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Built environment and seasonal variation in active transportation: A longitudinal, mixed-method study in the Helsinki Metropolitan Area

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ABSTRACT

Introduction: Participation in active transportation declines seasonally in urban areas with a distinct cold winter season, resulting in a loss of physical activity and a switch to motorized transport modes during the winter period. Despite the considerable evidence available on the relationship between the objectively measured built environment and participation in active transportation, few studies have examined the influence of the built environment on facilitating year-round active transportation. This longitudinal study examined the potential effect of the built environment on seasonal changes in adults' walking and cycling for transport.
Methods: The study uses data on adults' (18–65 years) active transportation behavior collected in the Helsinki Metropolitan Area, Finland (*n* 384). A structural equation model including both individual-level and built environment variables was constructed to assess changes in walking and cycling behavior. In addition, a qualitative thematic analysis was performed to identify recurring topics in citizens' descriptions of their wintertime physical activity behavior.
Results: Cycling for transport decreased drastically during the winter season, with many participants ceasing to cycle altogether. Changes in walking for transport were less consistent and showed no significant sample-level difference in the minutes of walking for transport in the baseline and follow-up surveys. The results of the structural equation model indicated that changes in cycling and walking behavior were directly affected by neighborhood residential density and urban structure. Results of the qualitative analysis emphasized the importance of the wintertime maintenance of pedestrian and cycling infrastructure.
Conclusions: Our results highlight the multiple ways the built environment may contribute to maintaining summer active transportation behavior during the winter period, ranging from macroscale features of the urban form to the microscale of street-level design and maintenance. This knowledge supports policy and planning efforts to support the continuous use of active transportation modes throughout the year.

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1. Introduction

Participation in active transportation decreases significantly in many urban areas located in climates with a distinct cold winter season. The resulting shift to motorized transport modes has been connected to lower levels of overall physical activity and increased physical inactivity (Arnardottir et al., 2017; Cepeda et al., 2018; Stigell and Schantz, 2015), thereby negatively impacting public health. Prior research on seasonal variation in active transportation, such as walking and cycling for transport, in areas with a distinct cold winter season has been mostly conducted in the Northern U.S. (Sears et al., 2012; Spencer et al., 2013), Canada (McCormack et al., 2010; Nahal and Mitra, 2018; Winters et al., 2007; Collins and Mayer, 2015), and the Nordic countries (Arnardottir et al., 2017; Chapman and Larsson, 2021; Kallio et al., 2016; Liu et al., 2015a, 2015b; Stigell and Schantz, 2015). Studies addressing personal, social, and environmental influences on seasonal variation in active travel have identified several barriers to year-round walking and cycling for transport. These include low temperatures, increased precipitation, poor road conditions, and limited daylight hours (Bergström and Magnusson, 2003; Spencer et al., 2013; Winters et al., 2007). Qualitative studies (e.g., Chapman and Larsson, 2021; Galway et al., 2021) have also discussed the practicalities of winter cycling, such as, using studded tires, finding suitable clothing, the type of bike (e.g., e-bike), and the availability of bike storage on cycling behavior.

Despite increasing research interest in the influence of climate and weather on transport behavior, few studies have examined how seasonal variation contributes to the effects of the built environment on active transportation in climates with a distinct cold winter season. However, results from comparative studies show that the effects of weather on transport mode choices may vary considerable between study locations with similar weather and climate conditions (Böcker et al., 2019). These differences are most likely attributable to differences in urban structure, the transport system, policy, and transport culture (Cervero et al., 2019) and indicate that contextual factors might affect seasonal variation in active transportation. Gaining insight into these associations is necessary for building the evidence base for promoting active transportation modes in urban environments located in climates characterized by seasonal variation. Increasing the opportunities to maintain habitual active transportation throughout the year can potentially reduce the switch to motorized transport modes during winter months and the resulting negative public health effects. Moreover, this knowledge is critical for predicting the effects of climate change on future travel behavior (e.g., Wadud, 2014), and for understanding how the built environment can support active transportation in more extreme future climate conditions.

The purpose of the present study is to examine associations between the neighborhood built environment and wintertime changes in walking and cycling for transport in an adult population. The study follows the ecological approach of active living, which emphasizes the multiple levels of influence on physical activity behavior (Sallis et al., 2006; Sallis and Owen, 2015). Here, we examine whether associations between the built environment and changes in active transportation vary between walking and cycling and if personal-level factors moderate these effects. This study explores the ways in which the built environment influences wintertime changes in walking and cycling for transport by adopting a mixed-method approach. Structural equation modeling is used to identify statistically significant associations between wintertime changes in active transportation and the objectively measured neighborhood built environment. In addition, qualitative thematic analysis is performed to identify recurring topics in citizens' descriptions of their wintertime physical activity behavior.

The paper is organized as follows. Section 2 briefly reviews the literature on the built environment correlates of active transportation and outlines the conceptual framework of the study. Section 3 introduces the data and the methodology used in this study. The empirical results are presented in Section 4 and further discussed in Section 5.

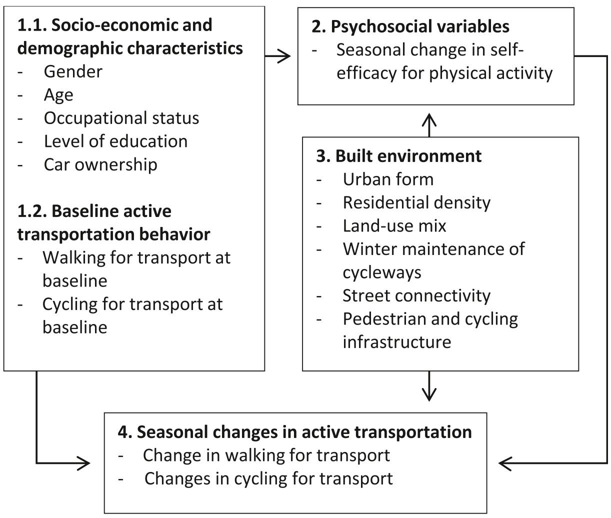

Fig. 1. Conceptual model and study variables.

2. Conceptual framework

Convincing empirical evidence exists on the direct relationship between the neighborhood built environment and walking and cycling for transport in day-to-day life. Walking for transport has been consistently positively associated with high destination availability, residential density, and street connectivity (Ewing and Cervero, 2010; Grasser et al., 2013; Saelens and Handy, 2008). Cycling for transport, on the other hand, has been connected with its separation from other modes of transport, the presence of cycling paths, street connectivity, land-use mix, and the presence of steep inclines, while associations with diverse density-based measures are less consistent (Christiansen et al., 2016; Fraser and Lock, 2011; Yang et al., 2019). As the environmental correlates of walking and cycling for transport differ to some extent, changes in walking and cycling are treated in this study as two separate outcomes (i.e., as two different endogenous variables).

Despite the increasing evidence on the environmental correlates of active transportation, only a handful of studies have examined associations between the built environment and year-round active transportation in colder climates. In a case study conducted in Toronto, Canada, Nahal and Mitra (2018) observed that year-round commuting by bicycle was positively associated with access to bicycle infrastructure and the age of the neighborhood housing stock. Other studies have reported negative associations between commuting distance and the likelihood of winter cycling (Kallio et al., 2016; Sears et al., 2012). In addition, qualitative and descriptive studies have discussed the influence of the winter maintenance of walk and cycleways on the winter-use of active transportation modes (e.g., Bergström and Magnusson, 2003; Chapman and Larsson, 2021; Galway et al., 2021; Spencer et al., 2013). Based on these findings, we thus expected the built environment to directly influence changes in winter transport walking and cycling (Fig. 1).

Besides environmental factors, personal-level psychosocial factors and socio-economic and demographic characteristics were expected to influence seasonal changes in active transportation. Here, we chose to focus on the effect of self-efficacy. Multiple studies have found that self-efficacy, which in this context refers to the individual's confidence in being physically active when met with internal or external challenges, has been associated with physical activity outcomes both independently and through interactions with built environment factors (Carlson et al., 2012; Kaczynski et al., 2012). These associations are generally strong for both overall and leisure-time physical activity (Choi et al., 2017), and more inconsistent for active transportation (Van Dyck et al., 2011). Social cognitive theory posits that self-efficacy is influenced by previous experiences and vicarious experiences and interacts with diverse socio-environmental factors (Bandura, 1997). Thereby, self-efficacy for physical activity was hypothesized to change between seasons. Consequently, changes in self-efficacy for physical activity were expected to influence changes in transport walking and cycling in winter. In addition, we hypothesized that self-efficacy has a mediating effect on environmental exposure variables and socio-economic and demographic factors.

3. Research materials and methods

3.1. Study area

The study was conducted in the Helsinki Metropolitan Area, Finland, including the municipalities of Helsinki, Vantaa, Espoo, and Kauniainen. The Helsinki Metropolitan Area is the largest urbanized area in Finland with a population of 1.2 million inhabitants (OSF, 2019). Following the Köppen climate classification, Southern Finland is categorized as a warm-summer humid continental climate, with the coldest month averaging below −3 °C and the warmest above 10 °C (Finnish Meteorological Institute, 2019b). The climate statistics of the study area are presented in Table 1.

3.2. Data collection

The data was collected with two consecutive online public participation GIS (PPGIS) surveys. The survey included sections covering personal characteristics, self-rated health, and physical activity behavior. In addition, the respondents were requested to mark their primary residential location on a base map in the survey's mapping view. Respondents were also asked to reflect freely on their wintertime physical activity behavior and habits in an open-ended question.

The first round of data collection took place in August 2018. A simple random sample of 10,000 adults aged 18–65 years and living permanently in the Helsinki Metropolitan Area was ordered from the Finnish Population Register Centre. Personal invitation letters to participate in the online survey were sent to the sample members, followed by a reminder post card in two weeks' time. Altogether 1,583 respondents participated in the survey, resulting in a response rate of 16%. Respondents of this baseline survey were invited to

Table 1
Study area climate statistics (Finnish Meteorological Institute, 2019a; The University of Helsinki Almanac, 2019).

Observations in Helsinki, Kaisaniemi	Mean temperature (°C)	Percpiration (mm/month)	Depth of snow (cm)[a]	Sunrise, sunset[a]
August 2018	18.6	52	0	5.33, 21.15
March 2019	0.4	45	10	6.38, 18.21
August 1981–2010 average	16.3	80	0	-
March 1981–2010 average	−1.3	38	23	-

[a] Measured on 15th day of month.
Sources: Finnish Meteorological Institute (2019a), The University of Helsinki Almanac Office (2019).

participate in a follow-up survey in March 2019. Overall, 434 respondents completed both the baseline and the follow-up questionnaires. For this study, respondents with missing data on active transportation behavior and respondents who had relocated between the two surveys were excluded, resulting in the final sample of 384 respondents.

3.3. Measures

3.3.1. Outcome measures

Participation in active travel was measured with the long form of the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003). Weekly minutes of walking and cycling for transport were estimated by multiplying the usual activity duration (minutes) by the number of days the activity was undertaken. Changes in walking and cycling for transport were calculated by subtracting the weekly minutes of walking and cycling at baseline (summer) from the weekly minutes of walking and cycling for transport at follow-up (winter). Thus, a negative change implies a decrease and a positive change an increase in winter walking or cycling in comparison to the same behavior at summer baseline. As follows, the respondents who did not change their walking or cycling behavior between baseline and follow-up were assigned the change value of zero. These measures were standardized and the standardized values (z-scores) were used in the structural equation models.

3.3.2. Built environment exposure variables

The built environment variables tested in this study were chosen based on existing evidence on the environmental correlates of walking and cycling for transport. These included residential density, land-use mix, intersection density, length of the pedestrian and cycling network, and a categorical variable describing the travel-related urban form at the residential location. In addition, based on the results of the thematic analysis on respondents' descriptions of their wintertime physical activity habits (Section 4.3), we examined the access to cycling routes with prioritized winter maintenance. All variables were measured within a 500-m and a 1-km Euclidean buffer distance from home, with the exception of travel-related urban form, which was defined as an attribute value of the residential location. This variable is based on a classification of travel-related urban zones produced and maintained by the Finnish Environmental Institute SYKE (Söderström et al., 2015; SYKE 2017) that has been found to be associated with active travel behavior in prior studies (Mäki-Opas et al., 2016). For this study, the study area was reclassified into the central pedestrian zone, the intensive public transport zone, the basic public transport zone, and the car-oriented zone (Fig. 2). The built environment variables are described in detail in Table 2 and reported in Table 3. Note that only those variables that showed significant influence on the outcome variables were included in the final structural equation model.

3.3.3. Individual-level variables

Self-efficacy for physical activity was measured as the respondent's confidence in being physically active when met with internal or external challenges, such as being tired or bad weather. Respondents were asked to rate their agreement with four statements

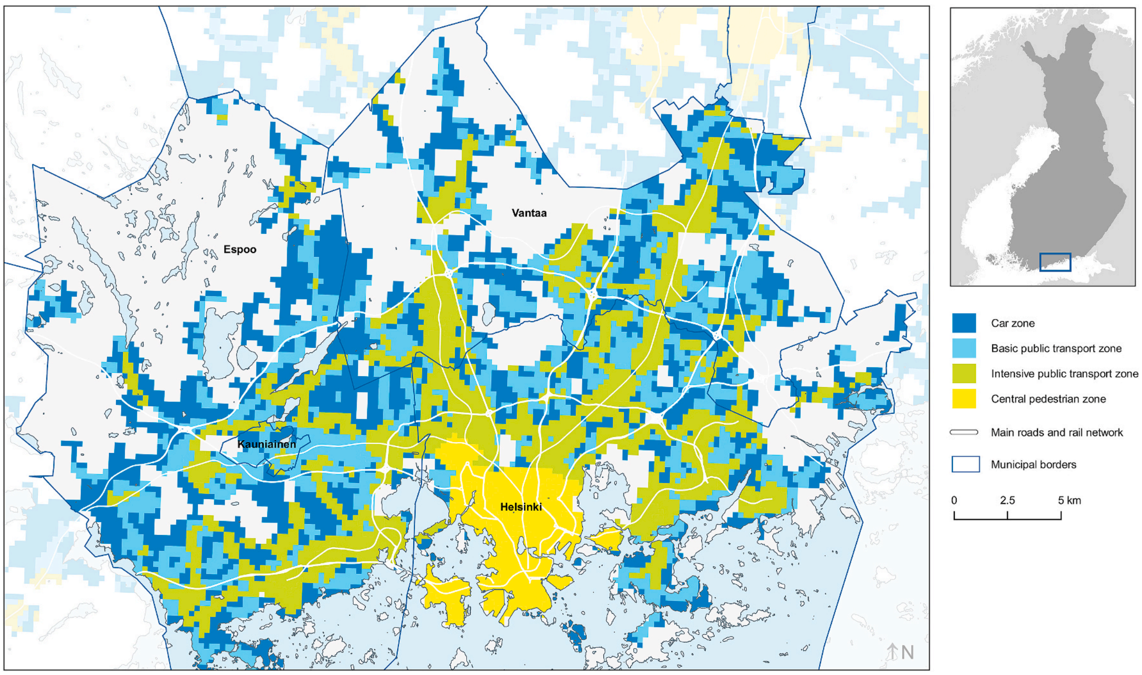

Fig. 2. Travel-related urban zones (SYKE, 2017) in the study area (Helsinki Metropolitan Area).

Table 2
Description of built environment exposure variables.

Variable	Description
Travel-related urban zone	A typology of travel-related urban zones (250m × 250m grid) developed for the Finnish urban regions. For this study, some zones were combined to reduce the number of individual categories. Classes *central pedestrian zone* (grid cells located within 2 km from Helsinki city center) and *fringe of the central pedestrian zone* (cells with high areal density within 3 km from the edge of the previous zone) were merged into one category. The *intensive* and *basic public transport zones* are defined by the availability of public transport options during the rush hours and the walking distances to the nearest public transport stop. The *intensive public transport zone* has a maximum of 5 to 10-min waiting time for public transport (5 min for busses, 10 min for rail connections) and the *basic public transport zone* a maximum of 15-min waiting time. In both zones, the maximum walking distance to the nearest public transport stop is 250m for a bus stop and 700m for a rail connection. Cells in the class *pedestrian zone of a sub-center* were combined with the two previous classes. The *car zone* includes the remaining urban areas that do not fit the requirements of the pedestrian or public transport zones.
Residential density	Residential density was measured within the home buffer as the ratio of the residential floor area to the land area in residential use.
Land-use mix	Land-use mix, indicating diversity of land-use in the residential area, was calculated following Frank et al. (2004). The following land-uses were considered: Residential, commercial, recreational (greenspace and recreational areas), and traffic.
Winter maintenance of cycleways	A binomial variable (yes/no) indicated residential location within a 500-m and a 1-km distance from a cycleway with priority in winter maintenance during the winter season 2018–2019.
Street connectivity	Number of intersections within the home buffer divided by the buffer area (km^2).
Pedestrian and cycling infrastructure	Length (in kilometers) of pedestrian and cycleways within the home buffer.

Table 3
Built environment exposure variables.

	Total sample (*n* 384)
Travel-related urban zone (%)	
Car zone	13.7
Basic public transport zone	24.3
Intensive public transport zone	34.3
Central pedestrian zone	27.7
Residential density, mean (SD)	
500-m buffer	0.56 (0.63)
1-km buffer	0.50 (0.42)
Land-use mix, mean (SD)	
500-m buffer	0.77 (0.14)
1-km buffer	0.79 (0.10)
Winter maintenance of cycleways (%)	
Prioirity maintained cycleway within 500 m	18.8
Prioirity maintained cycleway within 1 km	31.2
Street connectivity (intersections/km^2), mean (SD)	
500-m buffer	100.5 (39.5)
1-km buffer	87.3 (28.6)
Pedestrian and cycling infrastructure (km), mean (SD)	
500-m buffer	15.1 (8.5)
1-km buffer	52.9 (28.8)

SD = Standard deviation.

expressing confidence in being physically active on a scale from 1 ("I disagree") to 5 ("I agree") modified from Sallis et al. (1988). Self-efficacy was expected to vary depending on the season and was thereby measured separately during the baseline and follow-up. Change in self-efficacy was calculated separately for each statement by subtracting the score at baseline from the score at follow-up. Among the socio-economic and demographic factors age (in years), gender, occupational status (full-time occupied, i.e., employed and students), level of education, and car ownership (one or more cars per household) were tested for their influence on changes in self-efficacy and changes in active transportation behavior. Lastly, as we expected changes in the outcome variables to be greater for participants that actively used active transportation modes at baseline, variables on the walking and cycling behavior at baseline (dichotomized around the sample median) were included as individual-level variables.

3.4. Data analysis

3.4.1. Quantitative analysis

Wilcoxon signed-rank tests were used to test for seasonal differences in the weekly minutes of walking and cycling for transport. Structural equation modeling was used to test the main hypotheses of this study (Fig. 1). We hypothesized that changes in self-efficacy influence the seasonal changes in walking and cycling for transport and that socio-economic and demographic factors as well as certain neighborhood built environment characteristics influence changes in walking and cycling both directly and indirectly through the mediatory effect of self-efficacy. Personal-level socio-economic and demographic factors and neighborhood built environment characteristics were included in the framework as exogenous variables. A total of three endogenous variables and eight exogenous variables were included in the structural equation model. Of the three endogenous variables, two were related to changes in active transportation behavior and one to changes in self-efficacy. Change in self-efficacy was included as a latent factor in the model and its indicators were changes in four Likert-scale statements (see Table 7). The eight exogenous variables included six personal-level factors (i.e., age, gender, employment status, car ownership, and baseline cycling and walking activity level) and two built environment variables (residential density within a 500-m buffer distance and category "intensive public transport zone" of the travel-related urban zones typology).

The maximum likelihood (ML) approach was used to estimate the structural equation model using AMOS (version 25.0). Several models with different paths between the exogenous and endogenous variables were tested. Paths that consistently showed no significance were excluded from the model. The model with the best fit to the data was selected as the final model. Widely used indexes were used to assess the goodness-of-fit of the models, including the Chi-square value, the ratio of $\chi 2$ over degrees of freedom, the Comparative Fit Index (CFI), the Incremental Fit Index (IFI), and the Root Mean Square Error of Approximation (RMSEA) (Byrne, 2010). For a good model fit, the ratio of $\chi 2$ over degrees of freedom was expected to be smaller than 5.0, the CIF and IFI larger than 0.9, and the RMSEA smaller than 0.08.

3.4.2. Qualitative analysis

The study follows a mixed-methods approach that combines both quantitative and qualitative research materials. In addition to the quantitative analyses described in the previous sections, we analyzed the respondents' own descriptions of their wintertime physical activity behavior. This analysis was conducted to assist in interpreting the quantitative results and to expand our understanding of the environmental correlates of seasonal variation in active transportation beyond the neighborhood- and city-level built environment variables included in the quantitative analysis. The qualitative data were acquired from a section of the survey where the respondents were requested to reflect freely on their wintertime physical activity behavior. A two-step thematic analysis was performed to identify recurring topics related to wintertime active transportation. First, all answers were searched for potential mentions of barriers to and facilitators of wintertime active transportation relating to the built, natural, social, and policy environments. Next, topics identified in this initial search were used as coding categories as the data were examined once more.

Table 4
Socio-economic and demographic characteristics of survey respondents.

	Total (*n* 384)
Gender (%)	
Female	54.9
Male	43.8
Age, in years (%)	
18-29	13.5
30-39	18.2
40-49	22.9
50-59	28.6
60-65	16.4
Educational level (%)	
University degree[a]	58.1
Lower	33.1
Household monthly gross income (%)	
<1,500 euros	8.0
1,500–3,000 euros	27.3
3,001–4,500 euros	23.2
4,501–6,000 euros	17.4
>6,000 euros	14.3
Occupational status (%)	
Employed	67.2
Student	8.3
Retired	7.8
Unemployed	4.9
Other	3.9
Car ownership (household) (%)	
No cars	31.0
One or more cars	60.9
Self-efficacy for physical activity[b], median (SD)	
Summer (baseline)	3.40 (0.74)
Winter (follow-up)	3.20 (0.80)

SD = Standard deviation.
[a] Including undergraduate, graduate, and postgraduate degrees.
[b] On a scale from 1 to 5. Because of missing data, all percentages do not equal 100%.

4. Results

4.1. Descriptive results

The demographic and socio-economic characteristics of the survey respondents were compared to the adult population of the Helsinki Metropolitan Area (Official Statistics of Finland, 2018, 2019). Participants with undergraduate, graduate, or postgraduate degrees were over-represented in the sample, comprising 56% of the participants compared to 37% in the study area (Table 4). Also, females were slightly over-represented, the sample being 55% female compared to 51% of the same age group in the study area.

Data on walking and cycling for transport were not normally distributed and were thereby reported in median and inter-quartile range values. The majority of the respondents reported participation in walking for transport during a usual week at both the baseline and winter follow-up (Table 5), with no significant seasonal change on sample level ($z = -0.70$, $p = .487$, $r = -0.04$). By contrast, the share of participants cycling for transport decreased from 60% at the baseline to 19% of respondents at the winter follow-up. The weekly minutes of transport cycling were significantly lower at the winter follow-up ($z = 10.41$, $p < .001$, $r = 0.53$).

4.2. Model results

Table 6 presents the results of the final structural equation model, which shows a good fit to the data ($\chi2/df = 0.785$, CFI = 1.000, IFI = 1.024, RMSEA = 0.000). The table shows direct and total effects of the built environment and personal-level variables on seasonal changes in self-efficacy for physical activity and walking and cycling for transport. Table 7 presents the measurement model of the structural equation model that shows the latent factor of change in self-efficacy and its measurement indicators.

4.2.1. Change in self-efficacy for physical activity

Car ownership shared a weak negative association with a change in self-efficacy ($\beta = -0.044$, $p < .10$), suggesting that respondents with at least one car in the household were more likely to experience a decrease in self-efficacy in wintertime than respondents with no car in the household. Female respondents were more likely to experience a decrease in self-efficacy than males ($\beta = -0.110$, $p < .05$). An increase in age was positively associated with a change in self-efficacy ($\beta = 0.104$, $p < .05$). Residential location in the intensive public transport zone was positively associated with a change in self-efficacy ($\beta = 0.037$, $p < .10$), indicating that respondents living in this area were more likely to increase or maintain self-efficacy at winter follow-up.

4.2.2. Change in walking for transport

Residential density within a 500-m buffer distance shared a moderate ($\beta = 0.025$, $p < .05$) and residential location in the intensive public transport zone a weak positive association with a change in the weekly minutes of walking for transport ($\beta = 0.016$, $p < .10$). This signifies that individuals living in denser neighborhoods and those with a residential location at the intensive public transport zone are more likely to increase, have less decrease, or maintain their wintertime transport walking compared to those living in less dense neighborhoods or in other travel-related urban zones (Fig. 2). In addition, being female shared a weak positive association with a change in walking for transport ($\beta = 0.054$, $p < .10$), suggesting that female respondents were more likely to increase or maintain transport walking than males. Likewise, an increase in the respondent age was positively associated with a change in transport walking at follow-up ($\beta = 0.053$, $p < .10$). Fully occupied respondents, including those in full-time employment and students, were more likely to decrease transport walking than those without a full-time occupation ($\beta = -0.137$, $p < .01$). Transport walking decreased significantly more among the respondents that reported above sample median transport walking at baseline ($\beta = -0.312$, $p < .01$). Above median transport cycling at baseline was positively associated with a change in transport walking at follow-up ($\beta = 0.063$, $p < .05$), possibly suggesting a modal switch from cycling to walking. Change in self-efficacy showed a weak ($\beta = 0.016$, $p < .10$) influence on the change in walking for transport.

Table 5
Descriptive statistics of walking and cycling for transport.

	n	Summer (baseline)		Winter (follow-up)	
		Participation in behavior (%) [a]	Minutes/week (median [IQ range])	Participation in behavior (%) [a]	Minutes/week (median [IQ range])
Walking for transport					
Total sample	384	95.4	140 (80–263)	96.8	140 (78–260)
Above median [b]	192	100.0	263 (225-368	99.4	262 (120–368)
Below median [c]	192	91.2	80 (40–120)	94.6	113 (40–154)
Cycling for transport					
Total sample	384	59.9	38 (0–120)	19.1	0 (0–0)
Above median [b]	192	100.0	140 (75–225)	31.6	0 (0–75)
Below median [c]	192	20.7	0 (0–0)	5.7	0 (0–0)

IQ = Inter-quartile range.
[a] Participant reported at least one day with more than 10 min spend in behavior.
[b] Baseline weekly minutes above sample median.
[c] Baseline weekly minutes below sample median.

Table 6
The direct and total standardized effects on seasonal change in self-efficacy and walking and cycling for transport.

	Change in self-efficacy		Change in walking for transport		Change in cycling for transport	
	Direct effects	Total effects	Direct effects	Total effects	Direct effects	Total effects
Personal variables						
Age	0.104 [b]	(0.104 [b])	0.051 [c]	(0.053 [c])	- 0.042 [c]	(-0.042 [c])
Gender						
Female (ref. male)	- 0.110 [b]	(- 0.110 [b])	0.056 [c]	(0.054 [c])	- 0.072 [b]	(- 0.072 [b])
Occupational status						
Full-time occupied (ref. no)	0	(0)	- 0.137 [a]	(-0.137 [a])	0	(0)
Car ownership						
Yes (ref. no)	−0.044 [c]	(-0.044 [c])	0	(-0.001)	0	(0)
Walking for transport at baseline						
Above median (ref. below)	0	(0)	−0.312 [a]	(-0.312 [a])	0	(0)
Cycling for transport at baseline						
Above median (ref. below)	0	(0)	0.063 [b]	(0.063 [b])	−0.511 [a]	(-0.511 [a])
Built environment variables						
Residential density (500m buffer)	0	(0)	0.025 [b]	(0.025 [b])	0.087 [b]	(0.087 [b])
Travel-related urban zone						
Intensive public transport zone (ref. other zones)	0.037 [c]	(0.037 [c])	0.015 [c]	(0.016 [c])	−0.019 [c]	(-0.019 [c])
Psychosocial variables						
Seasonal change in self-efficacy	-	-	0.016 [c]	(0.016 [c])	0	(0)

[a] Significantly different from zero at $p < .01$.
[b] Significantly different from zero at $p < .05$.
[c] Significantly different from zero at $p < .10$.
Note: Both direct and total effects are listed and total effects are in parentheses. All effects are standardized.

Table 7
Results of the measurement model (the latent factors and its indicators).

Latent factor	Coefficient value	Measurement indicator
Changes in self-efficacy	1	Change in "I am confident I can keep being physically active even if I need to get up earlier"
	1.615[a]	Change in "I am confident I can keep being physically active even after a tiring day at work"
	3.073[a]	Change in "I am confident I can keep being physically active even if I feel down"
	2.422[a]	Change in "I am confident I can keep being physically active even if the weather is bad"

Notes: (1) [a] significantly different from zero at $p < .01$. (2) Coefficient values are unstandardized direct effects.

4.2.3. Change in cycling for transport

Residential density within a 500-m buffer was positively associated with a change in the weekly minutes of cycling for transport ($\beta = 0.087$, $p < .05$). Consequently, cycling for transport habits increase more (or alternatively decrease less) during winter months for those individuals living in denser neighborhoods compared to those residing in less dense neighborhoods. Considering the strong decline of transport cycling at the winter follow-up, this result shows that higher residential density predicts less wintertime decrease in transport cycling. On the other hand, residential location in the intensive public transport zone shared a weak negative association with a change in the weekly minutes of cycling for transport ($\beta = -0.019$, $p < .10$). This result suggests that individuals living in the intensive public transport zone were more likely to decrease transport cycling than those living in other travel-related urban zones. Age and gender were likewise associated with change in cycling, suggesting that older and female respondents were more likely to decrease cycling in wintertime than younger or male respondents. As expected, respondent with above median cycling at baseline were more likely to decrease the weekly minutes of transport cycling than those with low levels of cycling at baseline ($\beta = -0.511$, $p < .01$). Change in self-efficacy did not significantly influence the change in cycling for transport.

4.3. Qualitative results

Altogether 331 respondents provided answers to the open-ended question on wintertime physical activity behavior. Nineteen percent of the respondents discussed icy road conditions and the fear of falling as barriers to both wintertime walking and cycling: *"When the roads are icy, I only walk outside with studded shoes. I have fallen a couple of times, so this is necessary"*. Road conditions were seen to directly influence the amount of walking and cycling:*" I walk less when the roads are icy. I don't cycle at all during winter"*. Seven percent of the respondents specifically commented on the maintenance of pedestrian and cycling infrastructure and the maintenance of the common outdoor areas of the housing company: *"When the sidewalks are not well maintained during winter, I don't feel like being outdoors or running errands in the neighborhood"*. Poor road maintenance, including insufficient street lighting, slow or inadequate snow removal, road gritting, and salting, were seen to negatively impact the opportunities for both walking and cycling: *"I cycle to work all year round and in any weather. However, when the cycleways are not cleared from snow I have to stop."*

Other topics concerning the built environment but raised by fewer respondents (<5%) included the aesthetic quality of the environment (slush and grit on the sidewalks and cycleways, no street-level activities to look at) and the combination of steep road inclines and icy road conditions.

Regarding the natural environment, 9% of the respondents discussed adverse weather conditions (i.e., precipitation, wind, and general poor weather), 7% low temperature, and 6% short daylight hours as factors lowering their willingness to engage in physical activities outdoors. Several respondents noted that despite being a regular cyclist during the warmer months, they cease to cycle altogether during the winter months.

5. Discussion

This longitudinal study examined the potential of the built environment to support year-round active transportation in urban areas with a distinct cold winter season. In short, our results suggest that the residential built environment influences seasonal changes in both walking and cycling for transport in the adult population. This knowledge supports urban policy and planning efforts in cities that aim to increase the continuous use of sustainable and active transportation modes throughout the year and prepare for the increasing frequency of extreme weather conditions due to climate change (Turrisi et al., 2021).

In general, our results on the use of active transportation during the cold winter season were consistent with previous studies conducted in similar climates (Liu et al., 2015b; McCormack et al., 2010; Nahal and Mitra, 2018; Stigell and Schantz, 2015) and reviews on seasonal variation in physical activity and sedentary behavior (Chan and Ryan, 2009; Garriga et al., 2022; Tucker and Gilliland, 2007; Turrisi et al., 2021). We observed a drastic decrease in cycling for transport during the winter season, with many participants ceasing to cycle altogether. Changes in walking were less consistent and showed no significant sample-level difference in the minutes of walking for transport in the baseline and follow-up surveys. Unexpectedly, respondents with below median walking at the summer baseline reported increased walking at the winter follow-up. Post hoc analyses revealed that the increase in wintertime walking for transport mainly concerned respondents with above median cycling for transport at the baseline, thus suggesting at least a partial mode shift from cycling to walking or a combination of walking and public transport for this group. Similar results have been reported by Stigell and Schantz (2015), who observed an increase in wintertime walking for commuters who alternated between walking and cycling to work. Overall, our results confirm the findings of prior studies showing that, in contrast to the mixed effects on walking, cycling for transport is strongly influenced by seasonal variation in travel conditions (Liu et al., 2015b; Nahal and Mitra, 2018; Saneinejad et al., 2012; Stigell and Schantz, 2015).

5.1. *Effect of the built environment on seasonal changes in walking and cycling for transport*

A structural equation model was used to study the potential impact of the neighborhood built environment on seasonal changes in walking and cycling for transport. The final model confirmed several of the hypothesized relationships between the neighborhood environment and active transportation behavior. The strongest positive associations were found between residential density around home and walking and cycling for transport, suggesting that individuals living in more densely built urban areas were more likely to maintain their summer active transportation behavior during the cold winter season. These results suggest that the qualities of more densely built residential areas, such as higher destination availability and shorter trip distances, are suited to support not only summertime but also year-round active transportation. At the same time, some built environment features previously connected to the year-round use of active transportation did not explain changes in active transportation behavior in the present study. For example, Nahal and Mitra (2018) found a positive association between cycling during the winter and the presence of cycleways within a 500-m home buffer. However, in our analysis, environmental variables measuring the length of the pedestrian and cycling network and the winter maintenance of cycleways did not contribute significantly to the model after accounting for residential density and travel-related urban form and were therefore excluded from the final structural equation model.

Furthermore, we found that the associations between cycling and walking for transport and the travel-related urban zone of the residential location approached statistical significance ($p < .10$). In our model, the best model fit was found for a model including a categorical variable indicating a residential location in a transport-oriented neighborhood (intensive public transport zone, Fig. 2). According to the model results, respondents living in transport-oriented neighborhoods were less likely to maintain their summer cycling behavior during the winter season than respondents living in the other, more pedestrian- or car-oriented urban areas. An opposite relationship was observed for transport walking; a result that most likely indicates at least a partial travel mode shift from cycling to walking as discussed earlier. To better understand these results, we performed post hoc analyses comparing the weekly minutes of summer cycling for transport between the travel-related urban zones. These confirmed that, on average, the respondents living in the most car-oriented areas cycled less during the summer period than respondents living in the transport-oriented areas – a result explaining why the wintertime changes in their cycling behavior were generally less drastic. Respondents living in the most central and pedestrian-oriented areas, on the other hand, cycled more at baseline than respondents living in the transport-oriented neighborhoods and were also more likely to continue cycling during the winter season.

In our view, these results suggest that certain types of residential environments are particularly sensitive to seasonal changes in cycling for transport. While these differences are likely to stem from diverse urban structural factors, we assume that they are at least partly explained by differences in the average cycling trip distances. Existing evidence suggests that adverse winter conditions do not only decrease participation in cycling behavior but also shorten the average cycling trip distances. For instance, Bergström and Magnusson (2003) observed the winter mode share for cycling to decrease rapidly for trip distances exceeding 3 km. The areas identified in the present study as transport-oriented neighborhoods have generally lower residential density and destination availability than the most central parts of the study area. Consequently, while we do not have knowledge of the average trip distances in these areas, it seems likely that they are longer than in the more centrally located areas and thus more easily affected by unfavorable cycling conditions.

Following the conceptual model introduced in Fig. 1, we expected also individual-level factors to influence seasonal changes in walking and cycling for transport. Regarding socio-economic and demographic factors, changes in active transportation behavior were found to differ by gender, as female respondents were more likely to decrease cycling for transport during the winter season than males. This result is in line with prior studies reporting women to be more likely than men to stop cycling in wintertime (Nahal and Mitra, 2018; Saneinejad et al., 2012). Age and employment status were also associated with changes in the use of active transportation modes, suggesting that the wintertime loss of physical activity gained through active transportation may accumulate on certain subpopulations. From a travel equity perspective, it should be acknowledged that seasonal changes in active transportation conditions can be particularly burdensome to certain vulnerable groups that this study did not focus on, such as older adults, disabled individuals, or families with small children (Liu et al., 2017). Bad road maintenance and other similar built environment factors can act as extreme barriers for older adults' walking habits during winter season (Garvin et al., 2012).

Moreover, seasonal changes in self-efficacy for physical activity had a modest influence on changes in walking for transport, thus suggesting a mediating effect between self-efficacy and seasonal changes in walking. However, the direct effects of the built environment and socio-economic and demographic characteristics on the active transportation outcomes did not considerably differ from the total effects that included the mediating effect of self-efficacy, thus suggesting this effect to be rather small. Changes in cycling for transport, on the other hand, were not associated with self-efficacy and appeared to be more affected by external influences, such as changes in the cycling conditions. These results align with previous studies finding interaction effects between self-efficacy and the built environment in the U.S. (Carlson et al., 2012) but not among European populations (Van Holle et al., 2015). This difference may be attributed to cultural and geographical differences in active transportation behavior, as suggested by Van Holle et al. (2015).

While the results discussed above suggest a clear relationship between some built environment characteristics measured on a neighborhood level and the participation in year-round active transportation, we acknowledge that the ways in which our living environments influence these behaviors are likely to be more complex. In order to better understand these person-environment interactions, we conducted a thematic analysis of the respondents' own descriptions of their wintertime physical activity behavior to identify characteristics of the built environment that they perceived as barriers to and facilitators of wintertime active transportation. Among the most frequently mentioned barriers, icy road conditions and the subsequent fear of falling were seen to directly influence the willingness to walk and cycle. Insufficient street lighting and the poor maintenance of sidewalks and cycleways were also seen to negatively impact wintertime active transportation. These environmental characteristics represent the microscale features of the built environment that are typically observed at the human scale and that may easily be overlooked in spatial analyses focusing on macro- and neighborhood-level variables, such as the quantitative analysis of the present study. However, results from quantitative studies focusing on microscale built environment features suggest that they may influence walking and cycling behaviors independently from macroscale variables. (e.g., Cain et al., 2014; Steinmetz-Wood et al., 2020).

Lastly, the respondent descriptions of barriers for wintertime active transportation behavior were rarely limited to a single ecological level. Mentions of the built environment were often accompanied with remarks about other levels of ecological influence –the natural and policy environments, in particular. Features of the natural environment, more specifically, adverse weather conditions, including low temperatures, precipitation, and wind, as well as darkness and short day-light hours, were often mentioned alongside descriptions of environmental barriers. The negative influences of adverse weather conditions on active transportation have been previously discussed in multiple studies (e.g., Böcker et al., 2013; Böcker et al., 2019; Flynn et al., 2012). Likewise, several respondents directly addressed issues related to the practices and policies of the wintertime maintenance of cycling and pedestrian infrastructure. Recurring topics included mentions of slow or inadequate snow removal, road gritting, and salting. These observations align with previous qualitative studies that have identified inadequate road maintenance as a barrier especially to winter cycling (Chapman and Larsson, 2021; Galway et al., 2021; Spencer et al., 2013).

5.2. Implications for practice and policy

Participation in active transportation, cycling in particular, declines considerably during the winter period in areas characterized by a distinct cold season. This poses a challenge for planning and policy efforts to increase the mode share of active transportation in these areas. This study has explored seasonal variation in walking and cycling for transport following the ecological approach of active living, which emphasizes the multiple levels of influence on physical activity behavior (Sallis et al., 2006; Sallis and Owen, 2015). Our results demonstrate that wintertime active transportation is influenced by several aspects of the environment, some of which, such as weather and the climate, are out of our reach to change and require active adaptation, and some of which can be actively addressed with urban policy and planning. The results of this study suggest that the built environment can create opportunities for wintertime active transportation (particularly cycling, which decreases more), and that these opportunities need to be created on diverse planning levels and scales, ranging from the city and neighborhood levels to the microscale of pedestrian and cycling infrastructure design and maintenance.

Moreover, our results also support the findings of previous qualitative studies (e.g., Chapman and Larsson, 2021) stating that in urban areas with a distinct cold winter season, cycling in summer is perceived to be a different activity to winter cycling, and thus cycling infrastructure designed for summer conditions cannot automatically be expected to cater to the needs of winter cycling. Instead, improving winter cycling within the existing infrastructure needs to be identified as a specific planning objective alongside means to improve cycling in summer (with own and often different toolsets). Our results add to this knowledge by identifying characteristics of the urban structure that support cycling for transport in favorable conditions but that are also particularly sensitive for changes during the colder season. In terms of the relevant policy to support year-round cycling, such areas with a clear seasonal drop in participation in cycling behavior could be targeted to reduce the loss of public health benefits gained through regular cycling for transport.

Last, while this study did not proceed to examine seasonal shifts in the use of other modes of transport, it is evident that these are brought about following changes in walking and cycling for transport. For those residents who wouldn't consider cycling during the winter months, the use of public transport instead of a private car during winter could potentially have less drastic changes in physical activity levels as the use of public transport also includes active travel behavior in terms of walking (Rissel et al., 2012; Villanueva et al., 2008). Transport and urban planning that truly support year-round active transportation on a population level is likely to include integrated solutions that consider walking and cycling for transport together with public transportation instead of planning for each separately.

5.3. Study limitations

The present study has certain limitations. First, participation in active transportation was assessed with self-reported measures, which can lead to the overestimation of actual activity levels (Lee et al., 2011; Rzewnicki et al., 2003). Second, this study examined seasonal effects on a general level, and was thus unable to differentiate between the factors contributing to seasonal variation in physical activity, such as temperature difference, amount of daylight, or adverse weather conditions (Böcker et al., 2013). Last, a key limitation in the study design is the lack of items measuring residential self-selection. Thus, we do not know whether the respondents' residential location choice was affected by its opportunities for year-round walking or cycling for transport. If this was the case, respondents already inclined towards the year-round use of active transportation modes might have sought residential environments supporting these behaviors.

6. Conclusions

Our results suggest that the neighborhood built environment has a significant effect in supporting year-round walking and cycling for transport. The strongest positive associations were found between residential density and walking and cycling for transport, suggesting that individuals living in more densely built urban areas were more likely to maintain their summer active transportation behavior during the cold winter season. Consequently, built environment interventions have the potential to reduce the loss of public health benefits due to a shift from active to motorized transport modes during the winter season. Such actions could be directed specifically to support cycling for transport, which was found to decrease drastically during the winter season. Finally, the results of this study indicate that successful policies and planning efforts to increase wintertime active transportation should be delivered on multiple scales, ranging from macroscale features of the urban structure to the microscale of street-level design and maintenance.

Author contributions

AK:Conceptualization; Data curation; Formal analysis; Methodology; Visualization; Writing - original draft; Writing - review & editing. **SR**: Conceptualization; Formal analysis; Methodology; Writing - original draft; Writing - review & editing. **TR**: Writing - original draft; Writing - review & editing.

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