2011). Environmentally reformed travel habits during the 2006 congestion charge trial in Stockholm--a qualitative study. *Journal of Environmental Research & Public Health, 8*, 3202-3215.

Hirsch, J. A., Moore, K. A., Clarke, P. J., Rodriguez, D. A., Kelly R. Evenson, Brines, S. J., Zagorski, M. A., & Roux, A. V. D. (2014). Changes in the Built Environment and Changes in the Amount of Walking Over Time: Longitudinal Results From the Multi-Ethnic Study of Atherosclerosis. *Am J Epidemiol, 180*(8), 799-809.

Hollingworth, B., Mori, A., Cham, L., Passmore, D., Irwin, N., & Noxon, G. (2010). *Urban Transportation Indicators: Fourth Survey*. Retrieved from tac-atc.ca/sites/tac-atc.ca/files/site/doc/resources/report-uti-survey4.pdf

Hu, F. B., Sigal, R. J., Rich-Edwards, J. W., Colditz, G. A., Solomon, C. G., Willett, W. C., Speizer, F. E., & Manson, J. E. (1999). Walking compared with vigorous physical activity and risk of type 2 diabetes in women: a prospective study. *JAMA, 282*(15), 1433-1439.

Hutchinson, J., Prady, S. L., Smith, M. A., White, P. C., & Graham, H. M. (2015). A Scoping Review of Observational Studies Examining Relationships between Environmental Behaviors and Health Behaviors. *International Journal of Environmental Research & Public Health [Electronic Resource], 12*(5), 4833-4858. doi:10.3390/ijerph120504833

Kelly, P., Kahlmeier, S., Gotschi, T., Orsini, N., Richards, J., Roberts, N., Scarborough, P., & Foster, C. (2014). Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship. *Int J Behav Nutr Phys Act, 11*, 1-15. doi:10.1186/s12966-014-0132-x

Kesten, J. M., Guell, C., Cohn, S., & Ogilvie, D. (2015). From the concrete to the intangible: understanding the diverse experiences and impacts of new transport infrastructure. *Int J Behav Nutr Phys Act, 12*, 72. doi:10.1186/s12966-015-0230-4

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. W., Christian, H. E., Divitini, M. L., Foster, S. A., Bull, F. C., Badland, H. M., & Giles-Corti, B. (2014). A Longitudinal Analysis of the Influence of the Neighborhood Built Environment on Walking for Transportation: The RESIDE study. *Am J Epidemiol, 180*(5), 453-461.

Lachapelle, U., Frank, L., Saelens, B. E., Sallis, J. F., & Conway, T. L. (2011). Commuting by public transit and physical activity: where you live, where you work, and how you get there. *Journal of Physical Activity & Health, 8 Suppl 1*, S72-82.

Lachapelle, U., & Noland, R. B. (2012). Does the commute mode affect the frequency of walking behavior? The public transit link. *Transport Policy, 21*, 26-36. doi:10.1016/j.tranpol.2012.01.008

Land Transport Authority Academy. (2014) Passenger Transport Mode Shares in World Cities. *Journeyrs: Vol. 12* (pp. 54-64). Singapore.

Lee, I. M., & Buchner, D. M. (2008). The importance of walking to public health. *Medicine & Science in Sports & Exercise, 40*(7 Suppl), S512-518. doi:10.1249/MSS.0b013e31817c65d0

Lee, I. M., Rexrode, K. M., Cook, N. R., Manson, J. E., & Buring, J. E. (2001). Physical activity and coronary heart disease in women: is "no pain, no gain" passé? *JAMA, 285*(11), 1447-1454.

Litman, T. (2015). *Evaluation Public Transportation Health Benefits*. Retrieved from http://www.apta.com/resources/reportsandpublications/Documents/APTA_Health_Benefits_Litman.pdf

MacDonald, J. M., Stokes, R. J., Cohen, D. A., Kofner, A., & Ridgeway, G. K. (2010). The effect of light rail transit on body mass index and physical activity. *American Journal of Preventive Medicine, 39*(2), 105-112. doi:http://dx.doi.org/10.1016/j.amepre.2010.03.016

Mackett, R., & Brown, B. B. (2011). *Transport, Physical Activity and Health: Present knowledge and the way ahead*. Retrieved from https://www.ucl.ac.uk/news/pdf/transportactivityhealth.pdf

Mammen, G., & Faulkner, G. (2013). Physical activity and the prevention of depression: a systematic review of prospective studies. *American Journal of Preventive Medicine, 45*(5), 649-657. doi:10.1016/j.amepre.2013.08.001

Mansfield, T. J., & Gibson, J. M. (2016). Estimating Active Transportation Behaviors to Support Health Impact Assessment in the United States. *Front Public Health, 4*, 63. doi:10.3389/fpubh.2016.00063

Manson, J. E., Greenland, P., LaCroix, A. Z., Stefanick, M. L., Mouton, C. P., Oberman, A., Perri, M. G., Sheps, D. S., Pettinger, M. B., & Siscovick, D. S. (2002). Walking compared with vigorous exercise for the prevention of cardiovascular events in women. *The New England journal of medicine, 347*(10), 716-725.

Manson, J. E., Hu, F. B., Rich-Edwards, J. W., Colditz, G. A., Stampfer, M. J., Willett, W. C., Speizer, F. E., & Hennekens, C. H. (1999). A prospective study of walking as compared with vigorous exercise in the prevention of coronary heart disease in women. *The New England journal of medicine, 341*(9), 650-658.

McKenzie, B. (2014). *Modes Less Traveled - Bicycling and Walking to Work in the Unites States: 2008-2012*. Retrieved from http://www.census.gov/library/publications/2014/acs/acs-25.html

Miller, H. J., Tribby, C. P., Brown, B. B., Smith, K. R., Werner, C. M., Wolf, J., Wilson, L., & Oliveira, M. G. (2015). Public transit generates new physical activity: Evidence from individual GPS and accelerometer data before and after light rail construction in a neighborhood of Salt Lake City, Utah, USA. *Health & Place, 36*, 8-17. doi:10.1016/j.healthplace.2015.08.005

Mokhtarian, P. L., & Cao, X. (2008). Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. *TRB Transportation Research Part B, 42*(3), 204-228.

Morency, C., Trepanier, M., & Demers, M. (2011). Walking to transit: An unexpected source of physical activity. *Transport Policy, 18*, 800-806.

Munro, A. (2007). Public Transit in Canada, 2007. Retrieved from http://www.statcan.gc.ca/pub/16-002-x/2010002/article/11283-eng.htm

Ogilvie, D., Panter, J., Guell, C., Jones, A., Mackett, R., & Griffin, S. (2016). Public Health Research *Health impacts of the Cambridgeshire Guided Busway: a natural experimental study*. Southampton (UK): NIHR Journals Library.

Orleans, T., Laura C. Leviton, Kathryn A. Thomas, MJ, T. L. B., Jamie B. Bussel, Dwayne Proctor, Celeste M. Torio, & Weiss, S. M. (2009). History of the Robert Wood Johnson Foundation's Active Living Research Program Origins and Strategy. *American Journal of Preventive Medicine, 36*(2S), S1-S9.

Owram, K. (2016, March 22). Federal budget 2016 spends up to $3.4B in public transit to address 'lost productivity,' but falls short of Via Rail demands. *Financial Post*. Retrieved from http://business.financialpost.com/news/transportation/federal-budget-2016-spends-up-to-3-4b-in-public-transit-to-address-lost-productivity-but-falls-short-of-via-rail-demands

Pembina Institute. (2014). *Fast Cities: A comparison of rapid transit in major Canadian cities*. Retrieved from https://www.pembina.org/reports/fast-cities-report.pdf

Petticrew, M., Cummins, S., Ferrell, C., Findlay, A., Higgins, C., Hoy, C., Kearns, A., & Sparks, L. (2005). Natural experiments: an underused tool for public health? *Public Health, 119*, 751-757.

Physical Activity Guidelines Advisory Committee. (2008). *Physical Activity Guidelines Advisory Committee Report*. Retrieved from Washington, D.C.: https://health.gov/paguidelines/report/

Public Health Agency of Canada. (2014, November 4th, 2014). What is Active Transportation? Retrieved from http://www.phac-aspc.gc.ca/hp-ps/hl-mvs/pa-ap/at-ta-eng.php

Renne, J., & Ewing, R. (2013). *Transit-Oriented Development: An Examination of America's Transit Precincts in 2000 & 2010*. Retrieved from http://scholarworks.uno.edu/unoti_pubs/17

Reynolds, R., McKenzie, S., Allender, S., Brown, K., & Foulkes, C. (2014). Systematic review of incidental physical activity community interventions. *Preventive Medicine, 67*, 46-64. doi:10.1016/j.ypmed.2014.06.023

Rissel, C., Curac, N., Greenaway, M., & Bauman, A. (2012). Physical Activity Associated with Public Transport Use—A Review and Modelling of Potential Benefits. *Int. J. Environ. Res. Public Health, 9*, 2454-2478.

Rothman, K. J. (2012). *Epidemiology an introduction* (2nd edition ed.): Oxford university press.

Saelens, B. E., Vernez Moudon, A., Kang, B., Hurvitz, P. M., & Zhou, C. (2014). Relation between higher physical activity and public transit use. *American Journal of Public Health, 104*(5), 854-859. doi:10.2105/ajph.2013.301696

Sallis, J. F. (2009). Measuring Physical Activity Environments : A Brief History. *AMEPRE American Journal of Preventive Medicine, 36*(4), S86-S92.

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K. L., Davey, R., Kerr, J., Lai, P. C., Mitas, J., Reis, R., Sarmiento, O. L., Schofield, G., Troelsen, J., Van Dyck, D., De Bourdeaudhuij, I., & Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. *Lancet, 387*(10034), 2207-2217. doi:10.1016/s0140-6736(15)01284-2

Santos, A., McGuckin, N., Nakamoto, H. Y., Gray, D., & Liss, S. (2011). *Summary of Travel Trends: 2009 National Household Travel Survey*. Retrieved from

Shoham, D. A., Dugas, L. R., Bovet, P., Forrester, T. E., Lambert, E. V., Plange-Rhule, J., Schoeller, D. A., Brage, S., Ekelund, U., Durazo-Arvizu, R. A., Cooper, R. S., & Luke, A. (2015). Association of car ownership and physical activity across the spectrum of human development: Modeling the Epidemiologic Transition Study (METS). *BMC Public Health, 15*(1), 1-10. doi:10.1186/s12889-015-1435-9

Statistics Canada. (2009). National Population Health Survey Household Component: Documentation for the Derived Variables and the Constant Longitudinal Variables Cycles 1 to 7 (1994/1995 to 2006/2007). Retrieved from http://www23.statcan.gc.ca/imdb-bmdi/pub/document/3225_D10_T9_V3-eng.pdf

Statistics Canada. (2010). Statistics Canada National Population Health Survey Household Component Cycles 1 To 8 (1994/1995 To 2008/2009) Longitudinal Documentation Retrieved from http://www23.statcan.gc.ca/imdb-bmdi/document/3225_D5_T1_V5-eng.pdf

Statistics Canada. (2011a). Census metropolitan area (CMA) and census agglomeration (CA). *Census Dictionary.* Retrieved from https://www12.statcan.gc.ca/census-recensement/2011/ref/dict/geo009-eng.cfm

Statistics Canada. (2011b). Commuting to work. *NHS in Brief.* Retrieved from https://www12.statcan.gc.ca/nhs-enm/2011/as-sa/99-012-x/99-012-x2011003_1-eng.cfm

Statistics Canada. (2012). National Population Health Survey: Household Component, Longitudinal (NPHS). Retrieved from http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=3225

Statistics Canada. (2014). Retrieved from http://www.statcan.gc.ca/pub/82-003-x/2006008/article/phys/10307-eng.htm

Sugiyama, T., Francis, J., Middleton, N. J., Owen, N., & Giles-Corti, B. (2010). Associations Between Recreational Walking and Attractiveness, Size, and Proximity of Neighborhood Open Spaces. *American Journal of Public Health, 100*, 1752-1757.

Tudor-Locke, C., Bassett, D. R., Swartz, A. M., Strath, S. J., Parr, B. B., Reis, J. P., DuBose, K. D., & Ainsworth, B. E. (2004). A Preliminary study of one year of pedometer self-monitoring. *ann. behav. med. Annals of Behavioral Medicine, 28*(3), 158-162.

U.S. department of health and human services. (1996). *Physical activity and health: a report of the surgeon general* Retrieved from Atlanta, GA: https://www.cdc.gov/nccdphp/sgr/pdf/sgrfull.pdf

Urban Transit Task Force. (2010). *Recent Developments in Transit in Canadian Cities, 2010*. Retrieved from www.comt.ca/english/recent-nov2010.pdf

WalkScore. (2016). Walk Score Methodology. Retrieved from https://www.walkscore.com/methodology.shtml

Wasfi, R. A., Dasgupta, K., Orpana, H., & Ross, N. A. (2016). Neighborhood Walkability and Body Mass Index Trajectories: Longitudinal Study of Canadians. *American Journal of Public Health, 106*(5), 934-940. doi:10.2105/ajph.2016.303096

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

World Health Organization. (2003). *Social determinants of health: the solid facts 2nd edition*. Retrieved from http://www.euro.who.int/en/publications/abstracts/social-determinants-of-health.-the-solid-facts

World Health Organization. (2014). *Global Status Report on Noncommunicable Diseases 2014*. Retrieved from http://www.who.int/nmh/publications/ncd-status-report-2014/en/

Zunft, H. J., Friebe, D., Seppelt, B., Widhalm, K., Remaut de Winter, A. M., Vaz de Almeida, M. D., Kearney, J. M., & Gibney, M. (1999). Perceived benefits and barriers to physical activity in a nationally representative sample in the European Union. *Public Health Nutr, 2*(1a), 153-160.

Zweisystem. (2008). What is the SkyTrain? Retrieved from https://railforthevalley.wordpress.com/2008/12/18/what-is-skytrain/