UNDERSTANDING DETERMINANTS OF ACTIVE TRAVEL

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ABSTRACT

Lack of physical activity participation is one of the greatest challenges facing health care providers and policy makers in Canada. Increases in health problems linked to inactive lifestyles, such as obesity, heart disease, and asthma, have led health promotion experts to engage Canadians to become more active. Despite these efforts, many Canadians remain inactive and at risk. Active travel (AT), defined in this study as walking for travel, is a key form of physical activity that continues to decline. This dissertation examines the decline of AT and role the individual, physical, and social environment have on AT.

The individual environment is examined by providing evidence of how perceived barriers to walking influence the AT of population sub-groups by modeling each barrier comparing agreement versus disagreement. Results find females, senior citizens, and those with a higher body mass index identify the most barriers, while young adults, parents, those owning a driver's license, and those owning a bus pass identify the fewest barriers.

The physical environment is examined by providing an improved conceptualization of the built environment (BE). First, the BE-AT relationship is examined by comparing the relationship when measuring the BE using an aggregate method with a disaggregate approach of measurement. As a result, both aggregate and disaggregate BE variables are significant, but the aggregate approach hides the fact that only two of the five BE variables are significant when using the disaggregate approach. Second, the influence the modifiable areal unit problem (MAUP) has on the relationship between AT and the BE is investigated. The results find that the relationship between AT and the BE are influenced by scale zone effect of MAUP.

The social environment is examined through the adoption of a conceptual framework from the physical activity literature that combines the social environment with individual and physical environments. A series of linear regression models evaluating the different components of the social environment find that only role models and neighborhood social cohesion influence AT, despite the fact that the social environment is significantly related to walking for exercise in the literature.

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I would like to dedicate this work to my son, Callen Christopher Clark, and my wife, Cheryl Hames Clark, with all my love and thanks.

PREFACE

This dissertation is a compilation of four research papers that have been submitted (in preparation) for publication to peer-reviewed journals. For this reason, there is overlap between chapters, in particular the introduction and datasets. The contributions by the author include literature review, data preparation, statistical analysis, interpretation of results, and writing of the papers. Dr. Darren Scott, co-author of the four papers, contributed to this dissertation through guidance on paper topics and methodology, appraisal of manuscripts, and editorial review. The additional co-author of chapter 2 provided advice on methodological decisions. The research papers are as follows:

Chapter 2:

Clark, A.F., D.M. Scott, N. Yiannakoulias (2012) Examining the Relationship between Active Travel, Weather, and the Built Environment: A Multilevel Approach using a GPS-enhanced Dataset. Transportation. (under review)

Chapter 3:

Clark, A.F., D.M. Scott (2012) Understanding the impact of the modifiable areal unit problem on the relationship between active travel and the built environment. Urban Studies. (under review)

Chapter 4:

Clark, A.F., D.M. Scott (2012) The Social Environment and Walking for Travel: A Case Study for Hamilton, Ontario, Canada. Journal of Transport Geography. (under review)

Chapter 5:

Clark, A.F., D.M. Scott (2012) Examining how weekly walking for travel is influenced by barriers to walking within different sub-groups of the population in Hamilton, Canada. Journal to be determined. (under review)

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Chapter 1 Introduction

1.1. Justification of Research Topic

A lack of physical activity (PA) participation is one of the greatest challenges facing health care providers and policy makers in today's society. Physical inactivity contributes to health problems, such as asthma, obesity, high blood pressure, heart disease, and diabetes (U.S. Department of Health and Human Services, 1996), which cost the Canadian health care system $5.3 billion in 2010 (Canadian Fitness and Lifestyle Research Institute, 2010). These costs, born by society, have led health care providers and policy makers to encourage Canadians to become more active. Despite efforts to promote PA, only 52% of Canadians are active (Canadian Fitness & Lifestyle Research Institute, 2009). Furthermore, only 48% of Canadians are getting a moderate amount of PA (Canadian Fitness & Lifestyle Research Institute, 2009).

Although PA levels in Canada are increasing (Craig et al., 2004), there are still far too few Canadians participating in PA. One reason for this is a decrease in casual physical activity that used to be part of everyday life (Winston et al., 2001). Active travel (AT), defined in this study as walking for the purpose of travel, is one type of casual physical activity that continues to decline. In 2004, only 67% of the Canadian population walked to a destination at least once during the year (Cragg et al., 2006). While these numbers are high, an assessment of regular participation demonstrates the lack of regular AT as only 36% of Canadians walked to a routine destination on a regular basis (Cragg et al., 2006).

In order to better understand what factors influence the decision of an individual to use AT, this dissertation adapts a conceptual framework from the PA literature. The conceptual framework groups the various factors found to be related to AT into three environments: individual, physical, and social environments (Giles-Corti and Donovan, 2002, Cleland et al., 2010). While these environments have been examined individually in the past, this dissertation focuses on measurement issues and gaps in the literature for each environment. Understanding how the individual, physical and social environments influence AT allows researchers and policy makers to recommend more targeted policy that may increase AT use among urban residents.

1.1.1. Individual Environment

The individual environment refers to how socio-demographics and intrapersonal factors of individuals influence walking behaviour. Socio-demographic variables are primarily used in the literature to control for the underlying characteristics of the population and to see how personal characteristics influence walking. Four socio-demographic variables are consistently found to be related to walking: age (Harrison et al., 2007, Mendes de Leon et al., 2009), sex (Owen et al., 2007, Harrison et al., 2007, Booth and Owen, 2000), owning a driver's license (Clark et al., Under Review, Copperman and Bhat, 2007), and educational attainment (Ball et al., 2001, Clark et al., Under Review). The intrapersonal factors examined in the PA literature are preference and self-efficacy. Preference is defined as the desire and interest of an individual to walk, while self-efficacy is defined as the degree to which an individual believes he or she can walk (Bandura, 1977). These intrapersonal factors are found to significantly influence PA participation

(Ball, 2006), but researchers rarely use preference and self-efficacy as factors influencing AT. This may be a result of AT researchers not having the proper data to evaluate intrapersonal factors related to walking.

While preferences and self-efficacy have not been measured directly, recent research has started to examine how potential barriers influence PA and AT (Spinney and Millward, 2010a, Dawson et al., 2007, Adachi-Mejia et al., 2010). While some of this research has focused on AT, most of the barrier literature is focused on overall PA. Barriers refer to the environmental and personal obstacles that discourage PA. Researchers have used the concept of barriers to determine what prevents certain sub-groups of the population from participating in PA, such as walking.

A weakness associated with the individual environment and its impact on AT is that barriers to AT have yet to be fully examined as they relate to the socio-demographic characteristics of people. While it can be argued that everyone has a barrier preventing them from using more AT, there are some barriers that are more prevalent to certain sub-groups of the population. By understanding the influence that different barriers to AT has on specific sub-groups, researchers and policy makers can create policy that target specific barriers and sub-groups in order to minimize the influence of the barrier and increase AT.

1.1.2. Physical Environment

The physical environment, more commonly referred to in the literature as the built environment (BE), refers to the urban landscape of a city or municipal area. Recently, research has focused on how the BE influence AT, due to the BE's ability to be modified through planning policy. While researchers agree that a relationship exists between AT and the BE, there are many uncertainties regarding the nature of the relationship. These uncertainties are due, in part, to the methodology used to conceptualize the BE.

The conceptualization of the BE is a complex procedure that has been examined by many researchers in the past. There are two overarching approaches that have been used to conceptualize the BE: aggregate and disaggregate. The most common aggregate approach used to conceptualizing the BE is a walkability index (Frank et al., 2010). The most common form of the walkability index used in the literature summates four standardized measures of the BE into a single index to evaluate the degree to which a neighborhood is walkable: residential density, street connectivity, land-use mixture, and retail floor area ratio (Frank et al., 2010). While there are many other walkability indices used in the literature (Manaugh and El-Geneidy, 2011), the overriding characteristics are the same.

Instead of using an aggregate approach, such as a walkability index, to measure the BE, a disaggregate approach can be used. A disaggregate approach uses multiple measures of the BE individually to determine how they each relate to AT. By understanding how each individual BE variables relates to AT, policy makers are able to change policy to target changes in specific BE components. Over 50 disaggregate measures of the BE have been used in past work, but four are consistently found related to AT: population density (Boer et al., 2007, Braza et al., 2004, Kerr et al., 2006, Rodriguez and Joo, 2004, Ewing et al., 2004), land-use mix (Boer et al., 2007, Cervero and Duncan, 2003, Kerr et al., 2006, Krizek and Johnson, 2006, Ewing et al., 2004), street connectivity (Boer et al., 2007, Braza et al., 2004, Cervero and Duncan, 2003, Kerr et al., 2006, Ewing et al., 2004), and pedestrian infrastructure (Rodriguez and Joo, 2004, Ewing et al., 2004).

While both aggregate and disaggregate approaches can be used to conceptualize the BE, researchers have yet to compare and validate the two approaches. Failing to validate the aggregated walkability index provides researchers with little evidence as to the individual component of the index responsible for AT use. Policy makers may also make inaccurate assumptions regarding the true relationship between AT and the BE when they are unable to understand how each component of the index is related to AT.

Regardless of whether an aggregate or disaggregate approach is used to conceptualize the BE, deciding on what scale and zone to measure the BE is a difficult decision due to the different options found in the literature. The review by Brownson et al. (2009) finds 18 different scales used to measure the BE in three different zones, including buffers around the home, continuous grids across the city, and administrative areas. Although most of the scales find the BE and AT significantly related, the extent of the relationship is still unknown due to the inconsistent use of scale when measuring the BE.

The variety of geographical scales used to measure the BE increases the likelihood that the modifiable areal unit problem (MAUP) created bias in the findings of previous studies. MAUP is defined as “a problem arising from the imposition of artificial units of spatial reporting on continuous geographical phenomenon resulting in the generation of artificial spatial patterns" (Heywood, 1998). Although issues of MAUP as it relates to the relationship between AT and the BE has been examined in the past (Zhang and Kukadia, 2005, Mitra and Buliung, 2011, Duncan et al., 2010, Forsyth et al., 2007), there are still two weaknesses that need to be addressed in the current literature. First, there has been no evaluation of how MAUP influences the 18 different scales used to conceptualize the BE over the three zones. Second, there has yet to be a study examining how MAUP influences AT for adults.

1.1.3. Social Environment

The social environment refers to the influence friends and family can have on an individual's walking. Researchers have only started examining how the social environment influences walking (Cleland et al., 2010, Hohepa et al., 2007, Mendes de Leon et al., 2009), but there is a well-established relationship between the social environment and PA (Trost et al., 2002, Ball, 2006). From the PA literature, four themes of the social environment emerge (Hohepa et al., 2007) and were adopted to walking: companionship, encouragement, neighborhood social cohesion, and role models. The first theme of the social environment is walking companionship, which refers to walking with other people rather than alone. Companionship has not been examined in relation to AT, but regardless of the companion, research has found companionship to significantly increase PA participation (Ball et al., 2001, Cleland et al., 2010, Cutt et al., 2007, Giles-Corti and Donovan, 2002, Harley et al., 2009).

The second social environment theme is encouragement, which occurs when family, friends, or other acquaintances promote walking. Promotion occurs when people compliment improved physical appearance that is the result of exercise (Booth and Owen, 2000) or when feedback is given regarding participation in walking (Booth and Owen, 2000, Cleland et al., 2010, Darlow and Xu, 2011, Hohepa et al., 2007). Past work has found that encouragement can significantly increase AT (Cleland et al., 2010, Hohepa et al., 2007).

The third theme of the social environment is neighborhood social cohesion. The social cohesion of a neighborhood is determined by the amount a neighborhood is socially interconnected and residents feel like they belong. The cohesion of a neighborhood is measured through likert scale questions used to understand the friendliness and sociability of a neighborhood. Social cohesion is a popular topic in the transportation literature, including a well-established influence on AT (Mendes de Leon et al., 2009, Whalen et al., 2012, McDonald, 2007, Páez and Whalen, 2010).

The final theme of the social environment is role model. Role models, in regards to walking, are people who walk and whose own participation encourages other to become involved. Walking has yet to be related to role models, but PA research shows that there are many types of role models and they all play a part in increasing participation. Role models can be people close to the person such as friends, family, romantic partner, and co-workers or they can be strangers whose PA participation can increase activity levels such as professional athletes. Past research has found role models increase participation in PA (Booth and Owen, 2000, Darlow and Xu, 2011, Giles-Corti and Donovan, 2002, Harley et al., 2009).

The social environment has yet to be fully examined by transportation researchers as it relates to AT. Of the few studies that have related AT to the social environment, none have incorporated all four social environment themes. By examining all four themes of the social environment, researchers are able to better understand how the social landscape of an individual affects AT. Furthermore, the social environment has always been examined on its own without also evaluating the individual and physical environments. By factoring how all three environments (individual, physical, and social) relate to AT, allows researchers to fully understand how the neighborhoods plays a part in the decision to use AT.

1.2. Research Objectives

The primary research objective of this dissertation is to address the weaknesses and gaps from the literature discussed above to gain a better understanding of how the individual, physical, and social environments influence AT. Understanding how the three environments influence AT provides methodological and policy recommendations that researchers and policy makers can use to better evaluate AT. In order to meet the primary objective, several research questions need to be understood.

The first research question asks, *how does the relationship between AT and the BE change when conceptualization of the BE changes from an aggregate to disaggregate approach?* The results of the multi-level model used in Chapter 2 will provide evidence to compare how the model results differ when conceptualizing the BE using aggregate versus disaggregate approaches. The conclusions will also discuss the implications of using a walkability index to make urban planning policy decisions.

The second research question asks, *how much influence does the zone and scale effects of MAUP have on the relationship between AT and BE among adults?* The influence of MAUP has been examined in the past but Chapter 3 presents a unique systematic analysis that examines the BE using 14 different scales among 3 different zoning types. This analysis provides evidence to help further the understanding of how each scale used to conceptualize the BE in past literature is influenced by MAUP.

The third research question asks, to *what extent does the four components of the social environment influence AT while controlling for the individual and physical environments?* The adaptation of the conceptual framework from the PA literature provides a foundation for which to examine AT. Specifically, examining the social environment using four individual components, including companionship, encouragement, role models, and social cohesion, allows a more in-depth understand of the true impact the social environment has on AT participation.

The final research question asks, *how are sub-groups of the population influenced by barriers to AT?* Understanding the influence different barriers to AT have on specific sub-groups allows researchers and policy makers to create policy that target specific barriers and sub-groups in order to minimize the influence of the barrier and increase AT.

1.3. Description of Data

1.3.1. Space-Time Activity Research Project Data

The data for Chapters 2 and 3 of this dissertation come from the Space-Time Activity Research (STAR) Project collected in the Halifax Regional Municipality (HRM), Nova Scotia from April 2007 to May 2008. Detailed descriptions of the survey design can be found elsewhere (Spinney and Millward, 2010b). A summary of the study design follows. The objective of the Halifax STAR project was to collect information from individuals about the location and timing of activities across the urban landscape of HRM. Households were selected randomly with each member of the household over the age of 5 asked to participate in the study. One subject aged 15 or more from each household was selected randomly as the primary respondent. The data collection surveyed 1971 households with a response rate of 21%.

The STAR project dataset was collected through an up-front interview and a two-day time use diary. The up-front interview required subjects to complete a CATI phone survey that asked about personal and household socio-demographic characteristics and neighborhood characteristics. A two-day time use diary was collected using two methods: a GPS-prompted recall diary and traditional time use diary. Primary respondents were tracked using a passive-GPS tracking device and asked to fill out a memory jogger to assist them in remembering their daily schedule. The GPS data were then used for the prompted recall diary, which was completed over the phone using a CATI technique that uses a map of the GPS data to assist the interviewer in prompting the respondents' recall attributes of activities and trips done throughout the two day study (Spinney et al., 2012). All other respondents used a traditional pen and paper survey to record their activities and trips for the two days.

Chapters 2 and 3 of this dissertation focus on the primary respondents who completed at least one trip during the first day of the study, which leaves a final sample of 1855 subjects living in 84 census tracts. A socio-demographic profile of these respondents can be found in

Table 3. The first day of the data collection has been selected as every subject completed the first day of the study whereas not every subject completed the second day.

Table 1: Descriptive statistics for the Space-Time Activity Research Project Dataset

Variables	Sample Statistics
# of Individuals (n)	1855
Walking for Travel (%)	34.5%
Age, mean (s.d.)	52.01 (13.55)
Household Size, mean (s.d.)	2.780 (1.220)
Number of Cars per Licensed Driver, mean (s.d.)	0.801 (0.378)
Sex - Male (%)	47.0%
Completed Post Secondary Degree (%)	69.8%
Driver's License (%)	95.8%
Bus Pass (%)	4.7%
Student Status - Full Time or Part Time (%)	2.7%
Employment Status - Full Time or Part Time (%)	67.7%
Household Income (%)	
Under $20,000	1.9%
$20,000 to $39,999	10.3%
$40,000 to $59,999	14.3%
$60,000 to $79,999	15.8%
$80,000 to $99,9999	13.2%
Over $100,000	29.3%
Missing Income	15.1%
Participated in STAR on Weekday (%)	76.3%

1.3.2. Hamilton Active Living Study data

The data used for Chapters 4 and 5 in this dissertation come from the Hamilton Active Living Study (HALStudy). The purpose of the HALStudy was to learn about people's participation in physical activity and the barriers preventing people from participating in additional physical activity. The sample was collected from May to September of 2010 in Hamilton, Ontario, Canada. Hamilton is a city of 540,200 people located southwest of Toronto on Lake Ontario. In order to ensure that people living in various types of neighborhoods were sampled in this study, thirty neighborhoods in urban and suburban Hamilton were selected based on their walkability using a stratified random sampling design. Walkability is defined as the "extent to which characteristics of the built environment and land-use may or may not be conducive to residents in the area walking for either leisure, exercise, or recreation, to access services, or to travel to work" (Leslie et al., 2007).

After acquiring phone lists for each neighborhood, the phone numbers were randomized and cold calls were made to acquire ten subjects from each neighborhood. Although the neighborhood-based approach was the focus, participants were not restricted based on the location of their residence. All subjects willing to participate were invited to do so. As a result, the final dataset had 201 subjects living in 40 neighborhoods. A full socio-demographic profile of respondent characteristics can be found in The time-use diary with passive GPS tracking collected detailed accounts of the activities and trips of a participant during the seven-day study period. The GPS tracking was completely passive only requiring participants to charge the device nightly and to ensure they carried the device for the seven days of the study. The device used was the QStarz BT-Q1000X travel recorder and it recorded a point every 5 seconds. The time-use diary asked subjects to record every activity and trip for the seven days of the study. Details included start time, end time, activity type, mode, and involved persons. Subjects were only asked to include activities over 5-minutes of duration. All trips and legs of trips were recorded, regardless of their length. For instance, walking to a bus stop, waiting for a bus, riding the bus, walking to work from the bus stop were all recorded in the diary. The combination of GPS data and time-use diary allows a complete picture of the activities and trips over the seven days.

Table 2 of the sample used in this dissertation.

There were three components to the HALStudy: an upfront interview, a 7-day time-use diary with GPS tracking, and a personal questionnaire. The upfront interview required the participant to meet with a research assistant (RA). First, the RA asked the participant to draw their neighborhood on a tablet using a tablet mapping program called ESRI ArcPad®. Using this tool, participants drew what they considered their neighborhood on a map and the drawings were saved for future analysis. Second, the researcher measured the participant's height using a SECA Stadiometer and weight using a digital scale. The height and weight measurement allowed a body mass index (BMI) to be calculated. Finally, instructions were given on how to fill out the personal questionnaire, the time-use diary, and use the global positioning system (GPS) data logger.

The time-use diary with passive GPS tracking collected detailed accounts of the activities and trips of a participant during the seven-day study period. The GPS tracking was completely passive only requiring participants to charge the device nightly and to ensure they carried the device for the seven days of the study. The device used was the QStarz BT-Q1000X travel recorder and it recorded a point every 5 seconds. The time-use diary asked subjects to record every activity and trip for the seven days of the study. Details included start time, end time, activity type, mode, and involved persons. Subjects were only asked to include activities over 5-minutes of duration. All trips and legs of trips were recorded, regardless of their length. For instance, walking to a bus stop, waiting for a bus, riding the bus, walking to work from the bus stop were all recorded in the diary. The combination of GPS data and time-use diary allows a complete picture of the activities and trips over the seven days.

Table 2: Summary statistics for the Hamilton Active Living Dataset

Variables	**Sample Statistics**
Duration Walking for Travel, mean (s.d.)	88.444 (150.6)

Age	
Young Adults (18-30)	16.2%
Middle Ages (31-64)	62.0%
Senior Citizens (65+)	21.8%
Female	69.3%
Income Classification	
Income Poor	14.0%
Intermediate Income	33.5%
Income Rich	22.3%
Missing Income	30.2%
Marital Status - Single	39.7%
Parent of Child(ren)	31.3%
Driver's License Ownership	85.5%
Public Transit Pass Ownership	17.3%
Currently a Student	17.9%
Currently Employed	52.5%
Walkability Index, mean (s.d.)	0.000 (3.826)
Body Mass Index, mean (s.d.)	27.380 (6.851)

The personal questionnaire on active living was a detailed survey about all types of physical activity, including exercise, organized and unorganized sport, walking, bicycling, and active video games. Each of the physical activity sections asked questions about participation level in the physical activity, perceptions of the activity, and barriers to the physical activity. Additional sections of the questionnaire asked about perceptions of physical activity, perceptions of neighborhood, travel behavior preferences, and socio-demographic information.

1.4. Dissertation Contents

The remainder of this dissertation is organized as follows. Chapter 2 examines how the BE and weather conditions relate to the propensity to use AT. The HRM in Nova Scotia, Canada is the study area for this work. Data are derived from three sources: a socio-demographic questionnaire and a GPS-enhanced prompted recall time-use diary collected between April 2007 and May 2008 as part of the Halifax STAR project, a daily meteorological summary from Environment Canada, and a comprehensive GIS dataset from HRM. A binary multilevel model is used to examine how the propensity to use AT is influenced by the BE and meteorology while controlling for socio-demographic characteristics. The results indicate measures of the BE and meteorology are associated with the propensity to use AT.

Chapter 3 examines how the relationship between AT and the BE is influenced by the MAUP. The methodology compares the BE, as measured at 16 different geographic scales, to a binary measure of AT using a logit model with a dataset on from Halifax, Canada. The objective of this chapter is to determine if the scale and zone effects of MAUP influence the BE variable coefficients and significance between models. The results find that the relationship between AT and the BE are influenced by both scale and zonal effects of MAUP, which lead to a set of guidelines that can be used to select an appropriate scale to measure the BE to minimize the influence of MAUP. Future research needs to provide a better understanding of the conceptualization of a neighborhood to more accurately measure the BE.

Chapter 4 adapts a conceptual framework from the physical activity literature to examine how AT is related to the social, individual, and physical environments. The dataset used in this study is from the Hamilton Active Living Study in Hamilton, Canada. The data, collected from May to September 2010, uses socio-demographics, likert-scale questions about the social environment, and the duration of weekly walking for the 179 participants as recorded in the seven-day time-use diary. A series of linear regression models examine how four components of the social environment – namely, companionship, encouragement, role models, and neighborhood social cohesion - influence AT duration while controlling for the individual and physical environments. The results find that of the four components only role models and neighborhood social cohesion influence AT duration. Despite finding, in past literature, that many aspects of the social environment are related to different types of physical activity, in this study, the social environment has a limited impact on the duration of weekly AT.

Chapter 5 examines how the barriers to walking influence AT using data collected from 179 randomly-chosen adults in Hamilton, Canada. The survey used for this task asked questions about socio-demographics, walking, and barriers to walking. A series of binary logit model are used in this study to examine how population characteristics are affected by twenty perceived barriers to AT. Modeling potential barriers to walking finds different sub-groups of the population are influenced by different barriers. Females, senior citizens, and those with a higher body mass index identify the most barriers to walking, while young adults, parents, those owning a license, and those owning a bus pass identify the fewest barriers to walking. In conclusion, despite walking being a type of physical activity that is easy for all ages, very few people use AT on a regular basis. Furthermore, those who do use AT, do so infrequently. Understanding who is affected by barriers can help policy makers target sub-groups of the population in order increase AT.

Finally, Chapter 6 summarizes the contributions this dissertation makes to better understanding how the individual, physical, and social environment influences walking for travel. Additionally, this chapter discusses what future direction this research should take.

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Chapter 2 Examining the Relationship between Active Travel, Weather, and the Built Environment: A Multilevel Approach using a GPS-enhanced Dataset

2.1. Introduction

Physical inactivity is one the greatest challenges facing health care providers and policy makers today. Physical inactivity leads to health problems, such as asthma, obesity, high blood pressure, heart disease, and diabetes (U.S. Department of Health and Human Services, 1996), which cost the Canadian health care system $5.3 billion in 2010 (Canadian Fitness and Lifestyle Research Institute, 2010). These costs, born by society, have led health care providers and policy makers to encourage Canadians to become more active. Despite efforts to promote physical activity, only 52% of Canadians are active (Canadian Fitness & Lifestyle Research Institute, 2009). Furthermore, only 48% of Canadians are getting a moderate amount of physical activity (Canadian Fitness & Lifestyle Research Institute, 2009).

Although physical activity levels in Canada are increasing (Craig et al., 2004), there are still far too few Canadians participating in physical activity. One reason for this is a decrease in casual physical activity that used to be part of everyday life (Winston et al., 2001). Active travel (AT), defined as walking for the purpose of travelling, is one type of casual physical activity that continues to decline. In 2004, only 67% of the Canadian population walked to a destination at least once during the year (Cragg et al., 2006). While these numbers are high, an assessment of regular participation demonstrates the lack of regular AT as only 36% of Canadians walked to a routine destination on a regular basis (Cragg et al., 2006).

A priority of health care providers and policy makers is to increase physical activity participation, which can be accomplished by making AT a routine type of activity. Before making policy changes to increase AT, policy makers need to understand the factors that influence the use of active modes of travel. Previous research has shown that many factors affect AT in an urban environment, including objective and perceived measures of the built environment (BE) (Cervero and Duncan, 2003, Frank et al., 2010, Guo et al., 2007, Rutt and Coleman, 2005, Brownson et al., 2009), safety concerns (Alton et al., 2007, Carver et al., 2005), social interaction (Ball et al., 2001, Carver et al., 2005), and meteorology (Cervero and Duncan, 2003). Although these factors relate to AT, the BE is critical because its features can be controlled through planning policy (Frank and Engelke, 2001). This study identifies factors that affect the propensity (likelihood) to use active modes of travel on a daily basis in an effort to understand the relationship between AT and the BE. Despite the fact that researchers acknowledge that a relationship exists between AT and the BE, there is a lack of consensus about the extent of the relationship (Handy, 2005, Saelens and Handy, 2008). The lack of consensus exists due to differences in the methods used to measure both AT and the BE and the methods used to examine the relationship leading to few consistencies found in the results.

This study addresses the relationship between AT and the BE with a binary multilevel model using measures of the BE found to be significant in past research. AT is measured using a binary variable indicating whether an individual walks for travel (1) or not (0). A binary variable is used to find elements of the BE that policy makers can potentially target to increase the propensity of an individual to use active modes of travel. For instance, if pedestrian infrastructure is found to increase AT, policy makers can change policy to increase the number of sidewalks in the neighborhoods. The BE variables are measures that have been consistently found to be significant in past work and are measured at the census tract level: population density, street connectivity, land-use mix, pedestrian infrastructure, and retail floor area ratio. Meteorology is used as an explanatory variable to determine if weather conditions play a significant role in the decision to walk. Little is known about the relationship between walking and meteorology as it has been ignored in the majority of past research. Finally, the model controls for socio-demographic characteristics.

The sample for this study consists of 1855 people living in 84 census tracts in the Halifax Regional Municipality (HRM), Nova Scotia, Canada. HRM is a municipality with defined urban, suburban, and rural land-use patterns making Halifax a representative North American city. Evaluating the BE at the census tract level is useful as it allows the influence of the neighborhood to be addressed while smaller delineations, such as buffers around the home, account for more local effects. For modeling, the census tract is an exogenous level of geography allowing for independent modeling. Selecting the census tract as the geography to measure the BE leads to the use of a multilevel model to analyze the relationship between AT and the BE (Alfonzo, 2005). Using a multilevel model takes into account the inherent geography in the data and corrects the standard error of model coefficients (Kreft and De Leeuw, 1998).

The study makes the following contributions to the literature. Using a multilevel model to examine the relationship between AT and the BE allows a better understanding geography has on the relationship. Second, examining meteorology variables as explanatory variables in the model allows policy makers to understand whether BE can even make a difference in cities where there are extreme weather conditions. Third, the combination of BE variables used in this study is unique as this study combines variables that were found to be significant in past literature. Finally, this study compares how the model results differ when conceptualizing the BE using individual components versus a single walkability index and discusses the implications of using a walkability index to make urban planning policy decisions.

The next section of this paper reviews literature examining the relationship between AT and the BE to establish aspects of the BE that relate to AT. The methodology section describes the data collection process, variables, and modeling approach used for the analysis. The results section discusses the model specification and presents the results of the models. Finally, the conclusion summarizes the key findings and discusses their importance in the context of the literature and the implications they have on policy.

2.2. Background

Recent research has focused on the relationship between AT and the BE. While researchers agree that a relationship exists, there are many uncertainties regarding the nature of the relationship. These uncertainties are due to the various measures and methods used to evaluate the relationship between AT and the BE. Often, studies use different measures of AT, the BE, and analysis methods to examine the relationship. This section reviews past research to establish how past work influences the current study.

Recent work by Frank et al. (2010) describes the development of a walkability index to examine the relationship between AT and the BE. The walkability index incorporates four different measures of the BE into a single index to evaluate the degree to which a neighborhood is walkable: residential density, street connectivity, land-use mixture, and retail floor area ratio. The neighborhood is measured as a one-kilometer buffer around the household of each subject with a single value representing the entire walkability. The linear regression model developed by Frank et al. finds a significant positive relationship between walkability and the number of minutes spent per day using active modes of travel in King County, WA.

Other authors have incorporated Frank's method of measuring the BE (Leslie et al., 2007, Owen et al., 2007). Leslie et al. examine the validity of the walkability index to represent the degree to which a census division is walkable. The results show the walkability index as a valid measure to determine the walkability of a census division. The study also found residents of high and low walkable census divisions can perceive the differences between the extremes, meaning that residents are influenced by the BE around them.

Owen et al. built on the work by Leslie et al. by examining the relationship between frequency of weekly walking for transport and the walkability index using a multilevel model with individuals living within census divisions. The study found a significant relationship between walking behavior and the walkability index measured at the census division level.

A review of different walkability indices by Manaugh and El-Geneidy (2011) shows that there are some differences between indices, but the overriding characteristics are the same. The benefit of the walkability index is that the index can evaluate the degree AT is influenced by the walkability of a neighborhood. Using a single index to represent the BE also simplifies the model by identifying neighborhoods with high or low walkability along with avoiding modeling issues such as interactive variables and spatial multicollinearity. A weakness of the walkability index is that policy makers are unable to determine the individual components of the index responsible for AT use. Policy makers may also make inaccurate assumptions regarding the true relationship between AT and the BE when they are unable to understand how each component of the index is related to AT.

Instead of using a walkability index to measure the BE, a more disaggregate approach can be used. A disaggregate approach takes individual measures of the BE into a model to determine how each measure of the BE relates to AT. This approach allows researchers to identify specific measures of the BE as barriers to AT making it possible to change policy in order to target specific components of the BE.

Initially, researchers, such as Cervero and Duncan (2003), used quasi-disaggregate approaches of measuring the BE by using a factor analysis to join together related measures of the BE. Cervero and Duncan used a binomial choice model to identify the probability that an individual will choose to walk to different destinations within 15 minutes of their home. The final BE measures were created from 18 different individual BE measures that were measured using a one-mile and five-mile buffer around the home. The results of the factor analysis provided four main measures of the BE: land use intensity, land-use mixture, land-use accessibility, and walking quality. When including these measures of the BE in a binomial choice model only land-use mixture is found to significantly increase the probability of walking.

More recently, researchers have used approximately 50 disaggregate measures of the BE to measure the relationship between AT and the BE, which can be found in various reviews focusing on AT (Brownson et al., 2009, Crane, 2000, Saelens and Handy, 2008). Despite these findings there are only a few BE variables commonly found to be related to AT. Rutt and Coleman (2005) examine the relationship between walking, as defined by frequency of walking trips during the last month, with the BE using stepwise regression. The BE is measured using a quarter-mile radius around the home with land-use diversity found to increase the frequency of walking trips. Guo et al. (2007) examine the probability of making a non-auto trip using a bivariate ordered probit model. The BE is measured at a one-mile and quarter-mile buffers around the home with population density (1-mi) being found to significantly increase the probability of making a discretionary non-auto trip. A review by Brownson et al. (2009) summarized the literature examining the relationship between the BE and AT to identify the BE variables that are consistently found related to AT. The results of the review find four disaggregate variables consistently related to AT: population density (Boer et al., 2007, Braza et al., 2004, Kerr et al., 2006, Rodriguez and Joo, 2004, Ewing et al., 2004), land-use mix (Boer et al., 2007, Cervero and Duncan, 2003, Kerr et al., 2006, Krizek and Johnson, 2006, Ewing et al., 2004), street connectivity (Boer et al., 2007, Braza et al., 2004, Cervero and Duncan, 2003, Kerr et al., 2006, Ewing et al., 2004), and pedestrian infrastructure (Rodriguez and Joo, 2004, Ewing et al., 2004).

2.3. Data and Methodology

2.3.1. Data

The data for this study comes from the Space-Time Activity Research (STAR) Project collected in HRM from April 2007 to May 2008. Detailed descriptions of the survey design (Spinney and Millward, 2010), and a socio-demographic profile of respondent characteristics (Millward and Spinney, 2011), are reported elsewhere. A summary of the study design follows. The objective of the Halifax STAR project was to collect information from individuals about the location and timing of activities across the urban landscape of HRM. Households were selected randomly with each member of the household over the age of 5 asked to participate in the study. One subject aged 15 or more from each household was selected randomly as the primary respondent. The data collection surveyed 1971 households with a response rate of 21%.

The STAR project dataset was collected through an up-front interview and a two-day time use diary. The up-front interview required subjects to complete a CATI phone survey that asked about personal and household socio-demographic characteristics and neighborhood characteristics. A two-day time use diary was collected using two methods: a GPS-prompted recall diary and traditional time use diary. Primary respondents were tracked using a passive-GPS tracking device and asked to fill out a memory jogger to assist them in remembering their daily schedule. The GPS data were then used for the prompted recall diary, which was completed over the phone using a CATI technique that uses a map of the GPS data to assist the interviewer in prompting the respondents' recall attributes of activities and trips done throughout the two day study (Spinney et al., 2012). All other respondents used a traditional pen and paper survey to record their activities and trips for the two days.

This study focuses on the primary respondents who completed at least one trip during the first day of the study, which leaves a final sample of 1855 subjects living in 84 census tracts. The first day of the data collection has been selected as every subject completed the first day of the study whereas not every subject completed the second day.

2.3.2. Concepts and Measures

2.3.2.1. Dependent Variable

The dependent variable in this analysis is a binary measure of AT, which indicates whether an individual walks during the day of study (1) or not (0). Using a binary measure of AT in modeling will measure the propensity or likelihood of walking. Statistics show that Canadians do not regularly use active modes of travel (Cragg et al., 2006), so this study is using a binary variable to determine what aspects of the BE could encourage people to use AT regularly.

2.3.2.2. Individual Level Variables

Three groups of individual level variables are used in this study: socio-demographic, meteorology, and the BE (see

Table 3). The socio-demographic variables control for any confounding effects that would alter the relationship between AT and the BE. The variables used were collected from the CATI interview and include sex (female as reference), age, household size, household income (over $100,000 as reference), and number of cars per licensed driver. An additional variable is also added to control for

Table 3: Descriptive statistics of independent variables

Independent Variables	**Sample Statistics**
Census Tract Level	
# of Census Tracts (n)	84
Built Environment	
Pedestrian Infrastructure (×10), mean (s.d.)	3.851 (5.620)
Retail Floor Area Ratio(×10), mean (s.d.)	2.720 (2.054)
Population Density ($\times 10^{-3}$), mean (s.d.)	1.856 (1.804)
Land-Use Mix (×10), mean (s.d.)	6.549 (1.192)
Street Connectivity (×10), mean (s.d.)	2.222 (1.547)
Individual Level	
# of Individuals (n)	1855
Socio-Demographic	
Age ($\times 10^{-1}$), mean (s.d.)	5.201 (1.355)
Household Size, mean (s.d.)	2.780 (1.220)
Number of Cars per Licensed Driver, mean (s.d.)	0.801 (0.378)
Sex - Male (%)	47.0%
Completed Post Secondary Degree (%)	69.8%
Driver's License (%)	95.8%
Bus Pass (%)	4.7%
Student Status - Full Time or Part Time (%)	2.7%
Employment Status - Full Time or Part Time (%)	67.7%
Household Income (%)	
Under $20,000	1.9%
$20,000 to $39,999	10.3%
$40,000 to $59,999	14.3%
$60,000 to $79,999	15.8%
$80,000 to $99,9999	13.2%
Over $100,000 (Reference)	29.3%
Missing Income	15.1%
Participated in STAR on Weekday (%)	76.3%
Weather	
Mean Temperature, mean (s.d.)	7.304 (9.430)
Total Precipitation, mean (s.d.)	4.271 (9.630)
Maximum Wind Speed ($\times 10^{-1}$), mean (s.d.)	4.337 (1.509)
Built Environment	
Distance from Home to Work/School in km, mean (s.d.)	5.130 (10.771)

participation on a weekend compared to a weekday. Binary socio-demographic variables and their definitions are as follows:

- Education level - respondent had graduated with at least a post-secondary degree (1) vs. attended college or university without a degree or lower education level (0)
- Bus pass - respondent had a bus pass at time of survey (1) vs. no bus pass (0)
- Driver's license - respondent had a driver's license at time of survey (1) vs. no driver's license (0)
- Employment status - respondent had a full time or part time job at time of survey (1) vs. no job or retired (0)
- Student status - respondent is a full time or part time student at time of survey (1) vs. not a student of any kind (0)

Distance from home to work or school is the only BE variable measured at the individual level. The measure is based on the shortest path distance in kilometers between home and either work or school. Distance measures were only derived for those respondents who either worked or attended school on the first day of the survey, and all other subjects were given a distance of 0. The continuous distance measure is included in this study to capture the relationship between proximity to work or school and walking.

2.3.2.3. Census Tract Level Variables

All variables measured at the census tract level are measures of the BE. The BE variables are selected based on the finding of being significantly related to AT in past literature. When examining past literature, the walkability index developed by Frank et al. (2010) is consistently found to significantly increase AT regardless of the study area or scale. As a result, the four components of the walkability index are included in this model: population density, land-use mix, street connectivity, and retail floor area ratio. An exhaustive literature review by Brownson et al. (2009) confirm that population density, land-use mix, and street connectivity are consistently related to AT. The literature also finds pedestrian infrastructure (Cervero and Duncan, 2003, Brownson et al., 2009) significantly related to AT. While there are many other variables that have been found related to AT, such as fraction of commercial land use (Guo et al., 2007), accessibility to recreation (Guo et al., 2007), and physical activity accessibility (Rutt and Coleman, 2005) among many others, the five BE variables selected for this study are ones that have been consistently found related to AT.

The selected variables were developed in ArcGIS© 9.3.1 using the methodology found in *Standards for Environmental Measurement Using GIS* (Forsyth et al., 2006) using data provided by the HRM. The variables are:

- Population density - the number people living in a census tract per square kilometer
- Land-Use Mix - The degree to which a census tract has uniformly diverse land use. Ranges from 1 for completely diverse to 0 for only one land use. Land-use categories include residential, commercial, institutional, office, park and recreation, and industrial.
- Street connectivity - the ratio of number of four-way intersections to all intersections. Ranges from 1 for grid-like street structure to 0 for cul-de-sac street structure.
- Retail floor area ratio - measures the ratio of the area (m^2) of the building footprint to the area (m^2) of the parcel. Higher the ratio, the less store frontage is present, meaning there is less parking available for customers.
- Pedestrian infrastructure - the ratio of length of sidewalk in meters to length of road in meters. Higher the ratio, the more sidewalks are available for pedestrians.

These five BE variables are also combined into a walkability index based on the index developed by Frank, et al. (2006, 2010). Each BE variable is standardized into *z-score* to give each variable the same value in the same scale. After standardizing the variables they are summed to create a single walkability index.

2.3.3. Method of Analysis

A binary logit multilevel model is used to analyze the relationship between active travel and the BE to account for the ecological or hierarchical nature of the data. The model estimated in this study measures AT use of individuals living within census tracts. This multilevel model is estimated with STATA 11.0 SE (StataCorp, 2009) using the adaptive Gaussian quadrature (AGQ) method (Pinheiro and Chao, 2006). The approximation is computationally intensive, but avoids the biases of other estimation methods, such as penalized quasi-likelihood and marginal quasi-likelihood. All models are developed from the base null model presented in Equation 1.

[1] $$AT_{ij} = \beta_{0ij} + u_{0j},$$

where i represents the individual level,

j represents the census tract level,

AT_{ij} represents the use of active modes of travel (1) or not (0),

β_{0ij} is the intercept of the model,

μ_{0j} *is* the unexplained random intercept variance also known as the between census tract variance.

From the null model, a set of models are developed to identify the impact that each set of variables has on the random intercept effect and the log likelihood. The first additive model includes the socio-demographic variables added to the null model. The second additive model includes the socio-demographic variables and meteorology. The final two additive models add the BE variables at both the individual and CT level to the third model; one model using disaggregate BE variables and the other model using the walkability index representing the BE.

2.4. Results

2.4.1. Model Specification

As discussed previously, four additive models are specified for this study in order to determine the influence of each set of variables on AT. Model 1, the null model, determines if there is a significant difference in the propensity to use AT between census tracts. This model has a *log likelihood* of -1180.1492. The between census tract variance is found to be 0.282 with a *p-value* of 0.000, meaning there is a significant amount of unexplained variance between census tracts at the 95% significance level.

Model 2 adds the socio-demographic variables to Model 1 to control for the personal characteristics of the population surveyed. This model has a *log likelihood* of -1088.5719. Adding the socio-demographic characteristics account for 45.6% of the differences in AT use between census tracts. The between census tract variance is 0.153 and the *p-value* is 0.001, showing there is still significant unexplained variance between census tracts at the 95% significance level.

Model 3 adds the meteorology variables to Model 2 to identify elements of the weather that impact AT. This model has a *log likelihood* of -1066.4795. Adding the meteorology variables to the socio-demographic characteristics accounts for an additional 12.5% of the differences in AT participation between census tracts. The between census tract variance is 0.118 and the *p-value* is 0.005, showing there is still significant unexplained variance between census tracts at a 95% significance level.

Model 4a adds the disaggregate BE variables to Model 3 to identify specific attributes of the BE that impact AT. This model has a *log likelihood* of -1045.1400. Adding the BE variables to the socio-demographic and meteorology variables accounts for an additional 41.2% of the differences in AT participation between census tracts. The remaining between census tract variance is 0.002 with a *p-value* of 0.477, meaning that the combination of BE, meteorology, and socio-demographics accounts for all of the unexplained variance between census tracts when measured at a 95% significance level.

Model 4b adds the BE variables in the form of a walkability index to Model 3 to determine if the overall index representing the five different component of the BE impact AT. The model has a *log likelihood* of -1047.5152. Adding the walkability index to the socio-demographic and meteorology variables accounts for an additional 37.4% of the differences in AT participation between census tracts. The remaining between census tract variance is 0.013 with a *p-value* of 0.365, meaning that the combination of BE, meteorology, and socio-demographics accounts for all of the unexplained variance between census tracts when measured at a 95% significance level.

2.4.2. Model Results

The remainder of this paper focuses on Models 4a and 4b, the binary multilevel models relating AT use with socio-demographics, meteorology, and the BE (disaggregate variables versus walkability index), the results of which can be found in Table 4. These models show that variables from each of socio-demographics, meteorology, and the BE are significantly associated with an increase or decrease in the propensity to use active modes. It is important to note that the results for socio-demographics and meteorology are consistent regardless of the method used to measure the BE, thus only the BE section (2.4.2.3) will be discussing differences between models. The following sections describe how each set of variables is related to AT.

2.4.2.1. Socio-Demographic

Socio-demographic variables control for the underlying characteristics of the sample collected in this study. The variables are entered into the multilevel model at the individual level. Seven socio-demographic variables are found to be significantly associated with a change in propensity of AT: age, household size, household income as related to an income over $100,000, having a driver’s license, having a bus pass, being a full time employee, number of cars per licensed driver, and participation in STAR on weekday. Age is associated with a reduced propensity to use AT. AT is most easily done by those who are younger and as age increases there is less AT use. Living in a household with a higher number of people is associated with a reduced propensity to use AT. AT is a more difficult alternative as larger households may have more time constraints than those with smaller households. Having a driver's license and bus pass have expected relationships, in which having a driver's license is significantly associated with decreasing AT and having a bus pass is significantly associated with increasing AT. Household income between $60,000 and $79,999 is related to a significant decrease in AT compared to incomes 'over $100,000', while the rest of the income classes have no significant difference in the propensity to AT than those with incomes over $100,000. Being

Table 4: Results of Models 4a and 4b – binary multilevel model relating AT to meteorology and the BE while controlling for socio-demographics

Variables	*Model 4a* Odds Ratio	*95% Confidence Interval*		*p-value*	*Model 4b* Odds Ratio	*95% Confidence Interval*		*p-value*
Socio-Demographic Variables								
Age	0.862	0.770	0.965	p<0.050	0.861	0.770	0.964	p<0.010
Household Size	0.838	0.752	0.935	p<0.010	0.834	0.748	0.930	p<0.010
Household Income (Over $100,000)								
$60,000 - $79,999	0.675	0.482	0.945	p<0.050	0.670	0.479	0.937	p<0.050
Driver's License	0.341	0.190	0.613	p<0.001	0.585	0.418	0.818	p<0.010
Bus Pass	4.461	2.484	8.011	p<0.001	0.337	0.187	0.605	p<0.001
Employed - Full Time or Part Time	1.410	1.040	1.911	p<0.050	4.479	2.488	8.060	p<0.001
# of Cars per Licensed Driver	0.592	0.423	0.828	p<0.010	1.421	1.049	1.926	p<0.050
Participated in STAR on Weekday	1.975	1.501	2.599	p<0.001	1.997	1.517	2.628	p<0.001
Meteorology								
Average Temperature	1.024	1.012	1.037	p<0.001	1.024	1.012	1.037	p<0.001
Total Precipitation	0.985	0.971	0.998	p<0.050	0.986	0.972	0.999	p<0.050
Maximum Wind Speed	0.948	0.871	1.030	0.208	0.943	0.867	1.024	0.164
Built Environment								
Distance from Home to Work/School	1.007	0.997	1.018	0.166	1.007	0.997	1.017	0.192
Pedestrian Infrastructure	1.391	0.901	2.149	0.137	-	-	-	-
Retail Floor Area Ratio	1.048	0.974	1.128	0.213	-	-	-	-
Population Density	1.144	1.022	1.280	p<0.050	-	-	-	-
Land-Use Mix	1.025	0.923	1.140	0.641	-	-	-	-
Street Connectivity	1.024	0.891	1.176	0.739	-	-	-	-
Walkability Index	-	-	-	-	1.107	1.073	1.143	p<0.001

Note: Socio-Demographic variables found insignificant in both models are not included in the table.

employed is related to a significant increase in the propensity to use AT. This may be a result of those employed taking more trips than those who are unemployed, so they have more chances to make the decision to walk then other people. Higher number of cars per licensed driver is significantly associated with decreasing AT. The higher number of cars available to a driver means they are less likely to require to use alternative modes, such as walking, to travel therefore they do not walk. Participating is the STAR study on a weekday is significantly associated with an increase in the propensity to use AT, suggesting there is far less AT occurring on the weekend than during the traditional work week.

2.4.2.2. Meteorology

Meteorology variables included in the model examine how the weather in HRM impacts AT participation. Average temperature, total precipitation, and the amount of snow on the ground were all found to be significantly associated with AT. Average temperature is significantly associated with an increase in the propensity to use AT. This suggests there are seasonal patterns associated with AT where the warmer seasons increase the probability of using AT and colder seasons decrease the probability. An increase in daily precipitation is significantly associated with a decrease in the propensity to use AT.

2.4.2.3. Built Environment

Including the disaggregate BE variables in Model 4a provides the ability to identify aspects of the BE that impact the propensity to use AT. Of the BE variables added to this model, only population density is found to be significant at the 95% significance level. Population density is associated with a significant increase in the propensity to use AT, meaning that urban areas with higher number of apartments, town homes, and condos are friendlier to AT.

Evaluating the BE at a slightly lower level of significance is important to identify the BE measures that are moderately related with AT. By decreasing the significance level to 0.15, pedestrian infrastructure is found to be associated with an increase in AT. If there are fewer sidewalks to walk on within a neighborhood, there is very little chance of an individual walking. The other important consideration is that these sidewalks need to be going somewhere as sidewalks will not increase AT if they have no meaningful destinations.

Including the census tract walkability index in Model 4b provides the ability to identify how the BE influences AT when aggregated. The results find walkability index, which combines pedestrian infrastructure, retail floor area ratio, population density, land-use mix, and street connectivity, to be significant at the 95% significance level. Walkability index is associated with a significant increase in the propensity to use AT, meaning that people living in more walkable urban areas have a higher propensity to use AT.

2.5. Conclusions

This study has examined the relationship using a methodology that allows policy makers to better understand what elements of the BE increase the propensity for an individual to use AT. For instance, the between census tract variance found in the data is completely explained by the socio-demographic variables, components of meteorology, and the BE. As each set of variables is added, the model fit improves. After controlling for socio-demographics, components of meteorology and the BE are found to be significantly associated with AT explaining 20.6% of the variation found between census tracts.

Relating AT with meteorology finds that average temperature (positive) and total precipitation (negative) are both significantly associated with AT. It would be interesting to investigate the relationship between AT and meteorology in different climates as people may adapt to an environment if extreme weather is a regular occurrence.

After controlling for socio-demographics and accounting for meteorology, population density and pedestrian infrastructure are found to be significantly associated with an increase in the propensity to use AT. In contrast, using the walkability index to conceptualize the BE from the five BE variables used in this study is found to be significantly related to AT, which is in agreement with past work (Frank et al., 2006, Leslie et al., 2007, Frank et al., 2010, Owen et al., 2007). It is important to note that these results do not control for self-selection, which is when people who like to walk choose to live in an environment that is conducive to walking (Pinjari et al., 2007, Bhat and Guo, 2007). If this study did include self-selection, the influence of the BE on AT may be even less significant.

Comparing the results from these two measurement techniques has shown that using an index to measure the BE hides the fact that only two of the five BE variables are significant when measured individually. When making policy decisions regarding the BE, policy makers need to understand that walkability indices aggregately measure the BE and may lead to incorrect assumptions about the individual variables that make up an index. For example, changing all five components that make up the walkability index will increase AT in HRM, but targeting one feature of the BE will only increase AT in HRM if population density or pedestrian infrastructure is the feature targeted. Researchers need to validate the BE variables before including them in a walkability index. Simply using a walkability index already developed, such as the one by Frank et al. (2010), will usually find a significant relationship with AT, but interpreting the results for policy is difficult without the initial validation.

Overall, the findings of this study suggest that modifying components of the BE may increase the propensity to regularly use AT modes regardless of the methodology used to measure the BE. Despite these findings there are still numerous issues surrounding the relationship between AT and the BE that are not fully understood in the literature. Future work also needs to address these issues, including selecting a scale to measure the BE, self-selection, social influence, and striving to find causality. Future work should also use datasets that have more days of data. For example, examining the relationship between AT and the BE with a 7-day dataset would allow AT to be evaluated to gain a more accurate picture of travel behavior.

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Chapter 3 Understanding the impact of the modifiable areal unit problem on the relationship between active travel and the built environment

3.1. Introduction

Using the built environment (BE) to increase active travel (AT) is not a new concept. Researchers and policy makers have often used development strategies, such as smart growth, new urbanism, and transit-oriented development, to decrease dependency on the automobile and increase use of other more sustainable modes of travel (Cervero and Radisch, 1996). Most recently, researchers have focused on investigating how the BE influences the use of active modes of travel (Forsyth et al., 2007). The BE is critical in increasing AT as its features can be controlled through planning policy (Frank and Engelke, 2001).

A recent literature review by Brownson et al. (2009), examining the relationship between AT and the BE, discusses many examples of how AT is influenced by the BE. Although the BE is consistently found to be significant, there is inconsistency in the methodology used to measure the BE and evaluate the relationship. This leads researchers to question the true impact of the BE on AT (Handy, 2005). If the impact of the BE on AT is minimal, researchers and policy makers need to consider other areas to increase AT.

To better understand the relationship between AT and the BE, researchers hypothesize residential self-selection may decrease the true impact of the BE (Handy, 2005). This leaves researchers asking if people who use active modes of travel are choosing to reside in neighborhoods that are more condusive to AT (Cao et al., 2006). Other researchers are more concerned with understanding how the conceptualization of the BE influences the relationship between AT and the BE (Forsyth et al., 2006, Frank et al., 2010, Mitra and Buliung, 2011, Zhang and Kukadia, 2005). Although conceptualizing the BE seems like a simple process, researchers are still finding it difficult to create the perfect set of variables to represent how a city is designed.

The conceptualization of the BE is a complex procedure that has been examined by many researchers in the past. Frank et al. (2010), Forsyth et al. (2006), and Brownson et al. (2009) have helped standardize the methodology to measure the BE. Frank et al. have developed a walkability index by standardizing characteristics of the BE, including population density, street connectivity, land-use mix, and retail floor area, to create a standard metric. Forsyth et al. have standardized the methods used to measure the BE using Geographical Information System (GIS) software. Brownson et al. summarized the literature examining the relationship between AT and the BE to identify the BE variables that are frequently found to be related to AT. One aspect of conceptualizing the BE that has yet to be fully addressed in the literature is the geographic scale used to measure the BE.

Deciding on the geographic scale used to measure the BE is a difficult decision due to the different scales used in the literature. The review by Brownson et al. (2009) finds 18 different scales used to measure the BE, including buffers around the home, continuous grids across the city, and administrative areas. Although most of the scales find the BE and AT significantly related, the extent of the relationship is still unknown due to the inconsistent use of scale when measuring the BE.

The variety of geographical scales used to measure the BE increases the likelihood that the modifiable areal unit problem (MAUP) created bias in the findings of previous studies. MAUP is defined as “a problem arising from the imposition of artificial units of spatial reporting on continuous geographical phenomenon resulting in the generation of artificial spatial patterns" (Heywood, 1998). There are two components to MAUP: scale effects and zoning effects. Scale effects refer to the spatial aggregation of the zones used to aggregate the BE, while zoning effects refer to the configuration of the different zones given a fixed level of spatial aggregation. When using GIS as a tool to evaluate a problem involving aggregated data MAUP is inevitable. Understanding the impact of MAUP is important to minimize the effect on the results of a geographic analysis.

The purpose of this study is to examine how the relationship between AT and the BE is influenced by MAUP. Although MAUP, as it relates to AT and the BE, has been examined in the past (Zhang and Kukadia, 2005, Mitra and Buliung, 2011, Duncan et al., 2010, Forsyth et al., 2007), this study makes four contributions to the literature. First, unlike work by Duncan et al. and Forsyth et al. who focus on land-use mix and population density respectively, this study examines how MAUP influences the relationship between the BE and AT using multiple measures of the BE. Second, conceptualizing the BE with fourteen different scales allows this study to examine how the different scales and zones used in past literature are influenced by MAUP when related to AT. Third, all three types of zoning used in the literature are compared in this study, whereas Mitra and Buliung compare administrative zones with buffers and Zhang and Kukadia compare administrative zones with grids. Finally, this study focuses on adults' AT, whereas work by Mitra and Buliung focused on children's active travel and Zhang and Kukadia's work examined travel mode choice.

This study addresses two questions that have yet to be fully examined in the literature:

1) Does the scale effect of MAUP change the coefficients for the BE variables as they relate to the AT of adults?

2) Does the zoning effect of MAUP change the coefficients for the BE variables as they relate to the AT of adults?

To answer these questions, fourteen binary logit models are estimated, with the dependent variable indicating whether an individual uses active modes of travel (1) or not (0). These models include a set of socio-demographic variables to control for personal characteristics and a suite of BE variables that have been found to be significant in past work, including population density, street connectivity, land-use diversity, pedestrian infrastructure, and retail land-use ratio. Each model uses a different scale to construct the BE variables including buffers of 200-meters (m), 300-meters, 400-meters, 500-meters, 600-meters, 800-meters, 1000-meters, 1600-meters, and 3200-meters; continuous grids of 200-meters, 400-meters, 800-meters, and 1600-meters; and administrative areas consisting of census tracts and census dissemination areas. . These scales are selected as they have all been used in past studies to measure the BE.

The sample for this study consists of 1855 people residing in the Halifax Regional Municipality (HRM), Nova Scotia, Canada. HRM is a municipality with defined urban, suburban, and rural land-use patterns making Halifax a representative North American city. Since the scales of past studies have been inconsistent, the methodology used in this study allows for a systematic analysis of how changing the BE scales and zones change the results of the binary logit model.

The next section of this paper reviews the literature examining how MAUP changes the relationship between AT and the BE. The methodology section describes the data collection process, variables, and modeling approach used for the analysis. The results section discusses the model specification and presents the results of the models. Finally, the conclusion summarizes the key findings and discusses their importance in the context of the literature.

3.2. Background

There is a lack of consistency in the research regarding the BE. Recent research has attempted to address this gap by establishing some consistency in the methodology used to conceptualize the BE. Work by Forsyth et al. (2006) Frank et al. (2010) and Brownson et al. (2009) have standardized some of the conceptualization issues related to the BE. One problem yet to be understood is how the geographic scale used to measure the BE impacts the relationship between AT and the BE.

Selecting the correct geographic scale is important as the wrong scale can lead to biased results because of the heavy influence by MAUP. MAUP occurs when the geographic scales used to measure the BE are arbitrary and does not examine the underlying process present in the data. The results found in any analysis where MAUP is present may be the result of the zoning system (Miller, 1999) rather than the results analyzing the problem. MAUP was first documented by Gehlke and Biehl (1934) when finding a relationship between estimated correlation coefficients and the level of census geography. The effects of MAUP have been documented in a variety of geographic contexts including "the computation of correlation coefficients, regression analysis, spatial interaction modeling, location-allocation modeling, the derivation of various indices (e.g., segregation index D, excess commute) and regional economic forecasting" (Scott, 2008).

Avoiding the biases created by MAUP can increase reliability of the analysis and confidence in the results. Jelinski and Jianguo (1996) suggest five approaches for dealing with MAUP. First, a basic entity approach advocates using individual entities in analysis to avoid MAUP entirely. By analyzing data at the individual level, data never requires aggregation into areal units. Second, an optimal zoning approach maximizes variation between zones and minimizes variation within zones. Although optimal zones avoid variations in the results, the optimization is subjective and will change with the types of problems and methods used. Third, a sensitivity analysis approach can determine what variables are sensitive to the variations in scale and zoning configuration. By understanding the scale and zoning effects, it is possible to use a scale influenced the least by MAUP. Fourth, the development of new methods of analysis that are spatial in nature can avoid MAUP. These methods would be geographical and independent of areal units to avoid MAUP's influence. Finally, using spatial analysis to examine the rates of change of variables can determine the influence of MAUP by understanding if variables change when measured at different scales. If the variables are unchanged MAUP has no effect on the variables.

Like past work, the relationship between AT and the BE is influenced by the zoning and scale effects of MAUP (Zhang and Kukadia, 2005, Mitra and Buliung, 2011, Duncan et al., 2010, Forsyth et al., 2007). The key to selecting the appropriate scale is to understand how the choice of geographic scale impacts the relationship between AT and the BE. By examining the literature, it is apparent that there are three key issues that need to be understood before selecting the correct scale to conceptualize the BE. Understanding the geographic scales used in past literature to measure the BE allows an inventory so researchers can choose from the scales used in the past. By understanding the impacts of the scale effect and zoning effect on the relationship between AT and the BE, researchers can minimize the influence of MAUP.

Selecting the appropriate scale to conceptualize the BE has never been adequately addressed in the literature leaving at least 18 different scales used to represent the BE (Brownson et al., 2009). Although these scales are too numerous to describe in this paper, they show a lack of consistency in the method used to conceptualize the BE. Two studies have attempted to examine the general issue of geographic scale on the relationship between AT and the BE. Forsyth et al. (2007) is one of the first researchers to examine the impact MAUP has on the relationship between walking and the BE. Although they stop after finding a correlation between walking and density, the correlation exists regardless of the scale used to measure density. Duncan et al. (2010) take a different approach by controlling for scale by modifying the land-use entropy index to account for the relative size of the census division. They find there is a significant relationship between walking and land-use entropy index only after controlling for relative size of the census division. Despite these findings, there is still much information needed before it is possible to fully understand the impact MAUP has on the relationship between AT and the BE.

Understanding the impact the scale effect of MAUP has on the relationship between AT and the BE is another issue that needs to be addressed. Past work has only examined the scale effect in a cursory manner by comparing the change in significance and the general patterns found in the model coefficients (Mitra and Buliung, 2011, Zhang and Kukadia, 2005). Zhang and Kukadia found that as the scale increases, the coefficients decrease while Mitra and Buliung found no discernible pattern. Despite these findings, it is important to note whether the change in scale is significant, so it is important to check the significance by using a difference-in-means *t*-test (Fotheringham and Wong, 1991).

Understanding the impact the zoning effect of MAUP has on the relationship between AT and the BE is the final issue that needs to be addressed. The zoning effect of

MAUP refers to the configuration of different zones given a fixed size. For example, if a 1-km grid is the fixed size, the grid can be placed at many different angles to cover the area of interest. In past research, the zoning effect has been addressed by comparing different zonal categories of equal area (Zhang and Kukadia, 2005, Mitra and Buliung, 2011). For instance, Mitra and Buliung (2011) compare 250-meter buffers around a home to census dissemination areas and 800-meter buffers around a home to traffic analysis zones. Although they do have the same average area, the individual spatial aggregation of the dissemination areas is not the same as the 250-meter buffers, thus making it a pseudo-analysis of the zone effect of MAUP.

3.3. Data and Methodology

3.3.1. Data

The data for this study come from the Halifax Space-Time Activity Research (STAR) project, which was conducted in the Halifax Regional Municipality from April 2007 to May 2008. Detailed descriptions of the survey design (Spinney and Millward, 2010) and a socio-demographic profile of respondent characteristics (Millward and Spinney, 2011) are reported elsewhere. The objective of the Halifax STAR project was to collect information from individuals about the location and timing of activities across the urban landscape. Households were selected randomly with each member of the household over the age of 5 asked to participate in the study. One subject aged 15 or more from each household was selected randomly as the primary respondent. The data collection surveyed 1971 households with a response rate of 21%.

The STAR project dataset was collected through an up-front interview and a two-day time use diary. The up-front interview required the primary respondents to complete a Computer Assisted Telephone Interview (CATI) that asked about personal and household socio-demographic characteristics and neighborhood characteristics. A two-day time-use diary was collected using two methods: a GPS-prompted recall diary for primary respondents and a traditional time use diary for secondary respondents. Primary respondents were tracked using a passive GPS tracking device and asked to complete a memory jogger to assist them in remembering their daily schedule. The GPS data were then used for the prompted recall diary, which was completed over the phone using a CATI technique that uses a map of the GPS data to assist the interviewer in prompting the respondents to recall attributes of activities and trips done throughout the two-day study. All other respondents used a traditional pen and paper survey to record their activities and trips for the two days.

This study focuses on the primary respondents who completed at least one trip during the first day of the study leaving a final sample of 1855 subjects. Household locations are geocoded by street address. The first day of the data collection was selected as every subject completed the first day of the study.

3.3.2. Concepts and Measures

3.3.2.1. Dependent Variable

The dependent variable is a binary measure of AT, which indicates whether an individual biked or walked to a destination during the day of study (1 - used AT; 0 - did not use AT). Using a binary measure of AT in modeling measures the propensity or likelihood of using AT modes. It is important to examine the propensity to use AT modes as statistics show that Canadians do not regularly use active modes of travel (Canadian Fitness & Lifestyle Research Institute, 2009). Understanding the factors related to AT use can decrease car use and increase physical activity levels of the adult population.

3.3.2.2. Independent Variables

Two groups of independent variables are used in this study: socio-demographic and the BE (see Table 5). The socio-demographic variables are used in the models to control for the personal characteristics of the sample. The variables were collected from the CATI interview. The second group of independent variables used in this study are BE variables. The BE variables are selected based on the exhaustive literature review by Brownson et al. (2009). Brownson et al. find there are four variables that are most commonly found to be related to AT: population density, pedestrian infrastructure, street connectivity, and land-use mix. Another variable consistently found to be significant is the walkability index by Frank et al. (2010), which combines four BE variables into a single measure, including population density, street connectivity, land-use mix, and retail floor area ratio. The review

Table 5: Summary statistics of the socio-demographic control variables and built environment variables

Variables	Statistics
Age ($\times 10^{-1}$), mean (s.d.)	5.201 (1.355)
Household Size, mean (s.d.)	2.780 (1.220)
Number of Cars per Licensed Driver, mean (s.d.)	0.801 (0.378)
Male	47.0%
Post Secondary Degree Attained	69.8%
Driver's License Held	95.8%
Bus Pass Owned	4.7%
Full-time Student	2.7%
Full-time Employee	67.7%
Participated in Study on the Weekend	24.9%
Household Income	
Under $20,000	1.9%
$20,000 to $39,999	10.3%
$40,000 to $59,999	14.3%
$60,000 to $79,999	15.8%
$80,000 to $99,9999	13.2%
Over $100,000 (Reference)	29.3%
Missing Income	15.1%

Scale, Mean (s.d.)	**Area (km^2)**	**Population Density ($\times 10^{-3}$)**	**Entropy Index (×10)**	**Street Connectivity (×10)**	**Pedestrian Infrastructure (×10)**	**Retail Floor Area Ratio (×10)**
Buffers						
200-meters	0.126	2.419 (1.742)	3.994 (1.691)	1.503 (2.350)	2.749 (5.330)	0.797 (1.589)
300-meters	0.283	2.000 (1.441)	4.649 (1.723)	1.534 (1.949)	2.737 (5.082)	1.138 (1.738)
400-meters	0.503	1.833 (1.350)	5.119 (1.656)	1.605 (1.759)	2.774 (4.944)	1.416 (1.742)
500-meters	0.785	1.671 (1.310)	5.431 (1.702)	1.640 (1.617)	2.596 (4.727)	1.637 (1.749)
600-meters	1.131	1.648 (1.261)	5.713 (1.617)	1.671 (1.539)	2.634 (4.607)	1.807 (1.713)
800-meters	2.012	1.531 (1.172)	5.994 (1.681)	1.682 (1.377)	2.456 (4.305)	1.997 (1.659)
1000-meters	3.142	1.447 (1.089)	6.373 (1.434)	1.727 (1.289)	2.567 (4.266)	2.067 (1.655)
1600-meters	8.042	0.969 (0.969)	6.856 (1.342)	1.756 (1.186)	2.463 (3.874)	2.356 (1.688)
Grids						
200-meters	0.040	3.598 (2.908)	2.910 (1.897)	1.294 (2.794)	2.675 (5.515)	0.491 (1.422)
400-meters	0.160	2.237 (1.707)	4.120 (1.867)	1.579 (2.264)	2.803 (5.276)	0.859 (1.570)
800 -meters	0.640	1.681 (1.292)	5.267 (1.659)	1.637 (1.778)	2.651 (4.636)	1.471 (1.759)
1600-meters	2.560	1.387 (1.081)	6.211 (1.440)	1.714 (1.350)	2.496 (4.216)	1.960 (1.753)
Administrative Areas						
Dissemination Areas	68.064	1.951 (2.196)	5.147 (1.457)	1.729 (1.915)	2.794 (5.364)	1.306 (1.585)
Census Tracts	10.378	1.472 (1.443)	6.392 (0.979)	1.728 (1.262)	2.517 (4.629)	2.141 (1.484)

leads to the decision to use the five variables to measure the BE that are consistently found to be significant in past work, including population density, pedestrian infrastructure, street connectivity, land-use mix, and retail floor area ratio.

The selected variables were developed in ArcGIS© 10 using the methodology found in *Standards for Environmental Measurement Using GIS* (Forsyth et al., 2006) from data provided by the Halifax Regional Municipality. Fourteen different geographical scales are used and can be grouped into three categories:

- Buffers (radii in meters): 200, 300, 400, 500, 600, 800, 1000, 1600
- Grids (length/width in meters): 200, 400, 800, 1600; and
- Administrative areas: census tract and census dissemination area.

These scales are selected based on the scales that have been used to measure the BE in past work.

The variables and their definitions are as follows. Population density is the number people living in a zone per square kilometer of total land use. The entropy index is the degree to which a zone has uniformly diverse land use. The index ranges from 1 for equal distribution of land uses to 0 for only one land use. Land-use categories include residential, commercial, institutional, office, park and recreation, and industrial. Street connectivity is the ratio of the number of four-way intersections to all intersections. It ranges from 1 for a grid-like street structure to 0 for a cul-de-sac street structure. Retail floor area ratio measures the ratio of the area (m^2) of the building footprint to the area (m^2) of the parcel. The higher the ratio, the less store frontage is present, meaning there is less parking available for customers. Pedestrian infrastructure is the ratio of length of sidewalk in meters to the length of road in meters. The higher the ratio, the more sidewalks are available for pedestrians.

3.3.3. Method of Analysis

3.3.3.1. Modeling Process

The method of analysis is a binary logit model, which is estimated for each of the fourteen scales used to measure the BE. The models are estimated with STATA 11.0 SE (StataCorp, 2009) to determine the propensity or likelihood of an individual using AT during the day of study. The logit model was chosen for this study as it makes no assumptions about the distribution of the variables and has the ability to provide valid estimates regardless of the study design (Harrell, 2001). The robust cluster standard errors are estimated in the model to minimize any bias due to heteroskedasticity in the data (Stock and Watson, 2008).

3.3.3.2. Analysis of MAUP-related errors

The fourteen models are compared to each other to examine how their significance and their coefficients change. The scale effect of MAUP is analyzed for both the control and explanatory variables included in the model using two methods of analysis. First, the variables found to be significant in each model are compared to each other to find the general trends of the coefficients within each aggregation scheme. Second, a difference of means *t-test*, as described by Fotheringham and Wong (1991), is used to determine if the differences in coefficient values found in the different models are significant[1].

A true analysis of the zoning effect of MAUP cannot be examined in this paper as that would mean the same scale (i.e. 1000-meter grid) would have to be used in multiple orientations. Instead a pseudo-analysis of the zoning effect is undertaken by comparing different types of zones having a comparable scale (Mitra and Buliung, 2011, Zhang and Kukadia, 2005). The zoning analysis is done by comparing the 200-meter buffer to the 400-meter grid, the 400-meter buffer to the 800-meter grid, the 800-meter buffer to the 1600-meter grid, and the 1600-meter buffer to the census dissemination areas using a difference-in-means *t*-test.

3.4. Results

The binary logit model results are found in Table 6 and Table 7. Each model uses the BE measured at a different zonal aggregation to examine how the relationship between AT and the BE is altered. The socio-demographic control variables are included in all models. The following sections describe the socio-demographic and the BE variables found to be significant for each scale of the BE. Further analysis also examines the scale and zoning effects of the MAUP.

[1] All difference-in-means t-tests are discussed in this study, but the full results are not included. These tables are available upon request from the authors.

Table 6: Preliminary binary logit model examining how the socio-demographics are related to active travel

Socio-Demographic Variables	**β (S.E.)**	**p**
Intercept	2.144 (0.639)	p<0.010
Sex (Male)	0.062 (0.088)	0.482
Age (×10^{-1})	-0.057 (0.059)	0.338
Household Size	-0.185 (0.054)	p<0.010
Household Income (Over $100,000)		
Under $20,000	-0.688 (0.419)	0.101
$20,000 to $39,999	-0.392 (0.200)	p<0.050
$40,000 to $59,999	-0.386 (0.169)	p<0.050
$60,000 to $79,999	-0.335 (0.138)	p<0.050
$80,000 to $99,999	-0.338 (0.173)	0.051
Missing Income	-0.166 (0.145)	0.252
Completed Post-Secondary Degree	0.288 (0.112)	p<0.050
Valid Driver's License	-0.912 (0.322)	p<0.010
Bus Pass	1.602 (0.325)	p<0.010
Student Status - Full Time or Part Time	-0.193 (0.330)	0.559
Employment Status - Full Time or Part Time	-0.028 (0.150)	0.852
Number of Cars per Licensed Driver	-0.453 (0.179)	p<0.050
Participated on Weekend	-0.441 (0.101)	p<0.010
Log Likelihood		-1230.114
Wald chi2(20)		124.840
Prob > chi2		0.000
Pseudo R2		0.043

Table 7: Results of the fourteen binary logit models examining how active travel is influenced by the BE while controlling for personal socio-demographics.

Geographical Scales	Population Density ($\times 10^{-3}$)		Entropy Index ($\times 10$)		Street Connectivity ($\times 10$)		Pedestrian Infrastructure ($\times 10$)		Retail Floor Area Ratio ($\times 10$)		Pseudo R^2
	β (S.E.)	**p**	**β (S.E.)**	**p**	**β (S.E.)**	**p**	**β (S.E.)**	**p**	**β (S.E.)**	**p**	
Buffers											
200-metres	0.081 (0.036)	p<0.050	0.039 (0.034)	0.259	0.005 (0.025)	0.848	0.034 (0.013)	p<0.050	0.087 (0.041)	p<0.050	0.099
300-meters	0.091 (0.049)	0.062	0.041 (0.034)	0.231	-0.018 (0.032)	0.577	0.044 (0.015)	p<0.010	0.066 (0.038)	p>0.100	0.100
400-meters	0.075 (0.048)	0.116	0.000 (0.034)	0.999	0.033 (0.032)	0.299	0.001 (0.023)	0.978	0.122 (0.038)	p<0.010	0.057
500-meters	-0.009 (0.052)	0.856	0.013 (0.033)	0.687	0.002 (0.039)	0.957	0.032 (0.017)	0.057	0.124 (0.042)	p<0.010	0.059
600-meters	0.036 (0.063)	0.569	0.059 (0.039)	0.135	0.041 (0.047)	0.379	0.030 (0.020)	0.131	0.095 (0.050)	0.057	0.100
800-meters	0.052 (0.071)	0.458	0.012 (0.037)	0.739	0.073 (0.056)	0.193	-0.008 (0.021)	0.701	0.176 (0.056)	p<0.010	0.098
1000-meters	0.061 (0.081)	0.453	0.026 (0.047)	0.587	0.075 (0.070)	0.285	0.000 (0.026)	0.995	0.156 (0.057)	p<0.010	0.099
1600-meters	0.309 (0.071)	p<0.010	-0.110 (0.046)	p<0.050	0.071 (0.082)	0.385	-0.014 (0.031)	0.640	0.117 (0.060)	0.052	0.066
Grids											
200-meters	0.040 (0.018)	p<0.050	0.040 (0.029)	0.169	0.043 (0.019)	p<0.050	0.040 (0.011)	p<0.010	0.039 (0.041)	0.350	0.101
400-meters	0.070 (0.034)	p<0.050	-0.005 (0.030)	0.861	0.031 (0.024)	0.194	0.025 (0.012)	p<0.050	0.133 (0.037)	p<0.010	0.057
800-meters	0.014 (0.060)	0.816	0.061 (0.035)	0.082	0.029 (0.037)	0.438	0.055 (0.018)	p<0.010	0.023 (0.040)	0.569	0.097
1600-meters	0.031 (0.095)	0.743	-0.018 (0.047)	0.702	0.054 (0.058)	0.357	0.019 (0.021)	0.355	0.141 (0.057)	p<0.050	0.097
Aggregated Zones											
Dissemination Area	0.033 (0.027)	0.229	-0.040 (0.038)	0.289	0.007 (0.031)	0.814	0.046 (0.015)	p<0.010	0.076 (0.034)	p>0.050	0.060
Census Tract	0.082 (0.046)	0.070	0.011 (0.059)	0.853	-0.050 (0.054)	0.352	0.048 (0.021)	p<0.050	0.071 (0.064)	0.267	0.060

Note: An individual model was estimated for each geographical scale. Socio-demographic variables are controlled for in each model, including age, sex, household size, household income, completed post-secondary degree, valid driver's license, bus pass, student status, employment status, number of cars per licensed driver, and participated in the study on the weekend.

3.4.1. Model Results

3.4.1.1. Socio-Demographic Variables

Before estimating the final models, a preliminary model, as shown in Table 2, was estimated controlling for personal characteristics of the sample population. The model has a McFadden's Pseudo R^2 of 0.0.043. The results find that household size, household income between $20,000 and $79,999, graduating with a post secondary degree, having a driver's license, having a bus pass, the number of cars owned per licensed driver, and participating in the study on the weekend all significantly change the propensity to use AT.

The size of a household is associated with a significant decline in the propensity to use AT. A household with a higher number of people has more constraints on its time, which forces members to use faster modes of travel. Having a household income between $20,000 and $79,999 significantly decreases the probability of using AT relative to an income of Over $100,000. This suggests people with incomes over $80,000 and under $20,000 have similar patterns in using AT and those with incomes in between are using AT significantly less. This may be a result of the residential patterns in Halifax, where both the poor and wealthy live in the downtown core and the middle class live in the suburbs. Graduating with a post secondary degree is significantly related to increasing the propensity to use AT, as post secondary graduates are more likely to be aware of the health and environmental benefits of using active modes of travel. Owning a driver's license and bus pass have an expected relationship with AT, where people who own a bus pass have a significantly higher propensity to use AT and those who own a driver's license have a significantly lower propensity to use AT. The number of cars owned per licensed driver in a household is the final variable that significantly decreases the propensity to use AT. As more cars are available to an individual, he or she is more likely to use the car than AT. Participating in the STAR study on the weekend leads to a significant decrease in the propensity to use AT, showing that most of the AT occurs during the work week.

The fourteen models, shown in Table 3, build on the preliminary socio-demographic model by adding the BE variables as measured at fourteen different scales. The results of the models show the results are only minimally affected by adding the BE variables. All the variables found significant in the socio-demographic model are still found significant in the final models, thus the socio-demographic variables are not presented in Table 3.

3.4.1.2. Built Environment Variables

The relationship between AT and the BE changes in the models depending on the geographical scale used to measure the BE. Each of the BE variables are found significant in at least one model. Three of the variables are more consistently found to be significant than the others: retail floor area, pedestrian infrastructure, and population density. Pedestrian infrastructure, which is a variable that is occasionally found to be related to AT, is significant in several models: the buffer zone sizes of 200-meters and 300-meters; grid zone sizes of 200-meters, 400-meters, and 800-meters; and the administrative zoning systems (i.e., census dissemination areas and census tracts). Pedestrian infrastructure is important to AT as the availability of sidewalks can make people feel safe to walk. If there are fewer sidewalks to walk on within a neighborhood, there is very little chance of an individual walking.

Retail floor area is consistently found to be significantly related to an increase in AT. Although this variable is part of the walkability index, this variable is rarely included in models on its own. The fact that it is often significant points to the importance of store frontage to the ability to drive a car. If there is no parking available (i.e. retail floor area is closer to one) then people are more willing to walk to a destination. Pedestrian infrastructure was found significant in the models with the buffer zone sizes of 200-meters, 400-meters, 500-meters, 800-meters, and 1000-meters; grid zone sizes of 400-meters and 1600-meters; and census dissemination areas.

Population density, which is most frequently found to be related to AT, is significant in the models with the buffer zone size of 200-meters and 1600-meters and grid zone sizes of 200-meters and 400-meters. Population density is associated with a significant increase in the propensity to use AT, meaning urban areas with higher number of apartments, town homes, and condos are friendlier to AT.

Reviewing the other BE variables finds two variables that are only found to be related to a change in the propensity for AT when measured at one scale: the entropy index and street connectivity. The entropy index or land-use mix is found to be related to a decrease in the propensity to use AT when measured at a 1600-meter buffer. Street connectivity is found to significantly increase the propensity for AT for the model using the 200-meter grid. For both of entropy index and street connectivity, the lack significance in the majority of the models suggest they do not increase AT.

3.4.1.3. McFadden's Pseudo R^2

After examining all of the models, it is important to understand the explanatory power of the models to determine if one model explains AT better than others. In order to better understand this relationship, McFadden's Pseudo R^2 value was calculated. McFadden's Pseudo R^2 suggests the level of improvement between the full model and the preliminary model (Freese and Long, 2006). From this, it is possible to compare the fourteen models to determine which model has the most improvement over the preliminary model (R^2 =0.043). The results show that there is significant variance in the pseudo R^2 values found, as they range between 0.057 and 0.101. This is a difference of 43.6%, which is quite a large improvement. The geographical scale with the highest explained variance is the 200-meter grid. Despite the fact that this model has the highest improvement over the preliminary model, there are many other models that have high R^2 values. From this analysis, it is difficult to make a decision on the model that best describes the relationship between AT and the BE based solely on McFadden's Pseudo R^2.

3.4.2. Scale Effects of MAUP

The scale effects of MAUP refer to the spatial aggregation of the zones used to aggregate the BE. From examining the descriptive statistics of the different BE variables, as seen in Table 1, it is apparent that the variance of the BE variables decreases as the scale of the zones increases. This data smoothing from an increase in the zone area size confirms past findings (Mitra and Buliung, 2011, Zhang and Kukadia, 2005). The occurrence of data smoothing and the results of a preliminary analysis combine to find that changing scale significantly changes the BE variables. This shows the importance of examining the influence of the scale effect of MAUP on the relationship between AT and the BE.

Determining if there are any changes between models uses a basic analysis of the coefficients and significance. The results show the coefficient values for the models have no patterns. This is in contrast to the findings by Zhang and Kukadia (2005) who found that as the scale increased the coefficients decreased. The findings in this study better relate to those found by Mitra and Buliung (2011), who similarly found no pattern in the coefficient values.

Measuring the BE at multiple scales results in differences between models. As many as three BE variables are found significant in the 200-meter buffer, 200-meter grid, and 400-meter grid models, while the 600-meter buffer model finds no BE variables significant. The variety of results prove that the scale effect of the MAUP can change the relationship between AT and the BE. In order to get a better idea of the impact the scale effect has on the relationship between AT and the BE, a standard-difference-in-means *t*-test is performed, results of which are available from the authors upon request.

The results of the difference-in-means *t*-test find all of the BE variables are influenced by the scale effect of MAUP when measured using a buffer. The retail floor area ratio has the highest diversity in the coefficients while street connectivity has the least differences in the coefficient values. There are no models that are statistically identical which supports the idea that changing the scale of the BE influences the relationship between AT and the BE.

The comparison of the coefficients found in the grid variables are similar to those in the buffers, as no BE variable is found to be all statistically different or the same. The entropy index, pedestrian infrastructure, and retail floor area are all influenced the most by changing the BE scale, while the coefficients for population density and street connectivity are influenced the least. Again, there are no grid models that are exactly the same, which like the buffers, highlight the influence that the scale effect of the MAUP has on the relationship between AT and the BE.

The results for the administrative zoning systems find the coefficients for population density, entropy index, and street connectivity to be significantly different between the scales. This shows that changing the scale with administrative zones has an impact on the coefficients of the models.

3.4.3. Zoning effect of MAUP

The zoning effect of the MAUP refers to the configuration of different zones given a fixed level of spatial aggregation. In this study, as in past work, a true analysis of the zoning effect of the MAUP is not undertaken as the spatial aggregation is not truly fixed. There are slight differences in aggregation between the grids and buffers and there are obvious differences between the aggregated areas and other zonal types. The only way to truly examine the zoning effect of the MAUP is to compare different orientations of the same zonal system. Instead, a pseudo-zonal analysis, which has been done in past work (Zhang and Kukadia, 2005, Mitra and Buliung, 2011), is used to compare zones with comparable areal measurements: the 400-meter grid is compared to the 200-meter buffer, the 800-meter grid is compared to the 400-meter buffer, the 1600-meter grid is compared to the 800-meter buffer, and the census dissemination area is compared to 1600-meter buffer.

The first zonal comparison is of the 400-meter grid to the 200-meter buffer. The variables found significant in each model are identical with population density, pedestrian infrastructure, and retail floor area found significant in both models. The differences between the models are found when comparing the coefficients using the standard-difference-in-means *t*-test. The results show all of the variables have coefficients that are significantly different. Although the variables are found significant in both models, the zoning effect of MAUP does influence the coefficients of the variables.

The second zonal comparison is of the 800-meter grid to the 400-meter buffer. This comparison shows that the BE variables are different. The 800-meter grid model only finds pedestrian infrastructure significant, while the 400-meter buffer model finds retail floor area ratio significant. The results show all of the variables have coefficients that are significantly different, with the exception of street connectivity.

The third zonal comparison is of the 1600-meter grid and the 800-meter buffer. The BE variables found to be significant in both the 1600-meter grid and 800-meter buffer is retail floor area ratio. Except for population density, the remaining BE variables are all found to have coefficients that are significantly different.

The final zonal comparison is of the 1600-meter buffer and census dissemination area. This comparison is more influenced by the zoning effect of the BE than the other model pairings due to the fact that the size of the dissemination areas changes from one area to another. They are paired because the average area of the dissemination area is similar to the 1600-meter buffer. It is also important to note that other cities may have a different average area of the dissemination area, so the comparison is dependent on the study area. The results of these models show the BE variables found significant again change between models, where the dissemination area model finds pedestrian infrastructure and retail floor area ratio to be significant and the 1600-meter buffer finds population density and entropy index to be significant. Examining the difference-in-means test finds the BE variables all have significantly different coefficients.

3.5. Discussion and Conclusions

This study has compared the relationship between AT and the BE at fourteen different scales to identify how the BE and socio-demographic variables are influenced by the scale and zonal effects of MAUP. The results of this study support the findings of past studies showing that changing the zonal type and size does change the relationship between AT and the BE. Comparing the pseudo R^2 finds that the model using a 200-meter grid scale has the highest variance explained by the BE (57.4%) and the 400-meter grid scale has the lowest variance explained by the BE (24.6%), although the difference between the two pseudo R^2 is moderate.

A summary of the findings shows both the scale and zoning effects of the MAUP influence the relationship between AT and the BE. A key finding of this study is that the scale effect of the MAUP impacts both the significance and the coefficients of the BE variables. Results find that all of the BE variables are found to be significant in at least one model, although there is no consistency in which variables of the five are significant between models. A lack of consistency was also found between the coefficients of the variables for each model, with some found to have major differences, while others do not. These results show that the BE variables are severely influenced by the scale effect of the MAUP, making it difficult to identify the ideal scale at which to measure the BE.

The final key finding of this study is that the zoning effect of the MAUP has a significant influence on the relationship between AT and the BE. Results find that while there is little difference between the 1600-meter buffer and the dissemination area models, the remaining model pairs are quite different. The majority of both the socio-demographic and the BE variables are found to have differences in the coefficients, while only the BE variables have differences in the significance.

Although the results show different zones measuring the BE lead to different relationships between AT and the BE, establishing the ideal scale to measure the BE is difficult. Riva et al. (2008) and Zhang & Kukadia (2005) both state important considerations that need to be addressed when selecting the ideal scale. Riva et al. believe that administrative areas, such as census tracts, are poor scales due to their heterogeneous nature. Although this may be true, the BE measured using the administrative areas finds some of the highest relationships with AT. One reason for Riva et al. findings was that they were more interested in finding optimized zones to examine the BE, rather than allowing policy objectives to dictate the scale. Zhang & Kukadia determine a 400-meter buffer around the home is ideal because it produces more tractable and stable results by using disaggregate data as much as possible and basing scale on travel behavior. These findings are supported by this study, but other factors need to be considered as well.

The previous findings lead to three decision rules to select the ideal scale to measure the BE. First, use a zone that is appropriate for the problem being investigated. Objectives, such as policy, should dictate the zone, so if the purpose of a study is to investigate walkable neighborhoods the zone should reflect the purpose. Second, the zone should be related to actual AT distances within the study whenever possible. For instance, the 400-meter buffer used by Boer et al. (2007) represents the median length of a daily walking trip in the dataset they used, the 1995 Nationwide Personal Transportation Survey. By taking into account actual AT behavior, the true impact of the BE can be evaluated. Third, using disaggregate data as much as possible, as suggested by Zhang & Kukadia (2005), will minimize the impact MAUP has on the models. If census geography or other aggregated scales are necessary, use methods, such as a multilevel model or robust cluster analysis, to account for the multicollinearity inherent in the data. Overall these three decision rules help in establishing the ideal scale to measure the BE when relating AT and the BE, although the scale used will still vary.

Future research needs to provide a better understanding of the conceptualization of a neighborhood. In order to help identify the ideal scale of BE, researchers should ask subjects to draw what they consider their neighborhood to be. These self-drawn neighborhoods can be compared to existing strategies of evaluating the BE to establish which representation best approaches reality. Future research should also examine the true impact of the zone effect of MAUP on the relationship between AT and the BE by measuring the BE using multiple orientations of the same spatial aggregation.

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Chapter 4 The Social Environment and Walking for Travel: A Case Study for Hamilton, Ontario, Canada

4.1. Introduction

Over the past decade, researchers have examined how the social environment influences physical activity (PA) participation (Ball, 2006, Cleland et al., 2010, Giles-Corti and Donovan, 2002, Harley et al., 2009, Mendes de Leon et al., 2009, Trost et al., 2002, Hohepa et al., 2007). In this context, the social environment is defined as the influence friends and family have on an individual's PA participation. Past research has consistently found that a positive social environment, influences PA (Trost et al., 2002, Ball, 2006). While the social environment is established as a factor influencing PA, research is only now beginning to unravel how the social environment influences walking. Walking is an important type of physical activity, as walking provides exercise to a wide range of people. Recently, researchers have started to examine how walking is related to the social environment (Cleland et al., 2010, Hohepa et al., 2007, Mendes de Leon et al., 2009), but little is known about how the social environment influences walking.

A conceptual framework is used in this study to understand how the social environment fits into the existing knowledge surrounding walking for travel[2]. The framework is adapted from the PA literature (Giles-Corti and Donovan, 2002, Cleland et al., 2010) by using the social, individual, and physical environments to better understand

[2] All future references to walking refers to walking for travel (i.e., walking as a mode of transport) unless otherwise specified.

what factors influence walking. The individual environment refers to intrapersonal factors (e.g., personal preferences and self-efficacy) and socio-demographics of individuals and the physical environment, otherwise known as the built environment, refers to the density, diversity, and design features of a city. Combining these different environments into a single analysis allows a better understanding as to the extent each relates to walking.

This study makes two major contributions to the literature. First, a conceptual framework from the PA literature (Giles-Corti and Donovan, 2002, Cleland et al., 2010) is adapted to include four components of the social environment, including companionship, encouragement, role models, and social cohesion. These four components work together to create a more comprehensive representation of the social environment. Second, the social environment and weekly walking are compared while controlling for individual and physical environments to better understand the true impact of the social environment on walking. This analysis has not been done before in the literature because the focus has been primarily on the physical environment.

The analysis in this study uses a series of linear regression models to determine how each theme of the social environment influences daily walking while controlling for the individual and physical environments. The data analyzed in this study are from the Hamilton Active Living Study (HALStudy) collected in the summer of 2010 in Hamilton, Canada. The data collection tools used in this study include GPS tracking for seven-days and a personal questionnaire asking about socio-demographics, walking participation, motivators for walking, and neighborhood social cohesion.

The next section of this paper presents the conceptual framework of the analysis. The data and methodology section describes the data collection process, variables, and analysis approach used for the study. The results section discusses the results of the analyses. Finally, the conclusion summarizes the key findings and discusses their importance in the context of the literature.

4.2. Conceptual Framework

The conceptual framework developed for this study is adapted from the PA literature and leads to a better understanding of how walking is influenced by the three environments: individual, physical, and social (Giles-Corti and Donovan, 2002, Cleland et al., 2010). The literature finds that each environment has is related to PA, but no known studies have examined the three environments in concert with walking. The individual environment refers to how intrapersonal factors and socio-demographics of individuals influence walking behaviour. The intrapersonal factors examined in the PA literature are preference and self-efficacy. In this study, preference is defined as the desire and interest of an individual to walk, while self-efficacy is defined as the degree to which an individual believes he or she can walk (Bandura, 1977). These intrapersonal factors are found to significantly influence PA participation (Ball, 2006), but most researchers rarely use preference and self-efficacy as factors influencing walking. This may be a result of walking researchers not having the proper data to evaluate intrapersonal factors related to walking.

Socio-demographic variables are primarily used in the literature to control for the underlying characteristics of the population and to see how socio-demographics influence walking. Four socio-demographic variables are consistently found to be related to walking: age (Harrison et al., 2007, Mendes de Leon et al., 2009), sex (Owen et al., 2007, Harrison et al., 2007, Booth and Owen, 2000), owning a driver's license (Clark et al., Under Review, Copperman and Bhat, 2007), and educational attainment (Ball et al., 2001, Clark et al., Under Review). Aging is negatively related to walking due to health and mobility issues that arise as people get older (Ferrucci et al., 2000, Harrison et al., 2007, Mendes de Leon et al., 2009). Males are found to walk significantly more than women (Owen et al., 2007, Harrison et al., 2007, Booth and Owen, 2000). Having a driver's license significantly decreases the propensity to walk (Clark et al., Under Review, Copperman and Bhat, 2007). Those who do not have a driver's license are forced to use alternative modes of travel, such as public transit, walking, or bicycling, all of which increase walking. Finally, a higher education level is related to a higher propensity for walking (Mendes de Leon et al., 2009, Booth and Owen, 2000). The increase in walking may be the result of more educated people having a better understanding of the benefits of walking than those with lower education levels.

The physical environment refers to the design of the urban landscape, such as measures of density (population density and residential density), diversity (land-use mix and accessibility), and design (street connectivity, parking availability, sidewalk availability). While past literature has tested many different components of the physical environment (Brownson et al., 2009), the general consensus is that the physical environment is significantly related to walking. This consensus has led to many researchers focusing on the relationship between walking and the physical environment, while possibly ignoring many other factors related to walking, such as the social environment and intrapersonal factors. Recent studies have examined how these other factors influence walking (Cleland et al., 2010, Hohepa et al., 2007), but the physical environment is still the primary focus for most researchers.

The review by Brownson et al. (2009) details the four most common measures of the physical environment that influence walking: population density (Boer et al., 2007, Braza et al., 2004, Ewing et al., 2004, Kerr et al., 2006, Rodriguez and Joo, 2004, Rutt and Coleman, 2005, Clark et al., Under Review), land-use mix (Boer et al., 2007, Cervero and Duncan, 2003, Ewing et al., 2004, Kerr et al., 2006, Rutt and Coleman, 2005), street connectivity (Boer et al., 2007, Cervero and Duncan, 2003, Ewing et al., 2004, Braza et al., 2004, Kerr et al., 2006, Rutt and Coleman, 2005), and sidewalk availability (Ewing et al., 2004, Rodriguez and Joo, 2004, Rutt and Coleman, 2005, Clark et al., Under Review). The review also discusses the composite measures developed to summarize different physical environment variables using a single index (Frank et al., 2010, Ewing et al., 2003, Frank et al., 2005, Kligerman et al., 2007, Ewing et al., 2006). These indices, referred to in the literature as walkability indices, combine multiple components of the physical environment into a single variable that is then used to evaluate how the physical environment impacts walking. The most common index found to be significantly related to walking in the literature was developed by Frank et al. (2010). Their index combines land-use mix, street connectivity, population density, and retail floor area ratio. These studies conclude that the physical environment influences walking and needs to be considered when examining walking behavior.

The social environment refers to the influence friends and family can have on an individual's walking. Researchers have only started to examine how the social environment influences walking (Cleland et al., 2010, Hohepa et al., 2007, Mendes de Leon et al., 2009), but there is a well established relationship between the social environment and PA (Trost et al., 2002, Ball, 2006). From the PA literature, four themes of the social environment emerge (Hohepa et al., 2007) and are adopted to walking: companionship, encouragement, neighborhood social cohesion, and role models.

The first theme of the social environment is walking companionship, which refers to walking with other people rather than alone. While companionship has not been examined in relationship to walking, the PA literature provides the most important findings as to the benefits of companionship. In one study, those who exercise with companions are less likely to stop exercising in the future (Harley et al., 2009). Companions also make exercise less isolated and hold individuals accountable to others who participate (Harley et al., 2009). No matter who the companion, research has found companionship to significantly increase PA participation (Ball et al., 2001, Cleland et al., 2010, Cutt et al., 2007, Giles-Corti and Donovan, 2002, Harley et al., 2009).

The second social environment theme is encouragement, which occurs when family, friends, or other acquaintances promote walking. Promotion occurs when people complement improved physical appearance that results from exercise (Booth and Owen, 2000) or when feedback is given regarding participation in walking (Booth and Owen, 2000, Cleland et al., 2010, Darlow and Xu, 2011, Hohepa et al., 2007). Past work has found that encouragement can significantly increase walking. (Cleland et al., 2010, Hohepa et al., 2007). One study found that women living in socioeconomically disadvantaged neighborhoods participated in more walking when encouraged by family and friends (Cleland et al., 2010). The second study found that juniors in high school walked to school more often when they had more support from their peers to walk (Hohepa et al., 2007).

The third theme of the social environment is neighborhood social cohesion. The social cohesion of a neighborhood is determined by the amount a neighborhood is socially interconnected – that is, residents feel like they belong in the neighborhood. The cohesion of a neighborhood is measured through likert scale questions used to understand the friendliness and sociability of a neighborhood. Social cohesion is a popular topic in the transportation literature (Mendes de Leon et al., 2009, Whalen et al., 2012, McDonald, 2007, Páez and Whalen, 2010), including the influence it has on walking. McDonald (2007) found children living in more cohesive neighborhoods have higher rates of children walking to school. Work by Mendes de Leon (2009) found older adults living in more cohesive neighborhoods are more likely to walk for exercise. Páez and Whalen (2010) found that active travelers prefer living in an active neighborhood where there is a sense of community.

The final theme of the social environment is role model. Role models, in regards to walking, are people who walk and whose own participation encourages others to become involved. Walking has yet to be related to role models, but PA research shows that there are many types of role models and they all play a part in increasing participation. Role models can be people close to the person such as friends, family, romantic partner, and co-workers; or they can be strangers, such as professional athletes, whose PA participation can increase activity levels. Past research has found role models increase participation in PA (Booth and Owen, 2000, Darlow and Xu, 2011, Giles-Corti and Donovan, 2002, Harley et al., 2009).

4.3. Methodology

4.3.1. Data

The data used for this study come from the Hamilton Active Living Study (HALStudy). The purpose of the HALStudy was to learn about people's participation in physical activity and the barriers preventing people from participating in additional physical activity. The sample was collected from May to September of 2010 in Hamilton, Ontario, Canada. Hamilton is a city of almost 540,200 people located southwest of Toronto on Lake Ontario. In order to ensure that people living in various types of neighborhoods were sampled in this study, thirty neighborhoods in urban Hamilton were selected based on their walkability using a stratified random sampling design. Walkability is defined as the "extent to which characteristics of the built environment and land-use may or may not be conducive to residents in the area walking for either leisure, exercise or recreation, to access services, or to travel to work" (Leslie et al., 2007).

After acquiring phone lists for each neighborhood, the phone numbers were randomized and cold calls were made to acquire ten subjects from each neighborhood. Although the neighborhood-based approach was the focus, participants were not restricted based on the location of their residence. All subjects willing to participate were invited to do so. As a result, the final dataset had 201 subjects living in 40 neighborhoods.

There were three components to the HALStudy: an upfront interview, a 7-day time-use diary with GPS tracking, and a personal questionnaire. The upfront interview required the participant to meet with a research assistant (RA). First, the RA asked the participant to draw their neighborhood on a tablet using a tablet mapping program called ESRI ArcPad®. Using this tool, participants drew what they considered their neighborhood on a map and the drawings were saved for future analysis. Second, the researcher measured the participant's height using a SECA Stadiometer and weight using a digital scale. The height and weight measurement allowed a body mass index (BMI) to be calculated. Finally, instructions were given on how to fill out the personal questionnaire, the time-use diary, and use the global positioning system (GPS) data logger.

The time-use diary with passive GPS tracking collected detailed accounts of the activities and trips of a participant during the seven-day study period. The GPS tracking was completely passive only requiring participants to charge the device nightly and to ensure they carried the device for the seven days of the study. The device used was the QStarz BT-Q1000X travel recorder and it recorded a point every 5 seconds. The time-use diary asked subjects to record every activity and trip for the seven days of the study. Details included start time, end time, activity type, mode, and involved persons. Subjects were only asked to include activities over 5-minutes of duration. All trips and legs of trips were recorded, regardless of their length. For instance, walking to a bus stop, waiting for a bus, riding the bus, walking to work from the bus stop were all recorded in the diary. The combination of GPS data and time-use diary allows a complete picture of the activities and trips over the seven days.

The personal questionnaire on active living was a detailed survey about all types of physical activity, including exercise, organized and unorganized sport, walking, bicycling, and active video games. Each of the physical activity sections asked questions about participation level in the physical activity, perceptions of the activity, and barriers to the physical activity. Additional sections of the questionnaire asked about perceptions of physical activity, perceptions of neighborhood, travel behavior preferences, and socio-demographic information.

For this study, the focus is on the social environment of walking. The data about social environment comes from various sections of the personal questionnaire, including walking, motivations for PA, PA knowledge, neighborhood satisfaction, and social cohesion. The sample size for this study included the 179 participants who answered the questionnaire and had diary entries available. The socio-demographic data collected as part of the personal questionnaire was also used in this study to account for the individual environment.

4.3.2. Concepts and Measures

4.3.2.1. Dependent Variables

The dependent variable for this study is the number of minutes spent walking for travel in a week. Walking for travel was selected as the dependent variables due to the minimal amount of research examining the relationship between walking and the social environment in the past. The social environment may be a key piece that will help policy makers and researchers to get more people to walk for travel. The walk trips were extracted from the diary for each subject. After all walking episodes were extracted from the diary walking episodes for travel were identified by comparing the surrounding activities. If the walking episode involved travelling from one location to another, it was coded as a walking trip. Otherwise, it was coded as walking for exercise.

4.3.2.2. Independent Variables

Three types of independent variables are included in the model based on the conceptual framework: socio-demographics, the built environment, and social influence. A statistical summary of the independent variables is provided in Table 8 and Table 9. The socio-demographic variables are used to control for the individual environment. These variables include age, sex, marital status - single, educational attainment - post-secondary degree, parent of child(ren), driver’s license ownership, bus pass ownership, and body mass index (BMI). Age (Harrison et al., 2007, Mendes de Leon et al., 2009), sex (Owen et al., 2007, Harrison et al., 2007, Booth and Owen, 2000), owning a driver's license (Clark et al., Under Review, Copperman and Bhat, 2007), and educational attainment (Ball et al., 2001, Clark et al., Under Review) are included as they have been found significant in past research. Bus pass ownership is included as those taking a bus are required to walk in order to get to a bus stop. Being a parent and marital status are included as they are control variables directly related to social influence. BMI is defined as a ratio of height and weight with a higher value meaning an unhealthier individual (Centers for Disease Control and Prevention, 2011) and is included to control for body type.

Table 8: Description of the summary statistics for the independent variable.

Variables	Statistics
Individual Environment	
Age (x10^{-1}), mean (s.d.)	5.020 (1.713)
Body Mass Index (x10^{-1}), mean (s.d.)	2.738 (0.685)
Female (%)	68.8%
Marital Status - Single (%)	41.9%
Post-Secondary Degree Attainment (%)	68.1%
Parent of Child(ren) (%)	29.4%
Driver's License Owner (%)	83.8%
Bus Pass Owner (%)	18.1%
Physical Environment	
Population Density (x10^{-3}), mean (s.d.)	3.816 (2.195)
Street Connectivity (x10), mean (s.d.)	4.220 (1.637)
Land-Use Mix (x10), mean (s.d.)	6.092 (1.253)
Pedestrian Infrastructure, mean (s.d.)	1.534 (0.376)
Retail Floor Area Ratio (x10), mean (s.d.)	3.533 (1.458)

The physical environment is measured using five measures that were consistently found significant in past literature (Brownson et al., 2009). The measures include population density, street connectivity, retail floor area ratio, pedestrian infrastructure, and land-use mix. The selected variables were developed in ArcGIS© 10 using the methodology found in *Standards for Environmental Measurement Using GIS* (Forsyth et al., 2006) from data provided by the City of Hamilton. Each variable is calculated based on a 1000-meter buffer around the home.

Table 9: Descriptive analysis of the social influence factors, including percentage of agreement or frequency, average number of minutes walking for travel, and difference-in-means tests.

Social Influence Factor (3 point likert scale based on frequency)	Rarely (%)	Sometimes (%)	Always (%)	Rarely (min)	Sometimes (min)	Always (min)	p[a]
Companionship							
How often do you walk alone?	17.9%	50.3%	31.8%	2.43	2.90	3.40	0.121
How often do you walk with members of your household?	33.5%	50.8%	15.6%	2.86	3.02	3.07	0.873
How often do you walk with members of your family who do not live with you?	72.6%	24.0%	3.4%	3.01	2.68	4.38	0.192
How often do you walk with friends?	46.9%	50.3%	2.8%	2.09	2.25	2.47	0.462
Social influence Factors (3 point likert scale based on agreement)	**Disagree (%)**	**Neither Agree nor Disagree (%)**	**Agree (%)**	**Disagree (min)**	**Neither Agree nor Disagree (min)**	**Agree (min)**	**p[b]**
It is difficult for me to walk more often because I have no one to walk with	70.9%	15.6%	13.4%	3.02	2.88	2.83	0.690
There are people I can count on to be physically active with me	27.4%	22.3%	50.3%	2.61	2.58	3.35	p<0.050
Encouragement							
I participate in PA because the doctor requests that I do	44.7%	30.7%	24.6%	3.10	2.97	2.76	0.397
My family encourages me to be active	22.3%	30.2%	47.5%	2.62	2.75	3.29	0.108
My family forces me to be active	69.8%	20.1%	10.1%	2.73	3.92	2.73	0.998
My friends encourage me to be active	31.3%	40.2%	28.5%	2.72	3.03	3.18	0.292
People important to me encourage me to participate in PA on a regular basis	25.7%	31.3%	43.0%	2.71	2.67	3.35	0.113
Neighborhood Social Cohesion							
I am satisfied with how many friends I have in my neighborhood	23.5%	17.9%	58.7%	2.96	3.15	2.92	0.918
I have a sense of community in my neighborhood	25.7%	17.3%	57.0%	2.71	2.73	3.16	0.236
I know my neighbors well	31.3%	20.1%	48.6%	2.85	2.55	3.22	0.321
My neighborhood is close-knit	24.6%	34.6%	40.8%	2.92	2.75	3.19	0.511
People in my neighborhood are willing to help their neighbors	12.8%	16.8%	70.4%	3.28	3.35	2.83	0.361
People in my neighborhood can be trusted	20.1%	26.8%	53.1%	2.49	3.34	2.97	0.251
People in my neighborhood do not share the same values	39.1%	41.9%	19.0%	2.73	3.16	3.06	0.466
People in my neighborhood generally don't get along with one another	57.0%	31.8%	11.2%	2.97	3.11	2.61	0.490
I am satisfied with the number of people I know in my neighborhood?	16.2%	16.2%	67.6%	3.08	3.26	2.88	0.653
Role Model							
My family participates in PA on a regular basis	22.9%	10.1%	67.0%	2.73	2.61	3.11	0.324
My friends participate in PA on a regular basis	17.9%	30.2%	52.0%	2.79	3.06	2.99	0.664
Seeing my friends participate in PA makes me want to participate	21.8%	29.6%	48.6%	1.89	3.22	3.31	p<0.010
Seeing other family members participating in PA makes me want to participate	24.0%	31.8%	44.1%	2.45	2.86	3.34	p<0.050

[1] p-value is calculated using ANOVA test to determine if there is significant difference in the duration of walking between rarely, sometimes, and always.

[b] p-value is calculated using a difference-in-means t-test between those who agree and those who disagree with the social influence factors.

The definitions for each variable are as follows. Population density is the number people living in the buffer per square kilometer. Entropy index is the degree to which a zone has uniformly diverse land use. The index ranges from 1 for equal distribution of land-uses to 0 for only one land use. Land-use categories include residential, commercial, institutional, office, park and recreation, and industrial. Street connectivity is the ratio of number of four-way intersections to all intersections. It ranges from 1 for grid-like street structure to 0 for cul-de-sac street structure. Retail floor area ratio measures the ratio of the area (m^2) of the building footprint to the area (m^2) of the parcel. The higher the ratio, the less store frontage is present meaning there is less parking available for customers. Pedestrian infrastructure is the ratio of length of sidewalk in meters to length of road in meters. The higher the ratio, the more sidewalks are available for pedestrians.

Social influence is measured using a series of likert-scale questions from the personal questionnaire. The questions are divided into four sections based on the literature: encouragement, role model, companionship, and neighborhood social cohesion. A list of the 24 questions and how they are organized into categories can be found in Table 9 along with a summary. Each question is entered into the models individually to allow for a better understanding of how each component comprising the social environment impacts walking. The reference category for the questions based on a frequency likert scale is ‘rarely’ and the reference category for the questions based on an agreement likert scale is ‘disagree’. While agreement scales are usually centred on ‘neither agree nor disagree’, the decision was made to use ‘disagree’ as the reference category to allow a direct comparison of walking duration between agreement and disagreement in the social influence.

4.3.3. Analysis Methodology

The method of analysis used in this study is a series of linear regression models, which are used to quantify the impact of the social environment on walking duration, while controlling for the individual and physical environments. The models are specified as

$$T = \beta X + \varepsilon$$

where **T** is the natural logarithm of the number of minutes spent walking on a weekly basis. A natural logarithmic transformation was necessary to normalize the data for the linear regression model. **X** represents the independent variables that reflect the individual, physical, and social environments associated with walking as measured for each individual. **β** is a vector of parameters estimated by the model. The dependent variable is based on a natural logarithmic transformation, so each parameter is interpreted as a percentage change in walking duration associated with a unit change in the independent variable. **ε** represents the unobserved error for the parameter.

4.4. Results

4.4.1. Preliminary Analysis

A preliminary analysis, presented in Table 9, examines how the social influence questions were answered and if there are any significant differences in walking duration as a result. The results in the analysis find no real pattern as to the way questions were answered. Parametric *t*-tests and analysis of variance (ANOVA) were performed to determine if there is any difference in the average walking duration between different likert scale answers. Difference-in-means *t*-tests found three questions to have a significantly different duration of walking depending on the likert scale answers.

The question “There are people I can count on to be physically active with me” from the companionship category finds a significantly higher amount of walking when people are in agreement compared to those who disagree. Similarly, the question “Seeing my friends participate in PA makes me want to participate” from the role model category has a significantly higher duration of walking for those who agree than those who disagree. Finally, the question “Seeing other family members participating in PA makes me want to participate” is found to have significantly higher duration of walking for those who agree than those who disagree.

4.4.2. Model Specification

The linear regression models are estimated in this study using a step-wise deletion method. All models in this analysis control for the individual and physical envirionments. A two-step modeling process is used in order to determine which questions from the social enviroment are included in the final model. First, each model has one social enviornment question added to the control variables to establish if the question has explanatory power. Second, the questions that are significant in the first set of models are added to a final model examining how the four categories of the social environment work together to influence the weekly duration of walking while controlling for the individual and physical environments[3].

[3] The results of the intermediate models are available from the authors upon request.

The initial models control for the individual and physical environments. The results find that none of the six companionship questions, one of the five encouragement questions, one of the nine neighborhood social cohesion questions, and two of the four role model questions are significantly related to a change in walking duration. These four variables are entered into the final model along with the individual and physical environment controls. Results of the final model are presented as follows in Table 10.

4.4.3. Model Results

4.4.3.1. Individual Environment

The individual environment is defined as the role that socio-demographics, self-efficacy, and personal preferences play on the decision to walk. While all three have been found to impact the decision to participate in PA only socio-demographics have been used in the literature as a factor related to walking. As a result, this study only controls for the socio-demographics as measures of the individual environment. Understanding how preferences and self-efficacy influences walking for travel is a complex analysis and beyond the scope of this study leaving future work to examine the impact.

The linear regression model finds three individual environment variables to be significantly related to a change in the duration of walking: age, driver's license ownership, and bus pass ownership. Age is one variable that is consistently found significant in the literature. In this study, like in past work, age is found to be significantly related a decrease in the duration of walking (Harrison et al., 2007, Mendes de Leon et al., 2009). As age increases by one year the duration of weekly walking decreases by 1.9%. The reasoning for this decline in walking duration may be the result of increased illness,

Table 10: Linear regression model examining how the four categories of social influence impact weekly walking duration in Hamilton, Canada.

Variables	β (S.E.)	p
Individual Environment		
Female	-0.238 (0.365)	0.516
Age ($x10^{-1}$)	-0.185 (0.097)	$p<0.100$
Marital Status - Single	-0.406 (0.354)	0.253
Parent of Child(ren)	-0.251 (0.362)	0.489
Driver's License Ownership	-1.142 (0.491)	$p<0.050$
Bus Pass Ownership	0.692 (0.415)	$p<0.100$
Post-Secondary Degree Attained	-0.110 (0.366)	0.765
Body Mass Index ($x10^{-1}$)	-0.290 (0.232)	0.212
Physical Environment		
Population Density ($x10^{-3}$)	0.108 (0.106)	0.311
Street Connectivity (x10)	-0.089 (0.206)	0.665
Land-Use Mix (x10)	0.303 (0.154)	$p<0.050$
Pedestrian Infrastructure	-0.224 (0.576)	0.697
Retail Floor Area Ratio (x10)	0.218 (0.209)	0.298
Social Environment		
Encouragement (Disagree is reference category)		
My family encourages me to be active		
Neither Agree nor Disagree	-0.262 (0.48)	0.585
Agree	0.160 (0.454)	0.724
Role Model (Disagree is reference category)		
My family participates in PA on a regular basis		
Neither Agree nor Disagree	-0.233 (0.618)	0.706
Agree	0.368 (0.411)	0.371
Seeing my friends participate in PA makes me want to participate		
Neither Agree nor Disagree	1.171 (0.461)	$p<0.050$
Agree	1.073 (0.439)	$p<0.050$
Neighborhood Social Cohesion (Disagree is reference category)		
People in my neighborhood can be trusted		
Neither Agree nor Disagree	0.937 (0.472)	$p<0.050$
Agree	0.726 (0.430)	$p<0.100$
Intercept	1.997 (1.539)	0.196
Number of Observations	179.000	
Probability	$p<0.010$	
R-Squared	0.255	

Note: The model is estimated with a dependent variable of the natural logarithm of weekly walking duration.

disease, and disability that occurs while people age. The older population may also have more concerns about the safety of their neighborhood caused by poor walkability and crime (Grant et al., 2010).

The second individual environment variable found significant is owning a driver’s license. The findings show that those who do not own a driver’s license walk 114.2% more than those who do. This finding is supported by other studies, which also find that not owning a driver's license increases walking, although the effect is much higher than in past studies (Clark et al., Under Review, Copperman and Bhat, 2007). While not everyone who owns a driver’s license uses a car as the primary mode of travel, there is a much lower propensity to walk when having a driver’s license. In contrast, those who do not have a driver's license walk far more often because they are required to use alternative modes of travel, such as public transit, walking or bicycling, to move around the city.

The final individual environment variable found significant is bus pass ownership. The findings show that those who own a bus pass walk 69.2% more than those who do not own a pus bass. The literature has not reported a relationship between owning a bus pass and walking, but using a bus to travel does require walking in order to get to bus stops. Finding both driver’s license and bus pass ownership to be significant highlights the importance of car travel to society and how difficult it is to encourage the public to use alternative modes of travel when they have a license.

4.4.3.2. Physical Environment

The physical environment, also called the built environment, refers to the structural foundation of the city. Objective measures of the physical environment used in this study include four-way intersection to all-way intersection ratio, entropy index, retail floor area ratio, population density, and street to sidewalk length ratio. Although each of the physical environment variables have been found significant in the literature (Brownson et al., 2009), only entropy index has been found to significantly increase the duration of weekly walking. Entropy index has been found to increase weekly walking duration by 30.9% for every 0.1 increase in the entropy index. This shows that when individuals live in a neighborhood where they can easily access multiple land-use types they are more likely to walk.

4.4.3.3. Social Environment – Companionship

Examining the companionship questions in this study find that companionship is not significantly related to walking for travel. While companionship has been found to increase the amount of walking for exercise (Ball et al., 2001, Cleland et al., 2010, Giles-Corti and Donovan, 2002) and help make walking for exercise habitual (Harley et al., 2009), companionship has no influence on the weekly duration of walking for travel in this study. One reason why companionship does not influence walking for travel may be the result of intra-personal constraints discussed in time geography research (Hägerstrand, 1970, Kang and Scott, 2011, Scott and Kanaroglou, 2002). These constraints refer to the need of two or more people to arrange their schedules so they can meet at the same time and place in order to walk together. When walking for travel these constraints are even more present as potential companions need to arrange their schedules to meet as well as traveling to and from the same general locations. All of these conditions make the intra-personal constraints too difficult to overcome, thus walking is not influenced by companionship.

4.4.3.4. Social Environment – Encouragement

The preliminary models find one encouragement question to be significantly related to a change in the duration of weekly walking. Agreeing with the question, "My family encourages me to be active", is found to increase walking by 70.2% compared to those who disagree. This finding is supported by past literature that has also found family support increases walking for travel (Cleland et al., 2010). After including encouragement in the final model with the other categories of the social environment, family encouragement becomes insignificant. One potential reason that encouragement becomes insignificant as related to walking duration, is that those who are influenced by encouragement may have a higher predisposition to car travel than walking. Thus, the encouragement they received increases other types of PA such as walking for exercise, bicycling, and sports, which are all found to be significantly related to encouragement (Booth and Owen, 2000, Darlow and Xu, 2011, Hohepa et al., 2007).

4.4.3.5. Social Environment – Neighborhood Social Cohesion

Both the preliminary model and the final model find the neighborhood social cohesion question "people in my neighborhood can be trusted" to be significantly related to duration of walking. Those who agree with the question walk 72.6% more than those who disagree. The results support past work that examined the social cohesion of a neighborhood for walking (Mendes de Leon et al., 2009, Páez and Whalen, 2010). Trusting people in a neighborhood increases walking as residents may feel safer to walk and if there is a problem, they know they can ask for help.

4.4.3.6. Social Environment – Role Model

Role models are a new category of the social environment to be investigated as they relate to walking for travel. Past research has found that role models do influence PA (Booth and Owen, 2000, Darlow and Xu, 2011, Giles-Corti and Donovan, 2002, Harley et al., 2009), but little is known about how walking is influenced by these role models. The preliminary models find two role model questions to be related to a significant increase in the duration of walking: "my family participates in PA on a regular basis" (increase in duration by 65.2%) and "seeing my friends participate in PA makes me want to participate" (increase in duration by 106.7%). After including both questions into the final model only the second was found to be significant.

The final results suggest that those who agree that seeing friends participating in PA makes them want to participate increases walking by 107.3% compared to those who disagree. This result shows that having a role model for walking can encourage walking. If an individual see peers around them being active, it makes walking a possibility. In contrast, those who never see anyone active, are less likely to walk. Overall, having a role model simply changes what people consider a possibility and alters preconceptions when it comes to travel.

4.5. Discussion and Conclusions

This study has provided an initial investigation examining walking as it relates to the three environments in which walking for travel takes place: individual, physical, and social environments. While many past studies have examined walking as it relates to the individual and physical environments, the social environment has been mostly ignored. More recently researchers have started to examine walking as it relates to the social environment (Cleland et al., 2010, Hohepa et al., 2007, Mendes de Leon et al., 2009, McDonald, 2007, Páez and Whalen, 2010), but more work needs to be done.

The purpose of this study was to examine four unique components of the social environment: companionship, encouragement, neighborhood social cohesion, and role models, to determine how they influence duration of walking. The results of the linear regression models lead to two of the social environment categories being found to be significant (social cohesion and role models) and two of the social environment categories being insignificant (companionship and encouragement). The social cohesion question "people in my neighborhood can be trusted" and the role model question "seeing my friends participate in PA makes me want to participate" are both found to significantly increase the duration of walking for travel in this study.

An unexpected finding of this study is that companionship does not influence walking in this study, despite companionship consistently being found significantly related to walking for exercise (Booth and Owen, 2000, Cleland et al., 2010, Cutt et al., 2007, Giles-Corti and Donovan, 2002, Harley et al., 2009). Understanding the reasoning for this unexpected finding can be tied back to time geography principals. The foundation of time geography, as developed by Hägerstrand (1970), discusses the three constraints that bound everyone in time and space, including capability constraints, coupling constraints, and authority constraints. This study focuses on the coupling constraints which define where, when, and how long an individual has to join other people to produce, consume, and travel. These coupling constraints are far more restricting when walking for travel than walking for exercise and other PA types found significant in the past.

For instance, if two people want to walk together they need to communicate to set up a time and place to leave for their destination. Individuals have their own personal activities that they need to schedule around, such as work, school, family commitments, recreational activities, etc. If these two people are unable to find a time that works for both of them, then they will not walk together. In contrast, when walking alone people are only constrained by their own schedule, so if they decide they want to walk for travel they can simply do so without being constrained by others.

In conclusion, this study has shown that the conceptual framework combining the individual, physical, and social environments can lead to a better understanding of what increases walking. If this study, like most others, ignored the social environment there would have been 29.6% less variance explained by the model. As a result, the four components of the social environment need to be considered along with the other environments to ensure a complete understanding of the factors influencing walking.

Future work using the conceptual framework developed in this study needs to develop a standardized method to conceptualize the social environment. While many studies in the past have examined the social environment as it relates to physical activity, it is difficult to quantify and conceptualize the qualitative data. Future research should also focus on the individual environment, which includes self-efficacy and preferences. Controlling for an individual's basic beliefs, likes, and dislikes seems straight forward, but there is very little research in the walking literature examining these important factors.

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Chapter 5 Examining how weekly walking for travel is influenced by barriers to walking within different sub-groups of the population in Hamilton, Canada

5.1. Introduction

Over the last decade, researchers have been trying to understand the factors that influence the decision to walk. Walking is important to understand as it can help mitigate health problems, such as asthma, diabetes, heart disease, obesity, and some forms of cancer (U.S. Department of Health and Human Services, 1996), which cost taxpayers billions of dollars every year (Canadian Fitness and Lifestyle Research Institute, 2010, U.S. Department of Health and Human Services, 1996). Walking is one of the most popular forms of physical activity (Gilmour, 2007, Rafferty et al., 2002, Bassett et al., 2008), but there is still much to be learned about how perceived barriers make walking difficult.

Despite walking being one of the more popular forms of physical activity and highly recommended by health promotion organizations (Canadian Society for Exercise Physiology, 2012), very few people regularly use active modes of travel. Active travel (AT), defined in this study as walking for the purpose of travel, is only used by 36% of Canadians to get to a routine destination on a regular basis (Cragg et al., 2006). This low modal share combined with the many benefits AT has on both the environment and health, has made AT a focus for researchers and policy makers (Frank et al., 2003, Pucher and Dijkstra, 2003). Understanding how factors, such as the built environment, social environment, and safety, are related to AT provides researchers and policy makers the opportunity to recommend policy changes that work to minimize or enhance the effect factors have on the decision to walk.

AT has been investigated extensively by researchers in order to gain a better understanding of the factors related to increasing and decreasing AT. Reviewing the literature finds five themes significantly related to AT: the built environment, the social environment, meteorology, safety, and topography. The built environment is the factor most frequently found to influence AT in the literature. A recent review by Brownson et al. (2009) identifies four measures of the BE significantly related to AT: population density, land use mix, street connectivity, and sidewalk availability. The walkability index developed by Frank et al. (2010), which combines population density, land-use mix, street connectivity, and retail floor area ratio into a single index, is also consistently found to be related to AT (Frank and Engelke, 2005, Frank et al., 2006, Frank et al., 2010).

The aesthetics of a neighborhood also play a role in the decision to AT, where unappealing neighborhoods make it less desirable for residents to AT (Ball et al., 2001). Friends and family members can increase an individual's AT behaviour as walking becomes a social experience rather than just travel (Ball et al., 2001, Mota et al., 2005, Timperio et al., 2006, Hohepa et al., 2007). The weather also plays a part in the decision to AT (Broderson et al., 2005, Cervero and Duncan, 2003, Copperman and Bhat, 2007). Extreme temperatures, precipitation, and high winds discourage people from using AT. The safety of a neighborhood is another factor influencing AT (Brownson and Baker, 2001, Gomez et al., 2004, Timperio et al., 2006, McMillan, 2007), as neighborhoods with higher incidences of crime and those with more dangerous streets discourage people from AT. Finally, living in a neighborhood that is hilly or has steep streets has been found to decrease AT (Timperio et al., 2006, Troped et al., 2001, Brownson and Baker, 2001, King and Castro, 2000). If topography makes AT too treacherous or difficult, people will avoid AT.

Researchers have also examined perceived barriers to walking (Spinney and Millward, 2010, Dawson et al., 2007, Adachi-Mejia et al., 2010), which primarily focus on general physical activity. Barriers refer to the environmental and personal obstacles that discourage physical activity. Researchers have used the concept of barriers to determine what prevents certain sub-groups of the population from participating in physical activity, such as walking. Spinney and Millward (2010) examine the extent income and time poverty act as barriers to regular participation in moderate or higher intensity physical activity among Canadian adults. The results find that time poverty is a more important variable than income poverty for regular physical activity engagement. Work by Dawson et al. (2007) examines the demographic factors associated with barriers to walking for middle-aged and older U.K. adults. Findings show that citing more than one environmental barrier to walking significantly decreases walking. They also find health problems affect walking more than perceived barriers. Adachi-Mejia et al. (2010) identifies perceived intrinsic barriers to physical activity among mothers in rural areas. Results find that lack of self-discipline, lack of time, and lack of interest are the most significant perceived barriers to physical activity participation.

This study builds on these past works to examine how potential barriers to AT impact different sub-groups of the population and their weekly duration of AT. To achieve this objective, this study uses data from the Hamilton Active Living Study (HALStudy) collected from May to September 2010 in Hamilton, Canada. From this data, a set of 20 binary logit models are used to determine which sub-groups are affected by each potential barrier. Each binary logit model uses a different barrier to walking as the dependent variable, comparing those who agree that the barrier prevents them from walking more often (1) with those who disagree (0). Socio-demographics are included to determine the sub-group influenced by each potential barrier. A walkability index is included in the model to examine the influence the neighborhood has on each potential barrier.

The next section describes the data collection process and the method of analysis used for this study. The results section discusses which sub-groups agree more often with the potential barriers to walking and how that affects walking duration. Finally, the conclusion summarizes the key findings and discusses their importance in the context of the literature.

5.2. METHODS

5.2.1. Data

The dataset used for this study is from the HALStudy, collected from May to September in 2010 after receiving institutional ethics approval for the protocol. The HALStudy is a multi-instrument survey that examined the active lifestyle of the adult population in Hamilton, Ontario, Canada. Subjects were recruited by cold-calling residents in 24 neighborhoods throughout the city. Several instruments were used in the HALStudy data collection: a training interview that collected height and weight, and a perceptual neighborhood drawing; a personal questionnaire; passive-GPS tracking for seven consecutive days; and a seven-day time-use diary. A full description of the data collection methodology can be found elsewhere (Clark and Scott, Under Review). All participants signed letters of informed consent before participating in the survey.

This study uses the data collected from the personal questionnaire on active living. The personal questionnaire is a detailed survey examining different types of physical activity, and includes questions about participation, perceptions, and potential barriers to types of physical activity. Additional questions were asked about perceptions of physical activity, perceptions of neighborhoods, travel behavior preferences, and socio-demographics.

For this study, the focus is on the barriers to AT. The data come from the walking and socio-demographic sections of the personal questionnaire. The final sample size is 179 participants that completed both the survey and the time-use diary. Each model has a sample size determined by the number of people who either agree or disagree with the barrier being modeled, as subjects who did not answer the question or stated they neither agreed nor disagreed are not modelled. The sample size ranges from 44 to 166 with an average of 137 subjects answering agree or disagree to the perceived barrier questions.

5.2.2. Concepts and Measures

5.2.2.1. Dependent Variable

The dependent variables are binary measures of the twenty barriers to walking questions examined in this study. Each question is based on the statement *"It is difficult for me to walk more often because..."* with the answers given using a five-point likert-scale. The likert-scale answers include strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, and strongly disagree. The list of the perceived barriers to walking questions is found in Table 11. Binary variables are created for each barrier; a value of one represents agreement with the barrier (strongly and somewhat agree) and a value of zero indicates disagreement with the barrier (strongly and somewhat disagree). Missing values and those who neither agree nor disagree are removed from the analysis to allow a direct comparison of those who agree to those who disagree for each barrier.

5.2.2.2. Independent Variables

Two types of independent variables are used in this study: individual characteristics and the built environment. A statistical summary of the independent variables is provided in Table 12. The individual characteristic variables are used to examine how sub-groups of the population are influenced by perceived barriers to AT. The variables used include age, sex, household income status, marital status, student status, employment status, parenthood, driver's license ownership, transit pass ownership, and body mass index (BMI). The explanation for choosing these variables and a definition of their specification are as follows.

Table 11: Descriptive analysis of barriers to walking. Difference-in-means t-tests comparing walking for travel for those who agree and disagree with each barrier.

It is difficult for me to walk more often because…	*n*	Disagree %	Disagree Weekly Minutes Walking	Agree %	Agree Weekly Minutes Walking	*p*-Value
Accessibility						
Work is too far away[a]	84	48.8%	106.7	51.2%	78.8	0.702
School is too far away[b]	49	59.2%	81.5	40.8%	119.9	0.353
Other destinations are too far away	136	62.5%	91.1	37.5%	81.8	0.770
Appearance Concerns						
I don't like to get hot and sweaty	141	80.9%	69.9	19.1%	117.9	0.574
I don't like being exposed to the sun	146	74.0%	81.1	26.0%	111.9	0.921
Exercise Saturation						
I get plenty of exercise by other means	138	57.2%	103.6	42.8%	56.2	0.117
I walk enough already	135	74.8%	82.5	25.2%	96.6	0.513
I walk too much already	139	94.2%	88.7	5.8%	60.5	0.107
Health						
I have a physical disability that affects my ability to walk	166	78.9%	77.1	21.1%	130.1	0.790
I have an injury that affects my ability to walk	152	75.7%	78.6	24.3%	127.6	0.943
I'm too old	156	99.4%	87.3	0.6%	31.0	0.869
I'm not in good health	153	81.7%	85.5	18.3%	120.4	0.368
Neighborhood Safety						
I don't have a safe place to walk because of crime	155	89.7%	72.2	10.3%	207.9	$p<0.100$
I don't have a safe place to walk because of stray dogs	157	94.9%	91.0	5.1%	92.4	0.650
Streets have poor lighting at night	138	82.6%	82.6	17.4%	159.3	0.941
I don't feel safe walking alone during the day	160	96.3%	83.4	3.8%	78.3	0.605
I don't feel safe walking alone at night	156	60.9%	85.9	39.1%	101.4	0.544
Sidewalk Quality						
There are no sidewalks in my neighbourhood (NH)	163	96.9%	93.4	3.1%	113.1	0.620
The sidewalks in my NH are not well maintained	160	94.4%	95.0	5.6%	96.7	0.607
Time Availability						
I don't have time	141	56.0%	110.0	44.0%	76.1	0.486
I don't make time	145	42.8%	114.5	57.2%	79.4	0.121
I don't have childcare assistance[c]	44	75.0%	97.2	25.0%	64.6	0.965
I work too much[a]	76	59.2%	102.8	40.8%	73.4	0.828
Walking Preference						
I don't like to walk	146	90.4%	132.0	9.6%	14.0	$p<0.050$
I don't feel like walking	136	75.7%	84.3	24.3%	117.4	0.486
I have no one to walk with	142	83.1%	87.0	16.9%	83.5	0.541
Routes are boring	136	79.4%	88.5	20.6%	71.6	0.206
Traffic Safety						
There is too much traffic in my neighborhood	139	83.5%	72.0	16.5%	137.7	$p<0.100$
Drivers often exceed the posted speed limits in my NH	145	54.5%	64.9	45.5%	113.1	$p<0.050$
There are dangerous crossings in my NH	138	73.9%	66.2	26.1%	125.5	$p<0.010$

[a] Questions were answered by employed individuals.
[b] Question was answered by students.
[c] Question was answered by parents with children.

Table 12: Summary statistics of independent variables used in the binary logit model.

Variables	Statistics
Weekly Walking for Travel Duration, mean (s.d.)	88.444 (150.6)
Age	
Young Adults (18-30)	16.2%
Middle Ages (31-64)	62.0%
Senior Citizens (65+)	21.8%
Female	69.3%
Income Classification	
Income Poor	14.0%
Intermediate Income	33.5%
Income Rich	22.3%
Missing Income	30.2%
Marital Status - Single	39.7%
Parent of Child(ren)	31.3%
Driver's License Ownership	85.5%
Public Transit Pass Ownership	17.3%
Currently a Student	17.9%
Currently Employed	52.5%
Walkability Index, mean (s.d.)	0.000 (3.826)
Body Mass Index, mean (s.d.)	27.380 (6.851)

Age is measured by classifying continuous ages into three groups: young adults (18-30), middle-aged (31-64), and senior citizens (65 and over). These age groups are selected as the relationship between age and perceived barriers may not be linear making it important to highlight different age groups. Age is important to examine in this study as different age groups may be affected by barriers differently.

Sex is defined as a binary variable, comparing females (1) to males (0). This is important to examine as research has documented that some barriers, such as safety, are more of a concern for women than for men. There is also evidence from past research that men are more likely to use AT than women (Owen et al., 2007, Harrison et al., 2007, Booth and Owen, 2000), highlighting the importance of examining sex differences in perceived barriers to AT.

Household income is defined in this study based on low-income cut-offs (LICO) as published by Statistics Canada (2012). LICO are defined as "income thresholds at which a family is relatively worse off compared to the average family, because it has to spend a greater portion of its income (i.e. at least 20% more than average) on basic goods and services (i.e. food, clothing and shelter) than the average family of similar size" (Spinney and Millward, 2010). High-income cut-offs (HICO) for financial wealth uses a 200% increase over LICO (Spinney and Millward, 2010) to establish three categories of wealth: HICO, LICO and intermediate income. The classification of HICO and LICO provided by Spinney and Millward are also used in this study to provide an understanding of how LICO and HICO are influenced by the barriers to AT as related to the middle class.

Marital status is defined in this paper as either single (1) or married/cohabitating (0). Examining marital status is important to evaluate as those who live with a partner have a natural live-in companion with whom to walk. While being single does not necessarily preclude having someone to walk with, a partner who lives in the same home may increase the likelihood of AT and minimize some perceived barriers, such as safety and social influences (Ball, 2006, Cleland et al., 2010). Similarly, parenthood, defined as having children living in the home (1) or no children living in the home (0), provide natural live-in companions for walking minimizing the impact of safety and social influences. Children also provide time constraints to their parents making it difficult for parents to find time to walk to destinations rather than using other modes of travel.

Employment status is defined as being a full-time or part-time worker (1) or not being a worker (0), while student status is defined as being a full-time or part-time student (1) or not being a student (0). Both of these variables are included in this study for the same reason; those who have major time commitments in life, such as school or a job, have far more pressure on their time leading to additional barriers.

Owning a driver's license or transit pass (1) versus not having them (0) identify who has access to various modes of travel. Those who have a license are more likely to use the car as primary mode of travel, while those with a transit pass walk and use transit to travel. By including these variables it is possible understand the influence travel mode has on the potential barriers to AT.

BMI is a method to evaluate the body type of individuals (Centers for Disease Control and Prevention, 2011). Those with higher BMI values are generally more unhealthy and are at far higher risks of disease, such as asthma, type-two diabetes, and heart disease. Including a continuous measure of BMI in this study provides evidence whether those with higher BMI experience different barriers then those with lower BMI values.

The built environment is measured using a walkability index. A walkability index combines multiple measures of the built environment into a single index indicating the walkability of a neighborhood. The index used in this study is based on a 1000-meter buffer around the home. The index combines population density, intersection density, retail floor area ratio, entropy index, and pedestrian infrastructure into a single value by normalizing the values for each variable and adding them together (Frank et al., 2010). The walkability index allows us to understand how different types of neighborhoods influence potential barriers to walking.

5.2.3. Analysis Methodology

The method of analysis is a binary logit model, which is estimated for each of the twenty potential barriers to walking. The models are estimated with STATA 11.0 SE (StataCorp, 2009) to determine the propensity or likelihood that an individual will agree that each barrier influences walking behavior. The logit model was chosen for this study as it makes no assumptions about the distribution of the variables and has the ability to provide valid estimates regardless of the study design (Harrell, 2001). Robust cluster standard errors is added to the model to correct the standard errors that are biased due to overlapping geographies and multicollinearity in the data (Stock and Watson, 2008).

The results of the models are presented using odds ratio, which is the number of those who agree in the barrier divided by the number of those who do not agree (Davies et al., 1998). Values greater than one have an increased odds of agreeing with the barrier while values between zero and one have an increased odds of not agreeing with the barrier. Values below zero can be interpreted by dividing the value of one by the odds ratio to get the reverse relationship. For example, an odds of 0.2 can be divided into 1.0 to find that for every 5 people who do not agree with the barrier there is one person who does agree (Davies et al., 1998). Odd ratios are only reported in this study in cases where they are found to be significant at a 90% significance level.

5.3. Results

5.3.1. Preliminary Analysis

From the people surveyed, 70.4% walked for travel at least once over the course of a week. Although this seems quite high, only 17.3% walk more than 150 minutes, meeting the recommended amount of weekly physical activity (Canadian Society for Exercise Physiology, 2012). While walking is not the only way to exercise, it is the easiest and most affordable way to get the recommended amount of moderate or vigorous physical activity. The average walking duration for those who do use AT is 89 minutes per week or 11 minutes per day, with a minimum walking duration of 0 minutes and a maximum duration of 526 minutes per week or 75 minutes per day.

A descriptive analysis of the barriers to walking describes the amount of agreement and disagreement with each barrier, as seen in Table 11. Comparing the percentages of people who agree and disagree with the barriers finds the majority of people disagree that the barriers prevent them from walking more often, with the exception of *work is too far away* and *I don't make time*.

A comparison of the weekly duration of AT between those who agree and disagree with potential barriers is shown in Table 11. A difference-in-means *t*-test determines if the difference in the average walking duration is significant. The results find five barriers to have a significant difference in the number of minutes spent AT per week between those who agree and disagree with the barriers. While *I don't like to walk* has found disagreeing with the barrier to have higher duration of walking, the other four barriers are found to have a higher duration of walking when agreeing with the barriers, including *I don't have a* *safe place to walk because of crime*, *there is too much traffic in my neighborhood*, *drivers often exceed the posted speed limits in my neighborhood,* and *there are dangerous crossings in my neighborhood*. Those who identify issues of safety as a barrier to AT may have certain characteristics that make them more likely to walk despite being concerned with safety. Further analysis is required to understand how these perceived barriers to AT are influenced by the characteristics of the population.

5.3.2. Model Results

Although there are thirty perceived barriers to AT discussed in the preliminary analysis, only a sub-set are selected to be modeled due to issues with sample size and variability in the answers provided by the subjects. First, at least 130 subjects have to either agree or disagree with the perceived barrier to ensure at least ten observations per variable are used in the model to avoid bias. Second, only barriers with both agreement and disagreement above 6% are modeled to ensure that all independent variables have enough variation to be estimated. When there is less than 6% of agreement or disagreement the models will not properly estimate because there is not enough variability in the model. After filtering out barriers that did not meet the above conditions, twenty barriers are left to be modeled. The results can be found in Table 13 and are discussed based on socio-demographic characteristics to determine how sub-groups of the population are affected by potential barriers to walking. An additional analysis compares those who agree with those who disagree with a barrier between socio-demographic sub-groups of the population in

Table 13: Results of binary logit models determining the characteristics of the individuals that influence each barrier to walking. The table is displaying the odds-ratio values significant at a 90% significance level for each variable

It is difficult for me to walk more often because…	Young Adults (18-30)	Senior Citizens (65+)	Income Poor	Middle Income	Female	Single	Student	Worker	Parent	Driver's License	Transit Pass	Body Mass Index	Walkability Index
Accessibility													
Destinations are too far away (Excluding School and Work)	2.825	-	-	-	2.043	-	-	-	-	-	-	-	-
Appearance Concerns													
I don't like to get hot and sweaty	-	-	-	-	3.118	-	2.627	-	-	-	-	2.224	1.121
I don't like being exposed to the sun	-	-	-	-	3.303	0.461	-	-	-	-	-	1.763	-
Exercise Saturation													
I walk enough already	4.912	-	-	-	-	-	-	-	-	-	-	-	-
I get plenty of exercise by other means	-	-	-	-	-	-	-	-	-	0.403	-	-	-
Health													
I'm not in good health	-	-	20.730	13.474	-	-	0.287	-	-	-	-	1.818	-
I have a physical disability that affects my ability to walk	-	-	10.141	6.292	-	-	-	0.338	-	0.395	-	-	-
I have an injury that affects my ability to walk	-	-	-	-	-	2.312	-	0.356	-	-	-	-	-
Neighborhood Safety													
I don't have a safe place to walk because of crime	-	-	11.261	4.181	-	-	0.119	-	0.339	-	-	-	1.191
Streets have poor lighting at night	-	2.710	-	-	2.226	-	-	-	-	-	-	-	-
I don't feel safe walking alone at night	-	-	-	-	7.630	-	-	-	-	-	-	0.597	-
Time Availability													
I don't have time	-	-	-	-	-	-	-	2.410	-	-	-	-	-
I don't make time	-	-	-	-	-	-	-	1.902	-	-	-	1.708	-
Traffic Safety													
There is too much traffic in my neighborhood	-	2.413	-	-	-	-	-	-	-	-	-	1.673	-
Drivers often exceed the posted speed limits in my neighborhood	-	-	-	2.596	2.021	-	-	-	-	-	-	-	-
There are dangerous crossings in my neighborhood	-	3.577	-	-	-	-	-	-	-	-	-	-	-
Walking Preference													
I don't like to walk	-	3.816	-	-	-	-	3.430	-	-	-	-	-	-
I don't feel like walking	-	-	-	-	-	2.332	-	-	-	-	-	-	-
I have no one to walk with	-	5.491	-	2.495	-	-	-	-	-	-	-	-	-
Routes are boring	-	-	-	-	3.406	-	-	-	-	-	2.194	-	-

order to determine if the potential barriers to walking alter the duration of AT within sub-groups[4].

5.3.2.1. Age

The first socio-demographic variable examined is age, focusing on how young adults and senior citizens compare to middle-aged adults. Young adults are found to significantly agree with two potential barriers more than middle-aged adults: *destinations are too far away* and *I walk enough already*. Both barriers express the dislike young people have towards walking as they perceive distances to be longer and believe minimal walking is enough. Examining the weekly duration of walking finds that young people who find destinations too far away, walk more often than those who do not. In contrast, young people who believe they walk enough already do not walk as often as their middle-aged counterparts, supporting the fact that this sub-group of the population does not enjoy walking.

Senior citizens have five potential barriers to walking have significantly more agreement than middle-aged adults: *streets have poor lighting at night, too much traffic, dangerous crossings, I have no one to walk with,* and *I do not like to walk.* The first three barriers are related to concerns about safety, as the elderly are a vulnerable population who do not have the same strength and mobility of younger age groups. Having no one to walk with is another barrier to walking and is related to safety. The social aspect of walking provides companionship along with a feeling of security that is important to

[4] Tables are available from the author upon request.

many elderly. The final potential barrier is *I do not like to walk*, showing seniors like to walk less than middle-aged adults resulting in less walking than any other age. All of these potential barriers to walking for seniors are found to decrease walking, suggesting they are barriers to walking for this sub-group of the population.

5.3.2.2. Income Status

The second socio-demographic variable, household income, compares low and middle income with high income. Three potential barriers to walking are found to be related to higher agreement for poor and middle income households compared to rich income households: *not in good health*, *have a physical disability,* and *no safe place to walk because of crime*. The first two barriers are related to quality of life. Households with lower income cannot access healthy foods and physical activity infrastructure as easily as medium and high incomes, thus increasing health problems and increasing the impact of disability (Larsen and Gilliland, 2009). When relating this back to walking duration, being disabled and in poor health is more of a barrier to the middle income population. While the poor are forced to walk regardless of their health, middle income households can afford to use the more expensive car to travel. Issues of crime can also be minimized by the affluent, as they have more choice as to the neighborhood they live. Lower income households may have a much more limited choice in the neighborhood they live. Crime concerns have a much bigger impact on the poor as the perceptions of crime may be much closer to reality than those perceived by the middle income families.

5.3.2.3. Female

The third socio-demographic variable examined is sex, comparing females to males. Seven potential barriers to walking are found to be related to higher agreement for females than males: *streets have poor lighting at night*, *don't feel safe walking alone at night*, *drivers often exceed the speed limit*, *don't like getting hot and sweaty*, *don't like being exposed to the sun*, d*estinations are too far away* and *routes are boring*. Concerns about walking at night due to safety and poor lighting is not an unusual concern for women as the findings of past research has determined these concerns to be related to women (Brownson and Baker, 2001, Gomez et al., 2004, Timperio et al., 2006, McMillan, 2007). These safety concerns have the highest impact on women, since women are the most likely population group to be victims of crime.

The other barrier found significant and to also negatively impact walking is *routes are boring*, which are related to aesthetics. When routes are perceived to be interesting, walking increases among women but do not change for men. While other barriers are found to have significantly more agreement among women than men, they do not negatively impact walking, as women who agree to the barriers actually walk more often.

5.3.2.4. Marital Status

The fourth socio-demographic variable examined is marital status, comparing unmarried and single people to those who are married or cohabitate. Two potential barriers to walking are found to be related to higher agreement among those single compared to those who have a partner, including *having an injury* and *not feeling like* *walking*. Those single who agree to having injuries walk more than those who disagree, suggesting that having injuries does not influence their walking. This may be a result of injuries being a temporary ailment that does not change the personal travel plan of those who agree. Not feeling like walking decreases the amount of walking done by those who are single. This finding may be due to married couples provide extrinsic motivation or encouragement to each other to be active, which is not readily available to those who are single.

5.3.2.5. Student Status

The fourth socio-demographic variable examined is student status, comparing students to non-students. Two potential barriers to walking are found to be related to higher agreement for students than non-students: *I don't like to get hot and sweaty* and *I don't like to walk*. While students are young and may be more concerned about their appearance than non-students, students who agree to this barrier are actually found to walk more often than students who disagree. The preference of not liking to walk has a significant influence on students, where they walk half the time than those who like walking.

Two potential barriers to walking are found to be related to higher agreement for non-students than students: *I'm not in good health* and *I don't have a safe place to walk because of crime.* Students are often young and healthy, thus those who are not students may have health problems that do not influence students. Those with health problems and not students walk less than non-students without health problems. Non-students also are concerned with crime more than students, which may be a result of students living in 'student ghettos' located close to a university or college. These areas are places where there is a community and most of the residents are affiliated with the university or college. Non-students are not all concerned about crime, but those who are concerned, walk less than students but more than non-students who are not concerned with crime.

5.3.2.6. Employment Status

The fifth socio-demographic variable examined is employment status, comparing workers to non-workers. Two potential barriers to walking are found to be related to higher agreement for workers than non-workers: *I don't have time* and *I don't make time*. These barriers are related to the time constraints of workers who work a regular shift. Workers who agree they don't have time or make time walk more than non-workers who agree, but not as long as those who disagree. While this finding suggests that being employed encourages walking, perceiving time constraints for workers significantly reduces weekly walking duration. The perceptions of not having time may be the result of a longer commute between home and work.

Two potential barriers to walking are found to be related to higher agreement for non-workers than workers: *having a physical disability* and *having an injury*. Both of these barriers would make working quite difficult, so the significance they have for non-workers is expected. This is confirmed by the fact that non-workers with injuries or disabilities walk less than workers with injuries or disabilities.

5.3.2.7. Parenthood

The sixth socio-demographic variable examined is parenthood, comparing parents to non-parents. One potential barrier to walking is found to be related to higher agreement for non-parents than parents: *I don't have a safe place to walk because of crime*. While parents may self-select a neighborhood where they live based on being safe and crime-free, child-free households do not have the same priorities. Despite these findings, non-parents who are concerned about crime walk significantly more than those who are not concerned. This finding suggests that those who walk perceive more crime in their neighborhood than the non-walking public because they are more aware of the world around them.

5.3.2.8. Driver's License Ownership

The seventh socio-demographic variable examined is driver's license ownership, comparing those owning a license to those not owning a license. AT is required for those who do not have a license and this is supported by those without a license walking 2.5 times longer than those with a license. Still, there are potential barriers that prevent those without a license from walking more, including *I get plenty of exercise by other means* and *I have a physical disability*. Those who agree they do not walk more often because they exercise by other means walk the same as those who disagree. This shows that those who are more inclined to be active will be active in many different ways, walking included. People without a license who indicate they have a disability do not walk as much as those who do not have a disability, suggesting that not having a license forces people to walk but having a disability decreases the amount of weekly walking.

5.3.2.9. Transit Pass Ownership

The eighth socio-demographic variable examined is transit pass ownership, comparing those owning a transit pass to those not owning a transit pass. One potential barrier to walking is found to be related to higher agreement for those with a pass than without a pass: *routes are boring*. This suggests that the routes taken for those who use transit regularly are preventing people from walking more often for travel and the evidence supports this finding with those who agree and having a pass walking significantly less than any other group. Those with a transit pass walk to and from stops but use transit the rest of the time. Maybe if there were more interesting routes within the neighborhood these people may walk more often instead of primarily using transit.

5.3.2.10. Body Mass Index

The ninth socio-demographic variable examined is BMI, comparing how potential barrier agreement relates to an increasing BMI . Five potential barriers to walking are found to be related to higher agreement when BMI increases: *I don't like to get hot and sweaty*, *I don't like being exposed to the sun*, *I'm not in good health*, *I don't make time*, and *there is too much traffic in my neighborhood*. Despite each of these barriers being stated that they have more agreement among those with higher BMI values, there is little evidence that they actually decrease walking duration. For instance, agreeing with living in a neighborhood where there is too much traffic has a higher walking duration for those who are underweight, normal weight and obese. The one exception to this pattern is that those who agree to not making time walk less than those who disagree and generally the amount decreases as BMI increases. This suggests that as BMI increases there is less priority placed on walking, which may be a contributing factor for BMI being high in the first place.

One potential barrier to walking is found to be related to higher agreement when BMI decreases: *I don't feel safe walking alone at night*. Having a higher BMI can increase a person's feeling of safety, as larger body types are more able to protect themselves when dangerous situations arise. Despite those with lower BMI's feeling unsafe walking at night and those with a higher BMI feeling safe, the low BMI group has the highest weekly walking duration and the high BMI group has the lowest weekly walking duration.

5.3.2.11. Walkability Index

The final variable examined is the walkability index, comparing how potential barrier agreement relates to increasing walkability. Two potential barriers to walking are found to be related to higher agreement when walkability increases: *I don't like to get hot and sweaty* and *I don't have a safe place to walk because of crime*. Those who do not like to get hot and sweaty may have higher agreement when living in a more walkable neighborhood, but there is no influence on walking duration. In general, for those who disagree, the more walkable a neighborhood, the higher the duration, but the agreement shows no pattern. Those who live in a dangerous neighborhood because of crime walk more in highly walkable neighborhoods regardless of agreement or disagreement. The higher agreement occurring as walkability increases may be the result of high walkable neighborhoods located in areas of the city where crime is more of a concern. As the walkability decreases, so does the concern of crime.

5.4. Discussion

This study has investigated potential barriers to AT in Hamilton, Canada using a descriptive analysis of the barriers followed by a series of binary logit models. The findings show that while many people AT, most do not walk very far throughout the week. Analyzing how the sub-groups of the population are influenced by the barriers to walking can provide policy makers with a profile for the type of people who are affected by each barrier. This also allows policy decisions to be made targeting specific population groups.

The results find that some barriers to walking have a larger impact on sub-groups of the population. While the Canadian public health system provides free health care to all Canadians, concerns with health barriers to walking are still more prevalent among the poor, middle class, and unemployed. This may be a result of the wealthy and employed being able to afford the additional services provided by health benefit packages, such as physiotherapy and drug plans. The wealthy are also able to afford health promotion activities, such as a gym membership and participation in sports, which all cost money. By working with the less fortunate, policy makers and health care providers can identify activities that can improve the perceived health of residents to minimize the impact health has on the ability to AT.

Issues of safety are a concern to the vulnerable sub-groups of women and senior citizens. Those who are more vulnerable will always have more fear of their neighborhood due to crime and pedestrian safety than the average citizen. While, this is not a new finding in the literature (Brownson and Baker, 2001, Gomez et al., 2004, Timperio et al., 2006, McMillan, 2007), it is important to identify as policy makers need to do a better job of increasing safety in dangerous areas in the city.

Finally, those who are employed are far more likely to be influenced by barriers due to time availability. The amount of time reserved for working makes it difficult for workers to AT. Time barriers are reinforced by the ever increasing distance between home and work caused by urban sprawl, which limits the ability to walk to work even when it is desired. In order to minimize the influence work has on AT it is important for health promoters to highlight walking for other purposes, such as shopping or visiting friends. Even though work may not be accessible, there are many other destinations that are far easier to reach on foot.

Future work examining walking will focus on how walking fits into the greater physical activity framework in Hamilton, Canada. By understanding overall physical activity participation, it is possible to determine if those who do not participate in walking participate in any other types of physical activity. Future work will also consider how subgroups of the population are affected by these barriers in relationship to actual walking behavior, as measured by the Global Positioning System data.

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Chapter 6 Conclusion

This dissertation has built on the current literature to better understand the determinants of active travel (AT). In particular, it has advanced the knowledge of the methodology used to conceptualize the built environment (BE) by examining the differences between disaggregate and aggregate measures of the BE as well as examining the influence the modifiable areal unit problem (MAUP) has on the relationship between AT and the BE. This dissertation has also adapted a conceptual framework from the physical activity literature, so that the social environment can be combined with the previously understood individual and physical environments. Finally, this dissertation examines how perceived barriers to AT influence different sub-groups of the population. Overall, each chapter of this dissertation work together to addresses gaps and weaknesses in the past literature by addressing the four research questions that guide this work.

6.1. Conceptualizing the Built Environment

Chapter 2 of this dissertation has addressed the first research question, *does the relationship between AT and the BE change when conceptualization of the BE changes from an aggregate to disaggregate approach?* The results have found that the relationship between AT and the BE does change when the method of conceptualization changes from an aggregate to disaggregate approach. Initially, the disaggregate approach is able to better inform policy makers what elements of the BE increase the propensity for an individual to use AT. For instance, after controlling for socio-demographics and accounting for meteorology, only population density and pedestrian infrastructure are found to be significantly associated with an increase in the propensity to use AT.

In contrast, using the walkability index to conceptualize the BE from the five BE variables used in this study is found to be significantly related to AT, which is in agreement with past work (Frank et al., 2006, Leslie et al., 2007, Frank et al., 2010, Owen et al., 2007). Comparing the results from these two measurement techniques has shown that using an index to measure the BE hides the fact that only two of the five BE variables are significant when measured individually.

These results show the danger of using walkability indices in research. If the goal of a study is to make the BE seem important then a walkability index can be used, but in reality it is a generalization of the local environment that can provide little relevance to policy and the search for causation. In contrast, a disaggregate approach can provide researchers and policy makers with the ability to understand the true impact the BE has on AT without any predetermined biases. The results of this study find the BE has very little relationship to AT and other factors need to be explored more extensively in order to better understand the determinants of AT.

6.2. Influence of Modifiable Areal Unit Problem

Chapter 3 of this dissertation has addressed the second research question, *how much influence does the zone and scale effects of MAUP have on the relationship between AT and BE among adults?* The results support the findings of past studies showing that changing the zonal type and size does change the relationship between AT and the BE.

Comparing the pseudo R^2 finds that the model using a 200-meter grid scale has the highest variance explained by the BE (57.4%) and the 400-meter grid scale has the lowest variance explained by the BE (24.6%), although the difference between the two pseudo R^2 is moderate.

Additionally, both the scale and zoning effects of the MAUP influence the relationship between AT and the BE. A key finding of this study is that the scale effect of the MAUP impacts both the significance and the coefficients of the BE variables. Results find that all of the BE variables are found to be significant in at least one model, although there is no consistency in which variables of the five are significant between models. A lack of consistency was also found between the coefficients of the variables for each model, with some found to have major differences, while others do not. These results show that the BE variables are severely influenced by the scale effect of the MAUP, making it difficult to identify the ideal scale at which to measure the BE.

The final key finding of this study is that the zoning effect of the MAUP has a significant influence on the relationship between AT and the BE. Results find that while there is little difference between the 1600-meter buffer and the dissemination area models, the remaining model pairs are quite different. The majority of both the socio-demographic and the BE variables are found to have differences in the coefficients, while only the BE variables have differences in the significance.

Although the results show different zones measuring the BE lead to different relationships between AT and the BE, establishing the ideal scale to measure the BE is difficult. Riva et al. (2008) and Zhang & Kukadia (2005) both state important considerations that need to be addressed when selecting the ideal scale. Riva et al. believe that administrative areas, such as census tracts, are poor scales due to their heterogeneous nature. Although this may be true, the BE measured using the administrative areas finds some of the highest relationships with AT. One reason for Riva et al. findings was that they were more interested in finding optimized zones to examine the BE, rather than allowing policy objectives to dictate the scale. Zhang & Kukadia determine a 400-meter buffer around the home is ideal because it produces more tractable and stable results by using disaggregate data as much as possible and basing scale on travel behavior. These findings are supported by this study, but other factors need to be considered as well.

The previous findings lead to three decision rules to select the ideal scale to measure the BE. First, use a zone that is appropriate for the problem being investigated. Objectives, such as policy, should dictate the zone, so if the purpose of a study is to investigate walkable neighborhoods the zone should reflect the purpose. Second, the zone should be related to actual AT distances within the study whenever possible. For instance, the 400-meter buffer used by Boer et al. (2007) represents the median length of a daily walking trip in the dataset they used, the 1995 Nationwide Personal Transportation Survey. By taking into account actual AT behavior, the true impact of the BE can be evaluated. Third, using disaggregate data as much as possible, as suggested by Zhang & Kukadia (2005), will minimize the impact MAUP has on the models. If census geography or other aggregated scales are necessary, use methods, such as a multilevel model or robust cluster analysis, to account for the multicollinearity inherent in the data. Overall these three decision rules help in establishing the ideal scale to measure the BE when relating AT and the BE, although the scale used will still vary.

6.3. Influence of the Social Environment

Chapter 4 of this dissertation has addressed the third research question, *to what extent does the four components of the social environment influence AT while controlling for the individual and physical environments?* The results of a series of linear regression models lead to two of the social environment categories being found to be significant (social cohesion and role models) and two of the social environment categories being insignificant (companionship and encouragement). The social cohesion question "people in my neighborhood can be trusted" and the role model question "seeing my friends participate in PA makes me want to participate" are both found to significantly increase the duration of AT for travel in this study.

An unexpected finding of this study is that companionship does not influence AT in this study, despite companionship consistently being found significantly related to walking for exercise (Booth and Owen, 2000, Cleland et al., 2010, Cutt et al., 2007, Giles-Corti and Donovan, 2002, Harley et al., 2009). Understanding the reasoning for this unexpected finding can be tied back to time geography principals. The foundation of time geography, as developed by Hägerstrand (1970), discusses the three constraints that bound everyone in time and space, including capability constraints, coupling constraints, and authority constraints. This study focuses on the coupling constraints which define where, when, and how long an individual has to join other people to produce, consume, and travel. These coupling constraints are far more restricting when walking for travel than walking for exercise and other physical activity types found significant in the past.

For instance, if two people want to walk together they need to communicate to set up a time and place to leave for their destination. Individuals have their own personal activities that they need to schedule around, such as work, school, family commitments, recreational activities, etc. If these two people are unable to find a time that works for both of them, then they will not walk together. In contrast, when walking alone people are only constrained by their own schedule, so if they decide they want to walk for travel they can simply do so without being constrained by others.

In conclusion, this study has shown that the conceptual framework combining the individual, physical, and social environments can lead to a better understanding of what increases AT. If this study, like most others, ignored the social environment there would have been 29.6% less variance explained by the model. As a result, the four components of the social environment need to be considered along with the other environments to ensure a complete understanding of the factors influencing AT.

6.4. Barriers to Active Travel

Chapter 5 of this dissertation has addressed the final research question, *how are sub-groups of the population influenced by barriers to AT?* The results find that some barriers to walking have a larger impact on sub-groups of the population. While the Canadian public health system provides free health care to all Canadians, concerns with health barriers to walking are still more prevalent among the poor, middle class, and unemployed. This may be a result of the wealthy and employed being able to afford the additional services provided by health benefit packages, such as physiotherapy and drug plans. The wealthy are also able to afford health promotion activities, such as a gym membership and participation in sports, which all cost money. By working with the less fortunate, policy makers and health care providers can identify activities that can improve the perceived health of residents to minimize the impact health has on the ability to AT.

Issues of safety are a concern to the vulnerable sub-groups of women and senior citizens. Those who are more vulnerable will always have more fear of their neighborhood due to crime and pedestrian safety than the average citizen. While, this is not a new finding in the literature (Brownson and Baker, 2001, Gomez et al., 2004, Timperio et al., 2006, McMillan, 2007), it is important to identify as policy makers need to do a better job of increasing safety in dangerous areas in the city.

Finally, those who are employed are far more likely to be influenced by barriers due to time availability. The amount of time reserved for working makes it difficult for workers to AT. Time barriers are reinforced by the ever increasing distance between home and work caused by urban sprawl, which limits the ability to walk to work even when it is desired. In order to minimize the influence work has on AT it is important for health promoters to highlight walking for other purposes, such as shopping or visiting friends. Even though work may not be accessible, there are many other destinations that are far easier to reach on foot.

6.5. Policy Implications

This research has many policy-related implications. First, when making policy decisions regarding the BE, policy makers need to understand that walkability indices are generalized measures of the BE and may lead to incorrect assumptions about the individual variables that make up an index. For example, changing all five components that make up the walkability index will increase AT in the Halifax Regional Municipality (HRM), but targeting one feature of the BE will only increase AT in HRM if population density or pedestrian infrastructure is the feature targeted. Researchers need to validate the BE variables before including them in a walkability index. Simply using a walkability index already developed, such as the one by Frank et al. (2010), will most likely find a significant relationship with AT, but interpreting the results for policy is difficult without the initial validation.

Second, policy makers need to understand that the true impact of the BE on AT is limited, as this dissertation finds the BE has little significance as related to AT. In fact, it seems that other factors, such as socio-demographics, weather, social influence, and potential barriers to AT, may play a much larger role in AT behaviour among adults. Further research may show that the BE influences discretionary AT or walking for leisure purposes far more than general AT. In the end, distance is most likely the ultimate barrier to AT, where AT is much more possible when destinations are within walking distance (Giles-Corti et al., 2005).

Third, policy makers need to be aware of the potential barriers to AT that can prevent individuals from walking for travel. While health promotion activities and promoting walking to discretionary destinations can both lead to increases in AT, policy is limited in its ability to have an impact on these activities. Instead, issues of safety experienced by vulnerable sub-groups, such as women and seniors, can be addressed. Safety can be improved in three main areas: lighting, street intersections, and sidewalks/multi-use pathways. Areas of neighbourhoods that have poor lighting can be brightened, including streets, parks, and shortcuts. Dangerous street intersections with high traffic speeds can be improved with the creation of new traffic signals and count-down crosswalks. Finally, new sidewalks and multi-use paths can be built to minimize the impact of pedestrian dangers as they relate to street traffic by helping to separate the pedestrians from traffic.

6.6. Directions of Future Research

The advance in the methods used to conceptualize the BE combined with the adaptation of a conceptual framework to better understand the determinants of AT provides two distinct directions that future research can take. First, methods used to conceptualize the BE can be improved by providing a better understanding of how neighborhoods are defined. By asking people to draw what they consider their neighborhood, researchers can better measure and evaluate the built environment of an individual's neighborhood.

Second, the conceptual framework developed in this dissertation needs to develop a standardized method to conceptualize the social environment. While many studies in the past have examined the social environment as it relates to physical activity, it is difficult to quantify and conceptualize the qualitative data. Future research should also focus on the individual environment, which includes self-efficacy and preferences. Controlling for an individual's basic beliefs, likes, and dislikes seems straight forward, but there is very little research in the AT literature examining these important factors.

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