How does the seasonality influence utilitarian walking behaviour in different urbanization settings in Scotland?

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Abstract

The relationship between the built environment and walking has been analyzed for decades. However, the seasonality effects on the relationship between the built environment and walking have not been well examined even though weather is one of the key determinants of walking. Therefore, this study used 2007-8 Scottish Household Survey data collected over two years and estimated the interaction effects between the urbanization setting (i.e., residential locations: urban, towns and rural areas) and seasons (i.e., spring, summer, autumn and winter) on walking. Scottish Urban-rural classification scheme is measured based on the population and access to large cities, and used as a key independent variable. The number of walking days for specific purposes such as work or shopping (utilitarian walking) during the past 7 days is used as a dependent variable. The results show that there are significant geographical variations of seasonality effect on utilitarian walking. That is, people living in rural areas are more sensitive to seasonality impacts than those living in urban areas. In addition, we found that the association between urbanization setting and utilitarian walking varies across seasons, indicating that their relationship can be miss-estimated if we ignore the seasonality effects. Therefore, policy makers and practitioners should consider the seasonality effects to evaluate the effectiveness of land use policy correctly. Finally, we still find the significant association between urbanization setting and utilitarian walking behaviour with the consideration of seasonality effects, supporting the claim of New Urbanism.

Keywords: seasonality; walking; built environment; continuous household survey

1. Introduction

The relationship between transport and health has been an important research topic for transport planners and researchers for decades (Frank 2000, Saelens, Sallis, and Frank 2003, Ewing et al. 2008). Especially, a body of transport studies have been focused on walking because it is the most common form of physical activity, generating diverse health benefits (Saelens and Handy 2008). Among rich empirical studies, many scholars have examined the relationship between the built environment and active travel such as walking and cycling because land use policy is often considered as a fundamental way to increase the level of active travel and decrease the auto dependency. For example, people living in urban areas tend to drive less due to the good accessibility to places and improved public transit system than residents in rural areas (Hong and Thakuriah 2015, Zhou and Kockelman 2008). In addition, several empirical studies found significant associations between the specific built environment characteristics such as density and mixed land uses and motorized and active travel (Cao, Handy, and Mokhtarian 2006, Chen, Gong, and Paaswell 2008, Frank et al. 2007).

However, the potential impacts of seasonality on the relationship between the built environment and active travel have not been well examined. Weather and daylight are very important determinants of active travel (Böcker, Dijst, and Prillwitz 2013, Gebhart and Noland 2014), and these may influence the effectiveness of land use policy on walking. For example, people may use more active transport modes during spring, summer and autumn than winter due to the longer daylight and moderate weather conditions regardless of their residential locations. In Scotland, the maximum difference in daylight is about 10 hours (i.e., 17 hours in summer and 7 hours in winter) and the average rainfall is much higher in winter than summer. Specifically, Met Office (2008) shows that the sunshine and rainfall during the 2008 summer in Scotland was 381.9 hours and 366.7 mm, respectively while 140.2 hours and 578.1mm during the 2008 winter. Because of these huge seasonal variations, the total amount of walking and the relationship between the built environment and walking may vary according to seasons.

This is very important to policy makers or practitioners for two reasons. First, land use policy is a long-term strategy, requiring huge efforts and costs. Therefore, practitioners need to understand the complex relationship between the built environment, seasonality and walking to avoid any miss-estimated associations between them. Second, several land use-walking studies (i.e., the relationship between land use and walking behaviour) employed travel survey data conducted in different seasons. For example, 2014 Puget Sound Regional Council travel survey data in the U.S. was collected between April and June, 2014 and 2011 Atlanta Regional Commission travel survey was conducted between February and October, 2011 with a break during summer (RSG 2014, PTV NuStats 2011). Some countries such as U.K. and New Zealand have national household travel surveys collected continuously through the year. It implies that using the above data could result in the inconsistent influences of land use on walking if there are significant varying seasonality effects on walking across areas. As indicated, Scotland has very different weather conditions through the year therefore, policy makers and practitioners should take the effect of weather / the seasons in mind when evaluating the effects of changes in the design of the environment on active travel.

This study aims to identify the above challenges by investigating the association between urbanization setting (i.e., residential locations: urban, town and rural areas) and walking behaviour with the consideration of interactions between residential locations and four seasons (i.e., spring, summer, autumn and winter). In addition, the analyses focus on utilitarian walking (e.g., walking for specific purposes- going somewhere such as work, shopping and friends) because commuting and business trips could be less sensitive to weather conditions compared to recreational or sport trips (Sabir 2011, Böcker, Dijst, and Prillwitz 2013). In specific, two research questions are examined; How does utilitarian walking behaviour change according to different seasons in Scotland?; How does seasonality influence the relationship between urbanization setting (residential locations) and utilitarian walking?

2. Literature review

A substantial amount of land use-travel behaviour studies (i.e., relationship between land use characteristics and travel behaviour) have focused on the motorized travel because of its connection to other urban sectors such as energy, environment and economics (Frank et al. 2006, Handy, Cao, and

Mokhtarian 2005, Hong and Goodchild 2014, Lee and Lee 2014). As the interests in sustainable transport and related health issues have risen steadily, more studies related to active travel have been conducted (Saelens, Sallis, and Frank 2003, Hong and Chen 2014, Handy et al. 2002, Pikora et al. 2003).

Even though there are variations in the results, many studies found positive associations between the built environment and active travel (Frank et al. 2007, Hong and Chen 2014). For example, Owen et al. (2004) reviewed several empirical studies and found significant associations between the built environmental attributes and walking in most cases. However, they also found contrasting results according to different types of walking. For example, one of the most often measured variables (i.e., aesthetic nature) is significantly associated with walking for exercise or recreation but not with utilitarian walking. That is, the environmental attributes correlated with recreational walking are different from those associated with utilitarian walking. Saelens and Handy (2008) reviewed several review and empirical studies and also showed that walking for transport is significantly associated with several land use factors such as density and mixed land use while pedestrian infrastructure and aesthetics are more strongly associated with recreational walking.

On the other hand, some studies produced opposite results. For instance, Bagley and Mokhtarian (2002) employed a structural equations modelling approach and examined the influence of residential neighbourhood type on different types of travel outcomes. They argued that attitude and lifestyle are important determinants of travel behaviour while residential location has little influence on travel behaviour. Feng (2016) also found that street characteristics have very significant impacts on active travel while the neighbourhood characteristics have only limited influences.

Because of the confusing results from the literature, some studies focused on the potential challenges and the remedies such as advanced analytical models, different types of built environment metrics and self-selection. Among these challenges, self-selection has been intensively analyzed in the land use-travel behaviour analysis with different approaches for decades. People may choose residential locations based on their attitudes towards certain transport modes, and it may result in spurious impacts if ignored in the analysis. Although variations exist, many empirical studies still found significant associations between the built environment and walking while controlling for self-selection (Handy 2006, Cao, Handy, and Mokhtarian 2006, Hong and Chen 2014).

However, few studies emphasized the potential impacts of seasonality on the relationship between the built environment and walking. People's walking behaviour can change depending on seasons because of different climate conditions. In addition, this impact may vary across spatial settings due to the different levels of accessibility. If this is true and empirical studies utilize travel surveys conducted during a particular season, it may lead to an incorrect conclusion about the relationship between the built environment and walking. In fact, several studies revealed the evidence for the potential associations between seasonality and the levels of physical activity or active travel. For example, weather including temperature, rain and humidity was found to have significant correlations with both walking and cycling (Noland and Ishaque 2006, Humpel et al. 2004). Gebhart and Noland (2014) employed bike share data with detailed weather information in Washington, DC and found very significant associations between weather (i.e., temperature, rain and high level of humidity) and the use of bike share as well as trip duration. Their result also showed that darkness is negatively associated with bike usage and durations. Pooley et al. (2011)'s study showed that the risk of wet or windy weather is negatively correlated with walking. Merchant, Dehghan, and Akhtar-Danesh (2007) defined four seasons based on the survey interview date and investigated the connection between seasonality and physical activities among Canadians. Their results confirmed that Canadians are more likely to participate in physical activities during summer than winter. In addition, energy expenditure from walking is higher in spring and summer than winter. Similarly, Matthews et al. (2001) found that the level of total physical activity increases during summer for both men and women compared to winter even though there are variations according to the activity types. Böcker, Dijst, and Prillwitz (2013) conducted a systematic review of previous empirical studies about the relationship between weather and travel behaviour. Their review showed clear evidence for the significant association between weather and active travel as well as research limitations.

In addition, some studies provided evidence for varying seasonality effects on active travel according to spatial settings. For example, Miranda-Moreno and Nosal (2011) found that having rain in the previous 3 hours is negatively associated with cycling and the magnitudes are different according to facilities located in different areas. Helbich, Bocker, and Dijst (2014) examined how the weather effects on cycling vary across space by using a geographically weighted logit model. Their results showed that weather has larger effects on cycling in remote areas than compact areas, potentially due to the urban morphological differences and short travel distances.

Finally, the seasonality impacts on different types of active travel have also been examined in-depth. For example, Sabir (2011) found that weather conditions are more strongly associated with recreational or sports trips compared to commuting or business trips. This result is consistent with other empirical studies that show the different impacts of weather on leisure or commuting trips (Helbich, Bocker, and Dijst 2014, Böcker, Dijst, and Prillwitz 2013).

In sum, the previous literature supports the significant correlations between both the built environment and walking and seasonality and walking behaviour. However, to the best of the knowledge, research on how seasonality influences the relationship between the built environment and walking is scarce.

3. Methods

3.1. Data

Scottish government has sponsored to conduct SHS to examine the characteristics of households in Scotland and their travel behaviour since 1999. It covers whole Scotland and consists of two parts: the first part is completed by a household reference person (i.e., highest income householder or their spouse/partner), and it includes diverse household level questions; the second part is completed by one randomly selected adult from each household, and it includes questions regarding several topics such as transport, neighbourhood and public services. Unlike travel or household surveys conducted every decade in a short time period, SHS collects data for two years to provide representative data for 32 local authorities in Scotland with each respondent interviewed one time. It is worth noting that this is not a longitudinal survey. In specific, data collected for each quarter, one year and two years is representative at the national, larger local authorities and each local authority levels, respectively.

Interviewers made up to six calls to make an appointment and visited interviewees' home for interview. For this study, 2007-8 SHS data is utilized and the final response rate for the main sample is 66%. .

SHS includes several transport related questions, and one asks how many out of the last seven days, did a random adult make a trip of more than a quarter of mile by foot for specific purposes (i.e., utilitarian walking-going somewhere such as work, shopping, friends etc). This variable is used as a dependent variable in this study. Several land use-walking studies used the number of walking trips from the travel diary as a dependent variable. However, it only includes trips made for a short time period (i.e., one or two days). In addition, many health experts argue that walking (moderate physical activity) 30 minutes a day at least five days per week (about 150 minutes per week) will improve health conditions significantly (CDC 2003). Therefore, using the number of walking days for a week as a dependent variable is preferred. Moreover, the Scottish government six-fold urban rural classification scheme (e.g., large urban areas, other urban areas, accessible small towns, remote small towns, accessible rural, and remote rural) is employed to define urbanization setting (residential locations). This variable is created based on the population and the access to a settlement of 10,000 or more. In general, urban areas are densely populated with a good range of services; towns are moderately populated with smaller number of services; and rural areas are the least populated areas and unlikely to contain many services (The Scottish Government 2008). For the analysis, they are re-categorized into three areas: urban, town and rural areas. Using specific land use characteristics such as density and mixed land uses would provide some benefits for practitioners. However, information about the participants' home locations is not available for researchers due to the privacy issue. One possible justification for the use of simple location scheme (i.e., urban, town and rural) is that urban areas are more compact and have better accessibility to different services than rural areas as documented above.

In addition, one neighbourhood variable -Scottish index of multiple deprivation (SIMD)- is included in the analysis. It is created by the Scottish government and describes the neighbourhood wealth across all of Scotland. Specifically, it is a composite index based on the indicators from seven domains (e.g., income, employment, crime, education, health, housing and access) and summarized at the data zone level (approximately between 500 and 1,000 household residents). 2007-8 SHS includes a 2006 SIMD decile index anchored by 1 (most deprived 10% data zones) and 10 (least deprived 10% data zones). A season variable is created based on the survey interview date. For example, it is defined as winter if the interview was conducted in December, January or February. Three months time frame is applied afterwards to define spring, summer and autumn (i.e., spring: March, April, May; summer: June, July, August; and autumn: September, October, November). It must be noted that this season variable is not as specific as weather data such as temperature and precipitations that other empirical studies employed. However, the main aim of this paper is to examine how the seasonality impacts change the relationship between urbanization setting (residential location) and walking, and we believe this simple season variable works for this purpose. In addition, four seasons in Scotland have huge variations in weather conditions as shown earlier. Finally, several socio-demographic factors for each person are included for the analysis.

3.2. Statistical model

Our dependent variable is a categorical variable, having a value from 0 to 7. It can be viewed as an ordinal variable and ordered logit model (OLM) could be employed for the analysis. However, OLM has a proportional odds assumption and an additional test showed that this assumption is violated. Therefore, multinomial logit model (MNLM) is utilized for the analysis. MNLM is widely used to analyze the nominal variable but also used with the ordinal variable to avoid the proportional odds assumption (Long 1997). The dependent variable is re-categorized to make the analyses simple: 0 day (reference group), 1-2 days, 3-4days, and 5-7days. Assume that our dependent variable (y) is a nominal variable with J outcomes. The probability of y equals to m given x (several independent variables) can be expressed as follows with MNLM:

$$\Pr(y_i = m|x) = \frac{\exp\,(\beta_m x_i)}{\sum_{j=1}^{J} \exp\,(\beta_j x_i)} \tag{1}$$

To identify the model, one of ^{2} s is constrained to be 0 (e.g., $\beta_1 = 0$) and this category (i.e., m=1) is called as a baseline category (reference group). Then, the model can be rewritten:

$$\Pr(y_i = 1|x) = \frac{1}{1 + \sum_{j=2}^{J} \exp(\beta_j x_i)}$$

$$\Pr(y_i = m|x) = \frac{\exp\,(\beta_m x_i)}{1 + \sum_{j=2}^{J} \exp\,(\beta_j x_i)} \qquad (2)$$

For our model, y has four outcomes (0 day, 1-2 days, 3-4 days and 5-7days) and x includes diverse socio-demographics, residential locations (i.e., urban, town and rural areas), deprivation (i.e., SIMD) and seasons (i.e., spring, summer, autumn and winter). In addition, 0 day is set as a baseline category. One of the common ways to interpret the MNLM result is to use odds. For example, the odds of outcome m versus baseline category (i.e. y=1) can be written:

$$odds_{m|1} = \frac{\Pr(y_i = m|x)}{\Pr(y_i = 1|x)} = \frac{\dfrac{\exp(\beta_m x_i)}{1 + \sum_{j=2}^{J} \exp(\beta_j x_i)}}{\dfrac{\exp(0)}{1 + \sum_{j=2}^{J} \exp(\beta_j x_i)}} = \exp([\beta_m - 0] x_i)$$

$$\log odds_{m|1} = \beta_m x_i \qquad (3)$$

If we want to know how odds changes for a unit change of x_k, we can differentiate log odds with x_k.

$$\frac{\partial \log odds_{m|1}}{\partial \mathrm{x_k}} = \beta_{km} \qquad (4)$$

This means that the $odds_{m|1}$ is expected to change by a factor of $\exp(\beta_{km})$ for a unit change in x_k, holding all other variables constant. Statistical computing program R with the nnet package is used for the estimation.

The interaction terms between residential locations and seasons are included in the final model to examine how the relationship between urbanization setting and utilitarian walking change according to different seasons. The effect display is a useful tool when interpreting the results from the statistical models with higher order terms (e.g., interaction), and the detailed explanation can be found in the Fox and Hong (2009)'s paper. The 'effects' package in R is utilized to produce the figure, and it describes the probability of having the number of walking days during the last seven days respect to the interaction between residential locations and seasons. The calculation process consists three steps: First, new dataset that includes all combinations of values of high-order predictors as well as the values of the other remaining predictors is created. Secondly, the fitted values (i.e. $X\hat{\beta}$) are estimated based on the model coefficients and this new dataset. Finally, these fitted values are transformed to the scale of the response (i.e., probability).

[Insert Table 1 here]

4. Results

The descriptive statistics of observations for each season are shown in Table 1. The average age of travellers is about 51 years, and 43% of the observations are male. Nearly half of the observations are workers, and 70% of the travellers own a valid driving license. 26% of the observations have health issues and 98% of the travellers are white. The average number of kids in the household is 0.41, and nearly 1 car is available per household on average. About 63%, 15% and 22% of the travellers are living in urban, town and rural areas, respectively. The average value of SIMD is about 5.44. There are some variations in the number of walking days during the last seven days across seasons, implying the potential association between the seasonality and walking behaviour.

The results of the relationship between the seasonality and utilitarian walking are shown in Table 2 and 3. Two models are used to check the consistency in results. The model in Table 2 examines the seasonal variations in utilitarian walking by comparing travellers interviewed in each month with those interviewed in December. In addition, the model in Table 3 compares utilitarian walking behaviour between people interviewed in spring, summer or autumn with those interviewed during the winter period. Most socio-demographic factors show significant associations with the number of utilitarian walking days during the last seven days, and the results are consistent with previous empirical studies. As one year increases, the odds of 1-2 walking days versus 0 day is expected to change by 0.99 (exp(-0.01)), holding all other variables constant. That is, people are likely to have fewer days of walking as they become older, potentially due to physical conditions. Male tend to have more 5+ days of walking than female. Having a driving license is only significantly associated with the high number of utilitarian walking days. Specifically, the odds of 5+ walking days versus 0 day is expected to change by 0.77, holding all other variables constant. People who are sick or disabled tend to have fewer days of walking compared to healthy people. Moreover, people who have more cars are likely to have fewer days of walking as expected. It implies that the improved access to private car may discourage utilitarian walking.

Two residential location variables have positive and significant associations with the number of utilitarian walking days during the last seven days. People living in town or urban areas tend to have more days of walking than residents in rural areas. As indicated in section 3.1, urban and towns are more compact and have good access to diverse services compared to rural areas. It means people living in urban or town areas can easily access diverse activities compared to residents in rural areas due to the high level of accessibility. This supports the argument of Smart Growth and New Urbanism, implying that compact developments with diverse services could encourage people to participate in active travel (Knaap and Talen 2005). This result is also consistent with previous land use-active travel studies (Hong and Chen 2014, Cao 2010, Cao, Handy, and Mokhtarian 2006). In addition, SIMD has a positive correlation with the number of walking days, indicating that people living in wealthy areas are likely to walk on more days than residents in deprived areas. In general, deprived areas are unsafe (crime rate is considered in the SIMD), preventing people from walking.

The results also show that there are significant variations in the number of utilitarian walking days during the last seven days across different seasons. People interviewed in July, August or September are likely to have more days of walking compared to those interviewed in December. In addition, Table 3 shows that people tend to have more days of walking in summer and autumn compared to winter. Scotland has high precipitation, cold temperature and short daylight hours in winter compared to summer and autumn. Therefore, this result implies the significant association between weather and utilitarian walking as previous studies found (Sabir 2011, Böcker, Dijst, and Prillwitz 2013).

[Insert Table 2 here]

[Insert Table 3 here]

The potential seasonality effects on the relationship between urbanization setting (residential locations) and utilitarian walking are examined by including interaction terms between them. The results from Table 4 show that the estimates of socio-demographics and SIMD are almost the same as the previous results. However, the coefficients of residential location and season variables differ from previous results because their meanings are changed due to the interaction terms. Two residential location variables have significant and positive associations with the number of utilitarian walking days during the last seven days, implying that people living in town or urban areas are likely to have more days of walking than residents in rural areas in winter. In addition, one season variable (i.e., summer) has a positive association with the number of walking days, indicating that people living in rural areas and interviewed in summer tend to have more days of utilitarian walking than those living in rural areas and interviewed in the winter period.

Three interaction terms have negative signs and are statistically significant at the level of 0.05 (i.e., p-value is smaller than 0.05). It indicates that the associations between residential locations and utilitarian walking become smaller for people interviewed in spring or summer than those interviewed in winter. As Helbich, Bocker, and Dijst (2014) found, there could be variations in the weather impacts on active travel across areas and it could change the magnitude of associations between residential locations and utilitarian walking. Interestingly, all significant interaction terms are associated with 1-2 days or 3-4 days. That is, there is no significant seasonality impact on the relationship between residential locations and utilitarian walking for people who walk more than 5 days per week. The potential explanation could be that people who walk most days of week (5+ days) are less sensitive to bad weather conditions compared to people who walk 1-4 days per week. In sum, the results imply that we could obtain the miss-estimated relationship between residential locations and utilitarian walking if we ignore the seasonality effects.

[Insert Table 4 here]

Figure 1 shows the effect display of the interaction between the three residential locations and four seasons. We can see that the probability of having 0 utilitarian walking day is much higher in winter than the summer period across residential locations. However, the relationship to the season is stronger in rural areas than urban areas. In addition, the probability of having 0 utilitarian walking day is lower during all seasons in urban areas than rural areas.

[Insert Figure 1 here]

5. Conclusion

The relationship between the built environment and walking has been examined for decades because walking is often considered as the easiest way to increase the level of physical activity in our daily life. Empirical studies produced mixed results and several methodological issues such as self-selection and different types of built environment metrics were identified as challenges to be overcome in the future study. However, there is a lack of studies about the seasonality effects on the relationship between the built environment and walking. Since most previous studies employed travel surveys conducted during a particular season, the overall influences of the built environment on walking can be over- or under-estimated if there are varying seasonality effects on walking behaviour across areas. Therefore, this study employs a continuous household survey in Scotland collected over 2 years to identify the above issue. In addition, the effects of seasonality on the relationship between the urbanization setting and utilitarian walking are investigated by estimating the interaction between residential locations and four seasons.

The results indicate that there are significant seasonality effects on the number of utilitarian walking days in Scotland. In general, people tend to walk on more days during summer and autumn than winter. The winter in Scotland has very short daylight hours, heavy rain and cold temperature. Therefore, walking occurs less often in winter months. The additional analysis of the interaction between residential locations and seasons shows more detailed evidence of seasonality impacts. The results confirm that the seasonality effects vary across areas, resulting in varying associations between residential locations and utilitarian walking behaviour across seasons. In specific, people living in town or urban areas in Scotland tend to have more utilitarian walking days than residents in rural areas. However, the association between residential locations and utilitarian walking becomes larger for observations interviewed during the winter period than those interviewed in summer or autumn, especially for people who walk 1-4 days per week. This result supports that inconsistent empirical results in the land use-walking studies could be generated because of data collected in different time periods. Moreover, it implies that the results from the previous studies that utilized travel surveys collected during a certain time period may not reflect the true relationship between the built environment and active travel. Therefore, policy makers and practitioners should understand their relationship in-depth and try to consider it in the analysis to evaluate the effectiveness of land use policy correctly. Finally, the result shows the significant correlation between urbanization setting and utilitarian walking behaviour regardless of seasons, indicating that the urbanization degree is still an important determinant of walking in Scotland. In sum, this study shows the impacts of seasonality on the relationship between the urbanization setting and utilitarian walking as well as the potential of land use policy for encouraging utilitarian walking in Scotland.

The major strength of this study is to use representative continuous household survey collected over two years to examine the seasonality effects on the relationship between the urbanization setting and utilitarian walking. However, it also has some limitations. First, employing recent data with detailed information about weather and other important events could provide more useful implications for practitioners. This study employs simple seasonal indicators (i.e., four seasons) thus, confounding effects can exist due to the omitted variables. For example, unexpected gentle weather during winter or heavy rains during spring or summer could change the results. Second, diverse and detailed built environment metrics need to be examined further. Finally, the self-selection issue should be taken into account to obtain more accurate results. Seasonality impacts may change walking behaviour not only depending on areas but also traveller's attitudes. That is, people who have affirmative attitudes towards walking may not change their behaviour as much as those who do not like walking even with bad weather conditions. Therefore, the connection between attitudes (potentially residential location choice), seasons and walking behaviour should be examined carefully.

Reference

Bagley, M. N, and P Mokhtarian. 2002. "The impact of residential neighbhorhood type on travel behavior: A structural equations modeling approach." *The Annals of Regional Science* 36:279-297.

Böcker, L, M Dijst, and J Prillwitz. 2013. "Impact of everyday weather on individual daily travel behaviours in perspective: A literature review." *Transport Reviews* 33:71-91.

Cao, X. 2010. "Exploring causal effects of neighborhood type on walking behavior using stratification on the propensity score." *Environment and Planning A* 42:487-504.

Cao, X, S Handy, and P Mokhtarian. 2006. "The influences of the built environment and residential self-selection on pedestrian behavior: evidence from Austin, TX." *Transportation* 33:1-20.

CDC. 2003. Prevalence of physical activity, including lifestyle activities among adults - United States, 2000-2001. In *Morbidity and Mortality Weekly Report*: CDC.

Chen, C, H Gong, and R Paaswell. 2008. "Role of the built environment on mode choice decisions: Additional evidence on the impact of density." *Transportation* 35 (3):285-299.

Ding, D, and K Gebel. 2012. "Built environment, physical activity, and obesity: what have we learned from reviewing the literature?" *Health & Place* 18:100-105.

Ewing, R, K Bartholomew, S Winkelman, J Walters, and D Chen. 2008. *Growing cooler: The evidence on urban development and climate change*. Washington, DC: ULI-the Urban Land Institute.

Feng, J. 2016. "The built environment and active travel: evidence from Nanjing, China." *International Journal of Environmental Research and Public Health* 13:1-14.

Fox, J. and J. Hong. 2009. "Effect displays in R for multinomial and proportional-odds logit models: extensions to the effects package." *Journal of Statistical Software* **32**: 1-24.

Frank, L.D. 2000. "Land use and transportation interaction: Implications on public health and quality of life." *Journal of Planning Education and Research* 20 (6):6-22.

Frank, L.D, B.E Saelens, K.E Powell, and J.E Chapman. 2007. "Stepping towards causation: Do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity?" *Social Science & Medicine* 65:1898-1914.

Frank, L.D, J. F Sallis, T.L Conway, J.E Chapman, B.E Saelens, and W Bachman. 2006. "Many pathways from land use to health: Associations between neighborhood walkability and active transportation, body mass index, and air quality." *Journal of the American Planning Association* 72 (1):75-87.

Gebhart, K, and R. B. Noland. 2014. "The impact of weather conditions on bikeshare trips in Washington, DC." *Transportation* 41:1205-1225.

Handy, S. 2006. "Self-selection in the relationship between the built environment and walking." *Journal of the American Planning Association* 72:55-74.

Handy, S, M.G Boarnet, R Ewing, and R.E Killingsworth. 2002. "How the built environment affects physical activity: Views from urban Planning." *American Journal of Preventive Medicine* 23 (2S):64-73.

Handy, S, X Cao, and P.L Mokhtarian. 2005. "Correlation or causality between the built environment and travel behavior? Evidence from Northern California." *Transportation Research Part D* 10:427-444.

Hanson, S, and P Hanson. 1977. "Evaluating the impact of weather on bicycle use." *Transportation Research Record* 629:43-48.

Helbich, M, L Bocker, and M Dijst. 2014. "Geographic heterogeneity in cycling under various weather conditions: evidence from Greater Rotterdam." *Journal of Transport Geography* 38:38-47.

Hong, J, and C Chen. 2014. "The role of the built environment on perceived safety from crime and walking: examining direct and indirect impacts." *Transportation* 41:1171-1185. doi: 10.1007/s11116-014-9535-4.

Hong, J, and A Goodchild. 2014. "Land use policies and transport emissions: Modeling the impact of trip speed, vehicle characteristics and residential location." *Transportation Research Part D* 26:47-51.

Hong, J, and P Thakuriah. 2015. "Relationship between Motorized Travel and Time Spent Online for Non-Work Purposes: An Examination of Location Impact." *International Journal of Sustainable Transportation*.

Humpel, N, N Owen, D Iverson, E Leslie, and A. Bauman. 2004. "Perceived environment attributes, residential location, and walking for particular purposes." *American Journal of Preventive Medicine* 26:119-125.

Knaap, G, and E Talen. 2005. "New urbanism and smart growth: a few words from the academy." *International Regional Science Review* 28:107-118.

Lee, S, and B Lee. 2014. "The influence of urban form on GHG emissions in the U.S. household sector." *Energy Policy* 68:534-549.

Long, J. S. 1997. *Regression models for categorical and limited dependent variables*: SAGE Publications, Inc., .

Matthews, C.E, P.S Freedson, J.R Hebert, E.J 3rd Stanek, P.A Merriam, M.C Rosal, C.B Ebbeling, and I.S Ockene. 2001. "Seasonal variation in household, occupational, and leisure time physical activity: longitudinal analyses from the seasonal variation of blood cholesterol study." *American Journal of Epidemiology* 153:172-183.

Merchant, A.T, M Dehghan, and N Akhtar-Danesh. 2007. "Seasonal variation in leisure time physical activity among Canadians." *Canadian Journal of Public Health* 98:203-208.

Met Office. 2008. "2008 weather summaries." Met Office Accessed 03 May.

Miranda-Moreno, L. F, and T Nosal. 2011. "Weather or not to cycle: Temporal trends and impact of weather on cycling in an urban environment." *Transportation Research Record* 2247:42-52.

Noland, R.B, and M.M Ishaque. 2006. "Smart bicycles in an urban area: evaluation of a pilot scheme in London." *Journal of Public Transportation* 9:71-95.

Owen, N, N Humpel, E Leslie, A. Bauman, and J. F Sallis. 2004. "Understanding environmental influences on walking: review and research agenda." *American Journal of Preventive Medicine* 27:67-76.

Pikora, T, B Giles-Corti, F Bull, K Jamrozik, and R Donovan. 2003. "Developing a framework for assessment of the environmental determinants of walking and cycling." *Social Science & Medicine* 56:1693-1703.

Pooley, C, M Tight, T Jones, D Horton, G Scheldeman, A Jopson, C Mullen, A Chisholm, E Strano, and S Constantine. 2011. Understanding walking and cycling: summary of key findings and recommendations. Lancaster University.

PTV NuStats. 2011. Atlanta regional commission: Regional travel survey final report.

RSG. 2014. Report: Spring 2014 Household Travel Survey: Puget Sound Regional travel survey.

Sabir, M. 2011. "Weather and travel behaviour " Doctorate, Department of Spatial Economics, Vrije Universiteit Amsterdam.

Saelens, B.E, and S Handy. 2008. "Built environment correlates of walking: A review." *Med Sci Sports Exerc* 40:550-566.

Saelens, B.E, J.F Sallis, and L.D Frank. 2003. "Environmental correlates of walking and cycling: Findings from the trasnportation, urban design and planning literatures." *Annals of Behavioral Medicine* 25:80-91.

The Scottish Government. 2008. Urban rural classification. Edinburgh: Scottish Government.

Zhou, B. B, and K. M Kockelman. 2008. "Self-selection in home choice: use of treatment effects in evaluating the relationship between the built environment and travel behavior." *Transporation Research Record* 2077:54-61.

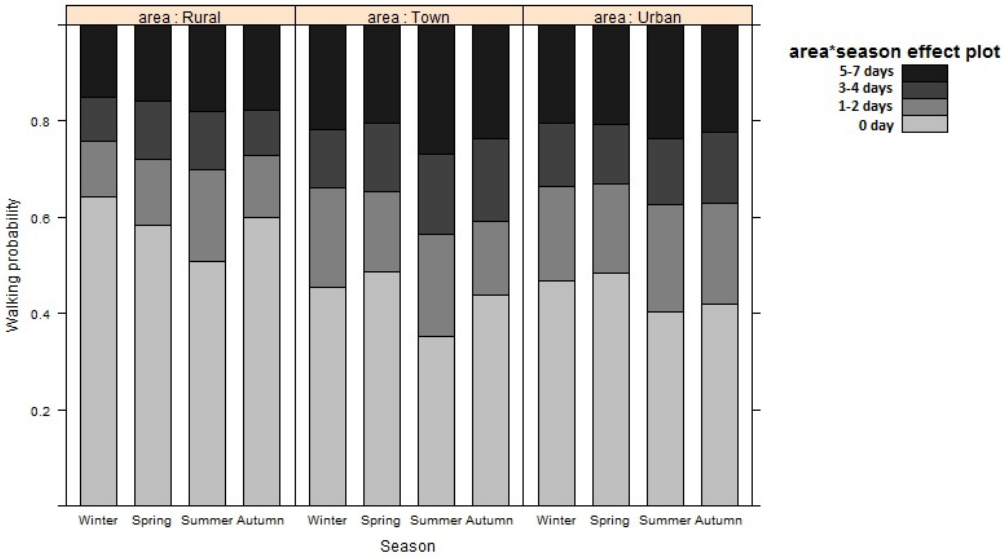

Figure 1 Effect plot for the residential location and season interactions

Table 1 Descriptive statistics of observations in different seasons

	Total		Spring		Summer		Autumn		Winter	
	Mean*	SD	Mean*	SD	Mean*	SD	Mean*	SD	Mean*	SD
Socio-demographics										
Age (min=16, max=80)	51.48	17.90	51.57	17.98	51.89	17.69	51.32	17.69	51.12	18.13
Gender (male=1)	43%	0.49	41%	0.49	42%	0.49	43%	0.49	45%	0.50
Work (work=1)	49%	0.50	48%	0.50	49%	0.50	50%	0.50	49%	0.50
Driving license (own=1)	70%	0.46	71%	0.45	70%	0.46	70%	0.46	70%	0.46
Health (illness or disability=1)	26%	0.44	27%	0.44	26%	0.44	26%	0.44	25%	0.43
Ethnicity (white=1)	98%	0.13	98%	0.13	98%	0.15	98%	0.15	98%	0.12
Number of kids	0.41	0.84	0.42	0.88	0.41	0.85	0.42	0.85	0.39	0.80
Number of cars	0.99	0.84	1.00	0.82	0.98	0.86	0.99	0.86	0.99	0.84
Residential location										
Urban (urban=1)	63%	0.48	64%	0.48	61%	0.49	62%	0.49	64%	0.48
Town (town=1)	15%	0.36	14%	0.35	16%	0.37	14%	0.37	16%	0.37
Rural (rural =1)	22%	0.42	22%	0.42	23%	0.42	23%	0.42	20%	0.40
Deprivation *(1: most deprived- 10: least deprived)*										
SIMD	5.44	2.79	5.48	2.79	5.43	2.78	5.42	2.78	5.42	2.82
Walking										
Number of walking days (0-7 days)	2.10	2.52	1.96	2.48	2.27	2.55	2.13	2.55	2.02	2.53
Sample size	11124		2923		2683		3010		2508	

* It represents the percentage for categorical variables

Table 2 Result from MNLM with month variables (reference group: 0 day)

	1-2days		3-4days		5+ days	
	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	-0.30	0.24	-0.66*	0.05	0.85*	0.00
Socio-demographics						
Age	-0.01*	0.00	-0.02*	0.00	-0.02*	0.00
Gender (male=1)	-0.08	0.17	-0.15*	0.02	0.21*	0.00
Work (work=1)	0.01	0.92	-0.17*	0.02	0.03	0.59
Driving license (own=1)	0.13.	0.10	0.00	0.97	-0.26*	0.00
Health (illness or disability=1)	-0.51*	0.00	-0.79*	0.00	-0.91*	0.00
Ethnicity (white=1)	-0.75*	0.00	0.22	0.41	-0.28	0.16
Number of kids	-0.04	0.32	-0.01	0.78	-0.06.	0.07
Number of cars	-0.18*	0.00	-0.34*	0.00	-0.61*	0.00
Residential location (reference: Rural)						
Town	0.55*	0.00	0.65*	0.00	0.63*	0.00
Urban	0.62*	0.00	0.51*	0.00	0.53*	0.00
Deprivation						
SIMD	0.04*	0.00	0.04*	0.00	0.04*	0.00
Season(Month) (reference: December)						
January	0.22	0.15	0.14	0.40	-0.02	0.91
February	0.15	0.29	-0.16	0.33	-0.13	0.32
March	0.19	0.17	0.05	0.75	-0.05	0.73
April	-0.04	0.81	-0.03	0.85	-0.09	0.51
May	0.03	0.84	-0.02	0.88	-0.02	0.87
June	0.32*	0.02	-0.02	0.89	0.03	0.85
July	0.72*	0.00	0.37*	0.03	0.48*	0.00
August	0.51*	0.00	0.58*	0.00	0.45*	0.00
September	0.48*	0.00	0.63*	0.00	0.43*	0.00
October	0.08	0.57	0.05	0.77	0.03	0.83
November	0.16	0.24	-0.04	0.81	-0.02	0.90

* Significant at the 0.05 level; . Significant at the 0.10 level

Table 3 Result from MNLM with season variables (reference group: 0 day)

	1-2days		3-4days		5+ days	
	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	-0.17	0.47	-0.68*	0.03	0.79*	0.00
Socio-demographics						
Age	-0.01*	0.00	-0.02*	0.00	-0.02*	0.00
Gender (male=1)	-0.08	0.17	-0.15*	0.02	0.21*	0.00
Work (work=1)	0.01	0.93	-0.17*	0.02	0.04	0.56
Driving license (own=1)	0.13.	0.09	0.01	0.92	-0.25*	0.00
Health (illness or disability=1)	-0.51*	0.00	-0.79*	0.00	-0.91*	0.00
Ethnicity (white=1)	-0.75*	0.00	0.22	0.42	-0.28	0.15
Number of kids	-0.03	0.32	-0.01	0.80	-0.06.	0.07
Number of cars	-0.19*	0.00	-0.34*	0.00	-0.62*	0.00
Residential location (reference: Rural)						
Town	0.55*	0.00	0.64*	0.00	0.63*	0.00
Urban	0.62*	0.00	0.51*	0.00	0.54*	0.00
Deprivation						
SIMD	0.04*	0.00	0.04*	0.00	0.04*	0.00
Season (reference: Winter)						
Spring (Mar-May)	-0.06	0.47	0.02	0.81	0.01	0.89
Summer (June-Aug)	0.36*	0.00	0.32*	0.00	0.35*	0.00
Autumn (Sep-Nov)	0.09	0.22	0.21*	0.01	0.19*	0.01

* Significant at the 0.05 level; . Significant at the 0.10 level

Table 4 Seasonality effects on the relationship between residential locations and walking with interaction terms

	1-2days		3-4days		5+ days	
	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	-0.39	0.14	-0.81*	0.02	0.73*	0.00
Socio-demographics						
Age	-0.01*	0.00	-0.02*	0.00	-0.02*	0.00
Gender (male=1)	-0.08	0.17	-0.14*	0.02	0.22*	0.00
Work (work=1)	0.01	0.87	-0.16*	0.03	0.04	0.53
Driving license (own=1)	0.13.	0.09	0.01	0.90	-0.25*	0.00
Health (illness or disability=1)	-0.51*	0.00	-0.79*	0.00	-0.91*	0.00
Ethnicity (white=1)	-0.74*	0.00	0.22	0.41	-0.28	0.15
Number of kids	-0.03	0.32	-0.01	0.81	-0.06.	0.08
Number of cars	-0.19*	0.00	-0.34*	0.00	-0.62*	0.00
Residential location (reference: Rural)						
Town	0.93*	0.00	0.63*	0.01	0.71*	0.00
Urban	0.84*	0.00	0.70*	0.00	0.62*	0.00
Deprivation						
SIMD	0.04*	0.00	0.04*	0.00	0.04*	0.00
Season (reference: Winter)						
Spring (Mar-May)	0.27	0.15	0.37.	0.07	0.15	0.38
Summer (June-Aug)	0.72*	0.00	0.51*	0.01	0.41*	0.02
Autumn (Sep-Nov)	0.17	0.35	0.09	0.65	0.22	0.20
Interaction						
Town:Spring	-0.57*	0.03	-0.28	0.35	-0.28	0.28
Town:Summer	-0.44.	0.09	0.06	0.85	0.06	0.82
Town:Autumn	-0.45.	0.10	0.28	0.35	-0.10	0.68
Urban:Spring	-0.36.	0.08	-0.49*	0.03	-0.17	0.39
Urban:Summer	-0.46*	0.02	-0.33	0.16	-0.12	0.54
Urban:Autumn	0.00	0.99	0.11	0.63	-0.03	0.89

* Significant at the 0.05 level; . Significant at the 0.10 level