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Examining the relationship between active travel, weather, and the built environment: a multilevel approach using a GPS-enhanced dataset

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Abstract This study examines how the built environment and weather conditions influence the use of walking as a mode of transport. The Halifax Regional Municipality 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 Space-Time Activity Research project, a daily meteorological summary from Environment Canada, and a comprehensive GIS dataset from the regional municipality. Two binary logit multilevel models are estimated to examine how the propensity to use walking is influenced by the built environment and weather while controlling for socio-demographic characteristics. The built environment is measured via five attributes in one model and a walkability index (derived from the five attributes) in the other. Weather conditions are shown to affect walking use in both models. Although the walkability index is significant, the results demonstrate that this significance is driven by specific attributes of the built environment—in the case of this study, population density and to a lesser extent, pedestrian infrastructure.

Keywords Active travel · Built environment · GIS · Walking · Walkability Index · Weather

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 (Brownson and Housemann 2000), which cost

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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 and Lifestyle Research Institute 2009). Furthermore, only 48 % of Canadians are getting a moderate amount of physical activity (Canadian Fitness and 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, defined as traveling between locations using an active mode such as walking or cycling, 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 seem high, an assessment of regular participation demonstrates the lack of regular active travel 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 active travel a routine type of activity. Before making policy changes to increase active travel, policy makers need to understand the factors that influence the use of active modes of transport. Previous research has shown that many factors affect such modes in an urban environment, including objective and perceived measures of the built environment (Brownson et al. 2009; Cervero and Duncan 2003; Frank et al. 2010; Guo et al. 2007; Rutt and Coleman 2005), safety concerns (Alton et al. 2007; Carver et al. 2005), social interaction (Ball et al. 2001; Carver et al. 2005), and weather (Cervero and Duncan 2003; Spinney and Millward 2011). Although all these factors relate to active travel, the built environment is critical because its features can be controlled through planning policy (Frank and Engelke 2001). This study identifies factors that affect the use of walking as a mode of transport in an effort to understand the relationship between active travel and the built environment. Despite the fact that researchers acknowledge that a relationship exists between active travel and the built environment, there is a lack of consensus about the extent of the relationship (Handy 2005; Saelens and Handy 2008). This is due to the various measures and methods used to evaluate the relationship between active travel and the built environment, which, in turn, has led to few consistencies among study findings.

This study addresses the relationship between active travel and the built environment using a binary logit multilevel modeling approach and attributes of the built environment found to be significant in past research. Active travel use is measured using a binary variable indicating whether an individual, over the course of a day, walked for transport (1) or not (0). The binary variable is used to identify attributes of the built environment that policy makers can potentially target to increase the propensity of an individual to use active modes of transport For instance, if pedestrian infrastructure is found to increase walking, policy makers could potentially increase sidewalk coverage in neighborhoods. The built environment variables used in this study are those found to be consistently significant in past work, and they are measured at the census tract level. The variables are: population density, street connectivity, land-use mix, pedestrian infrastructure, and retail floor area ratio. Daily weather conditions are used as explanatory variables to determine if weather plays a significant role in the use of walking. Little is known about the relationship between walking and weather as it has been ignored in the vast majority of past studies. Finally, the modeling approach controls for socio-demographic characteristics.

The sample for this study consists of 1,855 people living in 84 census tracts in the Halifax Regional Municipality, Nova Scotia, Canada. The study area has defined urban, suburban, and rural land-use patterns making Halifax a representative, mid-size North American city. Evaluating the built environment 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 built environment leads to the use of a multilevel model to analyze the relationship between walking and the built environment (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).

This study makes the following contributions to the literature. Using a multilevel model to examine the relationship between walking and the built environment allows a better understanding of geography's impact on the relationship. Second, examining weather variables as behavioral determinants in the model allows policy makers to understand whether the built environment can make a difference in cities where there are extreme weather conditions. Third, the combination of built environment variables used in this study is unique as this study combines variables that were found to be consistently significant in past literature. Finally, this study compares how the model results differ when conceptualizing the built environment using individual attributes 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 active travel and the built environment to establish which attributes of the built environment relate to active travel. The data and methods section describes the data collection process, variables, and modeling approach used for the analysis. The results section discusses the model specification and presents the model results. Finally, the conclusion summarizes the key findings and discusses their importance in the context of the literature and the implications they have on policy.

Background

Recent research has focused on the relationship between active travel and the built environment. 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 active travel and the built environment. Often, studies use different measures of active travel, the built environment, 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. (2006) described the development of a walkability index to examine the relationship between active travel and the built environment. The walkability index incorporates four different measures of the built environment into a single index to evaluate the degree to which a neighborhood is walkable: net residential density, intersection density, land-use mix, and retail floor area ratio. The neighborhood is measured as a 1-km buffer around the household of each subject with a single value representing walkability. The linear regression model developed by Frank et al. found a significant positive relationship between walkability and the number of minutes spent per day using active modes of transport in King County, WA.

Other authors have incorporated Frank et al.'s method of measuring the built environment (Leslie et al. 2007; Owen et al. 2007). Leslie et al. examined the validity of the walkability index to represent the degree to which a census division is walkable. Their results demonstrated that the walkability index is a valid measure to determine the walkability of a census division. Their 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 built environment around them.

Owen et al. (2007) built on the work by Leslie et al. (2007) 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. Their 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) showed that there are some differences between indices, but the overriding characteristics are the same. The benefit of the walkability index is that it can evaluate the degree to which active travel is influenced by the walkability of a neighborhood. Using a single index to represent the built environment simplifies a model by identifying neighborhoods with high or low walkability. Also, a single index avoids modeling issues such as multicollinearity among spatial variables. However, a weakness of a walkability index is that policy makers are unable to determine which components comprising the index are responsible for active travel use. Policy makers may also make inaccurate assumptions regarding the true relationship between active travel and the built environment when they are unable to understand how each component of the index is related to active travel.

Instead of using a walkability index to measure the built environment, a more disaggregate approach can be used. A disaggregate approach takes individual attributes of the built environment into a model to determine how each element relates to active travel. This approach allows researchers to identify specific components of the built environment that act as barriers to active travel, thus making it possible to suggest policies that target specific components of the built environment.

Initially, researchers, such as Cervero and Duncan (2003), used quasi-disaggregate approaches for measuring the built environment by using factor analysis to join together related measures of the built environment. Cervero and Duncan used a binomial choice model to identify the probability that an individual chose to walk to different destinations within 15 min of their home. The final built environment measures were derived from 18 built environment attributes that were measured using one-mile and five-mile buffers around the home. The results of the factor analysis identified four main components of the built environment: land-use intensity, land-use mix, land-use accessibility, and walking quality. When including these measures of the built environment into a binomial choice model, only land-use mix was found to significantly increase the probability of walking.

More recently, researchers have used $\sim$50 disaggregate measures of the built environment to examine its relationship with active travel. These measures can be found in various reviews focusing on active travel (e.g., Brownson et al. 2009; Crane 2000; Saelens and Handy 2008). However, despite the plethora of measures, only a few are commonly found to be related to using active modes of transport. Rutt and Coleman (2005), for instance, examined the relationship between walking, as defined by frequency of walking trips during the last month, and the built environment using stepwise regression. The built environment was 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) examined the probability of making a non-auto trip using a bivariate ordered probit model. The built environment was measured at one-mile and quarter-mile buffers around the home with one-mile population density 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 active travel and the built environment to identify built environment variables consistently found to be related to active travel. The review identified four such variables: population density (Boer et al. 2007; Braza et al. 2004; Ewing et al. 2004; Kerr et al. 2006; Rodriguez and Joo 2004), land-use mix (Boer et al. 2007; Cervero and Duncan 2003; Ewing et al. 2004; Kerr et al. 2006; Krizek and Johnson 2006), street connectivity (Boer et al. 2007; Braza et al. 2004; Cervero and Duncan 2003; Ewing et al. 2004; Kerr et al. 2006), and pedestrian infrastructure (Ewing et al. 2004; Rodriguez and Joo 2004).

Data and methods

Data

The data for this study come from the Space-Time Activity Research (STAR) project collected in the Halifax Regional Municipality from April 2007 to May 2008. A detailed description of the survey design (Spinney and Millward 2011) 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 the Halifax Regional Municipality. 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 1,971 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 computer assisted telephone interview (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 global positioning system (GPS)-prompted recall diary and a traditional time-use diary. Primary respondents were tracked using a passive GPS tracking device and were 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 used 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 period (Spinney et al. 2012). All other respondents used a traditional pen and paper survey to record their activities and trips for the 2 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 1,855 subjects living in 84 census tracts. The first day of the data collection was selected as every subject completed the first day of the study whereas not every subject completed the second day.

Concepts and measures

Dependent variable

The dependent variable in this analysis is a binary measure of active travel indicating whether an individual walked for transport on the day of study (1) or not (0). Statistics show that Canadians do not regularly use active modes of transport (Cragg et al. 2006). Motivated by such statistics, this study uses a binary variable to determine what aspects of the built environment could potentially be used as triggers to encourage people to walk more often.

Individual level variables

Three groups of individual level variables are used in this study: socio-demographic, weather conditions, and the built environment (see Table 1). The socio-demographic variables control for any confounding effects that would alter the relationship between walking and the built environment. The variables used were collected from the CATI interview and include sex (female is reference), age, household size, household income (over $100,000 is reference), and number of cars per licensed driver. An additional variable is also added to control for participation in the STAR survey on a weekday compared to a weekend. Further binary socio-demographic variables and their definitions are as follows:

- *Completed post-secondary degree* respondent graduated with at least a post-secondary degree (1) versus attended college or university without a degree or a lower education level (0).
- *Bus pass* respondent had a bus pass at the time of the survey (1) versus no bus pass (0).
- *Valid driver's license* respondent had a valid driver's license at the time of the survey (1) versus no valid driver's license (0).
- *Full-time or part-time employee* respondent had a full-time or part-time job at the time of the survey (1) versus no job or retired (0).
- *Full-time or part-time student* respondent was a full-time or part-time student at the time of the survey (1) versus not a student of any kind (0).

Weather conditions comprise another set of variables examined at the individual level. Weather is included in the analysis to determine the extent to which average temperature (°C), total precipitation (mm), and maximum wind speed (km/h) impact walking. These variables were obtained from Environment Canada (2010) for the day of data collection for each subject.

Distance from home to work or school is the only built environment variable measured at the individual level. The measure is based on the shortest path distance in km 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. All other subjects were given a distance of 0 km. The continuous distance measure is included in this study to capture the relationship between walking and proximity to work or school.

Census tract level variables

All variables measured at the census tract level are measures of the built environment. The variables were selected based on the finding of being significantly related to active travel in past studies. When examining such studies, the walkability index developed by Frank et al. (2006, 2010) is consistently found to be positively related to active travel regardless of the study area or scale—that is, as the walkability index increases, so too does active travel. Frank et al.'s walkability index aggregates four standardized built environment variables into a single measure: net residential density, intersection density, land-use mix, and retail floor area ratio. An exhaustive literature review by Brownson et al. (2009) also confirms that population density, land-use mix, street connectivity, and pedestrian infrastructure are consistently related to active travel. While many other variables have been found to be

Table 1 Descriptive statistics of independent variables

Variables	Statistics
Census tract level	
No. of census tracts (n)	84
Built environment	
Pedestrian infrastructure (×10), mean (SD)	3.851 (5.620)
Retail floor area ratio (×10), mean (SD)	2.720 (2.054)
Population density ($\times 10^{-3}$), mean (SD)	1.856 (1.804)
Entropy index (×10), mean (SD)	6.549 (1.192)
Street connectivity (×10), mean (SD)	2.222 (1.547)
Individual level	
No. of individuals (n)	1,855
Socio-demographic	
Age ($\times 10^{-1}$), mean (SD)	5.201 (1.355)
Household size, mean (SD)	2.780 (1.220)
Number of cars per licensed driver, mean (SD)	0.801 (0.378)
Male	47.0 %
Completed post-secondary degree	69.8 %
Valid driver's license	95.8 %
Bus pass	4.7 %
Full-time or part-time student	2.7 %
Full-time or part-time employee	67.7 %
Household income	
Under $20,000	1.9 %
$20,000–$39,999	10.3 %
$40,000–$59,999	14.3 %
$60,000–$79,999	15.8 %
$80,000–$99,999	13.2 %
Over $100,000 (reference)	29.3 %
Missing income	15.1 %
Participated in study on weekday	76.3 %
Weather	
Mean temperature (°C), mean (SD)	7.304 (9.430)
Total precipitation (mm), mean (SD)	4.271 (9.630)
Maximum wind speed (km/h $\times 10^{-1}$), mean (SD)	4.337 (1.509)
Built environment	
Distance from home to work/school (km), mean (SD)	5.130 (10.771)

SD standard deviation

related to active travel, 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), the five built environment variables selected for this study are ones that have been consistently found to be related to active travel.

The selected variables were developed in ArcGIS® 10 using the methods found in *Standards for Environmental Measurement Using GIS* (Forsyth et al. 2006) using data provided by the Halifax Regional Municipality. The variables are:

- *Population density* the number people living in a census tract per square km of land.
- *Entropy index* (*measures land-use mix*) the degree to which a census tract has uniformly diverse land use. The index ranges from 0 for only one type of land use to 1 for equal distributions of land uses. Land-use categories include residential, commercial, institutional, office, park and recreation, and industrial.
- *Street connectivity* the ratio of the number of four-way intersections to all intersections. It ranges from 0 for a cul-de-sac street structure to 1 for a grid-like 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 that there is less parking available for customers.
- *Pedestrian infrastructure* the ratio of sidewalk length (m) to road length (m). The higher the ratio, the more sidewalks are available for pedestrians.

These five built environment variables are also combined into a walkability index using the approach developed by Frank et al. (2006, 2010)—that is, each variable is standardized as a z-score and summed to create a walkability index.

Method of analysis

A binary logit multilevel model is used to analyze the relationship between walking as a mode of transport and the built environment to account for the ecological or hierarchical nature of the data. The model estimated in this study concerns walking 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:

$$W_{ij} = \beta_{0ij} + u_{0j}$$

where i represents the individual level, j represents the census tract level, W_{ij} represents the use of walking as a mode of transport (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 (Model 1), further models are developed to identify the impact of each set of variables on the random intercept effect and the log likelihood. Model 2 adds the socio-demographic variables to the null model. Model 3 includes the socio-demographic variables and weather conditions. The final two models add the built environment variables at both the individual and census tract levels to Model 3. Model 4a includes the five disaggregate built environment variables while Model 4b uses the walkability index developed from the five variables to represent the built environment.

Results

Model specification

As discussed in the last section, several models are specified for this study in order to determine the influence of each set of variables on the use of walking as a mode of transport. Model 1, the null model, determines if there is a significant difference between census tracts in terms of walking use. This model has a log likelihood of −1,180.1492. The between census tract variance is found to be 0.282 with a p value of 0.001, meaning there is a significant amount of unexplained variance between census tracts at the 0.05 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 −1,088.5719. Adding the socio-demographic characteristics accounts for 45.6 % of the differences in walking use between census tracts. The between census tract variance is 0.153 and the p value is 0.001, indicating that there is still significant unexplained variance between census tracts at the 0.05 significance level.

Model 3 adds the weather variables to Model 2 to identify weather conditions that impact walking. This model has a log likelihood of −1,068.5685. Adding the weather variables to the socio-demographic characteristics accounts for an additional 12.0 % of the differences in walking use between census tracts. The between census tract variance is 0.1196 and the p value is 0.005, indicating, once again, that there is still significant unexplained variance between census tracts at the 0.05 significance level.

Model 4a adds distance from home to work or school and the five disaggregate built environment variables to Model 3 to identify specific attributes of the built environment that impact walking. This model has a log likelihood of −1,047.0735. Adding the variables to the socio-demographic and weather variables accounts for an additional 41.4 % of the differences in walking use between census tracts. The remaining between census tract variance is 0.003 with a p value of 0.470, meaning that the combination of built environment, weather, and socio-demographics accounts for all of the unexplained variance between census tracts when measured at the 0.05 significance level.

Model 4b adds distance from home to work or school and the walkability index to Model 3 to determine if the overall index, which consists of the five different components of the built environment developed for this study, impacts walking use. The model has a log likelihood of −1,049.4428. Adding the walkability index to the socio-demographic and weather variables accounts for an additional 37.8 % of the differences in walking use between census tracts. The remaining between census tract variance is 0.013 with a p value of 0.366, meaning that the combination of built environment, weather, and socio-demographics accounts for all of the unexplained variance between census tracts when measured at the 0.05 significance level.

Model results

The remainder of this paper focuses on Models 4a and b, the binary logit multilevel models relating walking use to socio-demographics, weather, and the built environment (disaggregate variables vs. walkability index), the results of which can be found in Table 2. These models show that socio-demographic, weather, and built environment variables are significantly related to the propensity to use walking as a mode of transport. It is important to note that the results for socio-demographic and weather variables are consistent regardless of the method used to measure the built environment, thus only the built environment section discusses differences between the models. The following sections describe how each set of variables is related to walking.

Socio-demographics

Socio-demographic variables control for the underlying characteristics of the sample collected in this study. Such variables were entered into the multilevel model at the individual level. Eight socio-demographic variables are found to be significantly associated

Table 2 Results of Models 4a and 4b

Variables	Model 4a				Model 4b			
	Odds ratio	95 % Confidence interval		*p* value	Odds ratio	95 % Confidence interval		*p* value
Socio-demographic								
Age	0.862	0.770	0.965	<0.050	0.861	0.770	0.964	<0.010
Household size	0.838	0.752	0.935	<0.010	0.834	0.748	0.930	<0.010
Household income (Ref.: Over $100,000) $60,000–$79,999	0.675	0.482	0.945	<0.050	0.670	0.479	0.937	<0.050
Valid driver's license	0.341	0.190	0.613	<0.001	0.337	0.187	0.605	<0.001
Bus pass	4.461	2.484	8.011	<0.001	4.479	2.488	8.060	<0.001
Full-time or part-time employee	1.410	1.040	1.911	<0.050	1.421	1.049	1.926	<0.050
Number of cars per licensed driver	0.592	0.423	0.828	<0.010	0.585	0.418	0.818	<0.010
Participated in study on weekday	1.975	1.501	2.599	<0.001	1.997	1.517	2.628	<0.001
Weather								
Average temperature	1.024	1.012	1.037	<0.001	1.024	1.012	1.037	<0.001
Total precipitation	0.985	0.971	0.998	<0.050	0.986	0.972	0.999	<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	<0.050	–	–	–	–
Entropy index	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	<0.001

Statistically insignificant (*p* value >0.05) socio-demographic variables are not shown

with the propensity to use walking as a mode of transport: age, household size, household income, having a valid driver's license, having a bus pass, being employed, number of cars per licensed driver, and participation in the STAR survey on a weekday. Age is associated with a reduced propensity to walk. Walking is most easily done by people who are younger and as age increases there is less use of walking as a mode of transport. Living in a household with a higher number of people is associated with a reduced propensity to walk. Walking is a more difficult alternative as larger households may have more time constraints than smaller households. Having a valid driver's license and having a bus pass have expected relationships—having a driver's license is associated with decreasing walking and having a bus pass is associated with increasing walking. Household income between $60,000 and $79,999 is related to a significant decrease in walking use compared with incomes 'over $100,000'. Being employed is related to a significant increase in the propensity to use walking as a mode of transport. This finding is supported by Spinney et al.'s (2012) recent study which finds that the workplace is more important than the home as an origin or destination for walking trips. A higher number of cars per licensed driver is associated with decreasing walking. As the number of cars available to a person with a valid driver's license increases, that person is less likely to be constrained in their use of alternative transport modes such as walking. Participating in the STAR study on a weekday is associated with an increase in the propensity to use walking as a mode of transport suggesting that walking is less popular as a modal choice on the weekend than on weekdays.

Weather

Weather variables are included in the models to examine how weather in the Halifax Regional Municipality impacts walking. Average temperature and total precipitation are found to be significantly associated with the propensity to use walking as a mode of transport. Average temperature is associated with an increase in the propensity to use walking. This suggests that there are seasonal patterns associated with walking where the warmer seasons increase the likelihood of using walking as a transport mode while the colder seasons decrease the likelihood. An increase in daily precipitation is associated with a decrease in the propensity to walk.

Built environment

Including the individual built environment variables in Model 4a identifies specific aspects of the built environment that impact the propensity to use walking as a mode of transport. Of the built environment variables included in this model, only population density is found to be significant at the 0.05 significance level. Population density is associated with a significant increase in the propensity to walk, meaning that urban areas with higher numbers of apartments, town homes, and condos are conducive towards walking.

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

Including the census tract walkability index in Model 4b identifies how the built environment influences walking when its attributes are aggregated. The results find that the walkability index, which combines pedestrian infrastructure, retail floor area ratio, population density, land-use mix (measured by the entropy index), and street connectivity, is significant at the 0.05 significance level. The walkability index is associated with a significant increase in the propensity to walk, meaning that people living in more walkable urban areas have a higher propensity to use walking as a mode of transport.

Conclusions

This study has examined the relationship between walking and the built environment using an approach that allows policy makers to better understand what attributes of the built environment increase the propensity for an individual to use walking as a mode of transport. For instance, the between census tract variance found in the data is completely explained by the socio-demographic variables, weather, and the built environment. As each set of variables is added, the model fit improves. After controlling for socio-demographics and weather, the built environment is found to be significantly associated with walking, explaining 41.4 and 37.8 % of the variation found between census tracts when measuring the built environment using disaggregate and aggregate approaches, respectively.

The results concerning the weather variables find that average temperature (positive) and total precipitation (negative) impact walking use. These findings suggest that increasing walking as a mode of transport might be difficult to achieve in climates where there are consistently low temperatures or high amounts of precipitation. It would be interesting to investigate the relationship between walking and weather in different climates as people may adapt to an environment if such weather conditions occur regularly.

After controlling for socio-demographics and accounting for weather, population density and pedestrian infrastructure are found to be associated with an increase in the propensity to walk. Using the walkability index to account for variations in the built environment is also found to be significantly related to walking, which is in agreement with past work (Frank et al. 2006, 2010; Leslie et al. 2007; Owen et al. 2007). Comparing the results from these two measurement techniques shows that using an index to measure the built environment hides the fact that only two of the five built environment variables are significant when attributes are measured individually.

When making policy decisions regarding the built environment, policy makers need to understand that walkability indices are aggregate measures of the built environment and may lead to incorrect assumptions about the individual variables that make up an index. For example, enhancing all five components that make up the walkability index will increase walking in the Halifax Regional Municipality, but targeting only one feature of the built environment will be successful if that feature is population density or pedestrian infrastructure. Researchers need to validate built environment variables before including them in a walkability index. Simply using a walkability index, such as the one by Frank et al. (2006, 2010), will likely find a significant relationship with walking, but interpreting the results for policy is difficult without the initial validation.

Overall, the findings of this study suggest that modifying components of the built environment may in fact increase the propensity to use active modes of transport more regularly regardless of the method used to measure the built environment. However, despite these findings, there are still numerous issues surrounding the relationship between active travel and the built environment that are not fully understood in the literature. Future work needs to address such issues as selecting a scale to measure the built environment, self-selection, social influence, and finding causality. Future work should also use datasets that have more days of data. For example, examining the relationship between active travel and the built environment with a 7-day dataset might reveal higher levels of active travel than would be captured with only a snapshot of 1 or 2 days.

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