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Age as effect modifier of the associations between the physical environment and adults' neighborhood walking in the Netherlands

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ABSTRACT

Walking contributes to people's physical activity. While the physical environment (i.e., built and natural environmental characteristics) seems to be associated with people's neighborhood walking behavior, there is little evidence how these associations are moderated by age and vary across levels of urbanicity. This study examined the moderating effects of age and urbanicity on the associations between the neighborhood physical environment and the recreational and transportation walking of adults in the Netherlands. We used data on adults aged ≥ 18 years (N=65,785) taken from the Dutch National Travel Survey for 2015–2017. The outcome variable was the total duration of daily walking separately for recreation and transportation. We assessed the characteristics of the natural and built environments objectively based on respondents' home addresses within 300 m, 600 m, and 1000 m buffers. Tobit regression models with interaction terms between age and the physical environment were fitted. The results showed that age significantly modified the walking-environment associations and the moderating effects differed between weekdays and weekends. We also found that environmental characteristics (like residential density) correlated with walking differently among different age groups across urban and rural areas. Interventions intended to stimulate walking should be tailored to specific places and age groups.

1. Introduction

Physical and mental health problems are major issues in European countries. Over half of adults in Europe are overweighted due to unhealthy diets and physical inactivity (OECD, 2019). In recent years, these health problems have been aggravated in many European countries (Pan et al., 2021; Thorell et al., 2021).

Physical activities such as walking and cycling have been recognized to improve people's health, not only reducing stress, anxiety and depression but also hindering the development of all kinds of chronic diseases, such as obesity, type-II diabetes and cardiovascular diseases (Haskell et al., 2007; Koolhaas et al., 2017). Among such physical activities, walking is the easiest and most accessible form across age groups (Siegel, Brackbill, & Heath, 1995). Due to its health benefits at the population level, urban planners try to intervene in the urban structure to create more walkable, and thus healthier, environments (Barton & Tsourou, 2013). However, these efforts must be guided by a solid evidence base on which, and to what extent, physical environmental factors stimulate and/or hinder people's walking behavior, which may not be the same for everyone.

Many studies have been conducted to investigate walking behaviors and shown that the physical environment of neighborhoods is strongly associated with walking (Barnett, Barnett, Nathan, Van Cauwenberg, & Cerin, 2017; Ewing & Cervero, 2010; Wang, Chau, Ng, & Leung, 2016). Recent research has shown that the associations between physical environments and neighborhood walking differed between walking purposes (transportation/recreation) and between weekdays and weekends (Gao, Kamphuis, Helbich, & Ettema, 2020; Wang, Ettema, & Helbich, 2021). As people of different age groups have different physical function levels and neighborhood settings differ across urbanization levels, the walking-environment associations might also differ between age groups and between urban and rural areas. Considering this, some studies have examined the role of age and urbanicity in the differences in walking (Ghani, Rachele, Loh, Washington, & Turrell, 2018; Koohsari et al., 2017). However, to the best of our knowledge, the moderating effects of age still received less attention in the literature. It remains unclear how age moderates differently the associations of the neighborhood physical environment with transportation and recreational walking between weekdays and weekends and between urban and rural settings.

Given this research gap, in this study we took one step further and

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examined the moderating effects of age on walking-environment associations by taking a stratified analysis and simultaneously controlling for day of the week, trip purpose, and urbanicity. We aim to address the following two research questions: 1). To what extent age is a potential effect modifier of the associations between the neighborhood physical environment and transportation and recreational walking? 2). How these moderating effects differ between weekdays and weekends and between urban and rural areas? To answer these questions, we calculated a set of natural and built environmental variables and performed regression analysis with the interaction effects of age, stratifying the analysis by weekdays/weekends, transportation/recreation, and by urban/rural. We expect that the findings from this study can provide a deeper understanding of walking-environment associations and offer more specific insights for urban planners not only in the Netherlands but also globally to develop effective interventions for walking promotion.

2. Literature review

Past research on walking has explored a wide range of factors, such as travel attitudes (Alvdv, Ac, & Js, 2022), socio-demographic characteristics (Santos, Vale, Miranda, & Mota, 2009), and subjective measures (Lin & Moudon, 2010). In this section we present some of the more relevant works, i.e., physical environments (Section 2.1), age (Section 2.2) and urbanicity (Section 2.3).

2.1. Physical environment and walking

The physical environment of neighborhoods has been confirmed in many studies to have a close relation with walking (Mavoa et al., 2019; Pelclová et al., 2012; Saelens & Handy, 2008; Yu et al., 2022). Broadly, it can be classified into two categories: natural environments (e.g., green space and blue space) and built environments (e.g., land-use, streets, and buildings). Both have been proven to correlate with walking (Barnett et al., 2017; Kang, 2018; Saelens & Handy, 2008; Wang et al., 2016; Yang et al., 2019). While some natural and built environmental factors (e.g., green space and land use diversity) have been shown in some studies to have a positive impact on walking (Sarkar et al., 2015; Thornton et al., 2017), other factors (such as blue space and crossings) were considered barriers and could discourage walking (Ferrer, Ruiz, & Mars, 2015; Wang et al., 2021).

However, the reported associations between the physical environment and walking are not always consistent across studies. One of the reasons for these inconsistencies is that people have different walking behaviors on weekdays and at weekends (Brooke, Corder, Atkin, & van Sluijs, 2014; Bürgi & De Bruin, 2016). This implies that the associations between the physical environment and walking possibly also differ by weekdays and weekends, as revealed in a few studies (Gao et al., 2020; Wang et al., 2021). Another aspect contributing to mixed findings is that walking–environment relationships differ in terms of the walking purpose (i.e., walking for recreation vs. walking for transportation) (Wang et al., 2021). For example, while street connectivity, land-use diversity, and walking amenities play a role for transportation walking, recreational walking is more likely associated with proximity to public transportation, availability of neighborhood sidewalks, and access to parks and green spaces (Li et al., 2021; Ussery et al., 2018; Yun, 2019).

Although some studies have found that walking-environment relationships differ in terms of day of the week (weekdays and weekends) and walking purpose (transportation and recreation), most of them analyzed these factors separately. Moreover, some research reported that relationships between the neighborhood physical environment and walking differed between age groups and urbanization levels. However, there is still a lack of research on how age modified differently walking-environment relationships for different walking purposes between weekdays and weekends and between urban and rural areas. In order to develop effective strategies tailored for targeted groups to promote walking, a more refined analysis of walking-environment relationships is still needed.

2.2. Age and walking

Age is a major predictor of walking behavior. People in different age cohorts have different walking behaviors (Böcker, van Amen, & Helbich, 2017; Ghani, Rachele, Washington, & Turrell, 2016). For young adults, Larrañaga, Rizzi, Arellana, Strambi, and Cybis (2016) found that they performed more walking for transportation (e.g., commuting to work, to do errands, or to go from one place to another). This may be attributed to the fact that young adults are more fit and likely to participate in vigorous-intensity physical activities. In recent years evidence is emerging from some studies that the natural and built environments of neighborhoods influence walking among younger adults. For example, Oyeyemi, Adegoke, Oyeyemi, and Sallis (2011) investigated environmental correlates of walking among African young adults and found that crime rate at night and many interesting things to look at were strongly associated with walking. Also, Cole, Koohsari, Carver, Owen, and Sugiyama (2019) found a strong association between street connectivity, Walk Score, and walking.

For older adults, walking is important for the prevention of chronic diseases and is their most common favorite physical activity (Szanton et al., 2015). Compared to their younger counterparts, older adults–who have more time at their disposal but may face difficulties with certain forms of physical activity of moderate to vigorous intensity–tend to do less transportation walking but more recreational walking (Shimura, Sugiyama, Winkler, & Owen, 2012; Van Dyck et al., 2013). A number of studies found that the elderly were sensitive to their neighborhood environments and their walking behaviors were affected by certain natural and built environment characteristics, like residential density (Li, Fisher, Brownson, & Bosworth, 2005), access to services (Nagel, Carlson, Bosworth, & Michael, 2008), land use diversity (Li et al., 2005), traffic safety (Oyeyemi, Kolo, Oyeyemi, & Omotara, 2019), and green space (Besser & Mitsova, 2021).

Despite the existing evidence mentioned above, it remains unclear how walking-environment relationships differ across different age groups in terms of urbanicity (urban/rural), day of the week (weekdays/weekends), and walking purpose (transportation/recreation). A more refined analysis is still needed to take into account these factors simultaneously to gain a deeper understanding of age differences in walking.

2.3. Urbanicity and walking

A limitation of previous studies on walking–environment associations is that they usually do not consider the moderating effects of the urbanization level of residential environments (Fishman, Böcker, & Helbich, 2015; Gao et al., 2020; Gao, Kamphuis, Ettema, & Helbich, 2019). It is well-established that urban and rural areas provide fundamentally different geographical settings (Pateman, 2011). While urban areas have diverse land use, easy access to services, and higher street connectivity, rural areas have a comparatively sparse population, limited access to services, and more green and open spaces. A few studies noted that there were urban–rural differences in walking prevalence (Carlson et al., 2018; Forsyth, Oakes, Lee, & Schmitz, 2009; Moreno-Llamas, García-Mayor, & De la Cruz-Sánchez, 2021), but these studied could not shed light on the extent to which urban and rural residents' walking behaviors were influenced differently by the physical environment of their neighborhoods.

Some studies have been conducted to investigate the differences in environmental correlates of walking among urban and rural residents. Whitfield et al. (2019) found that sidewalks facilitated transportation walking among urban residents and paths and relaxing destinations were associated with transportation walking among rural residents. Koohsari et al. (2017) reported that crossing density was associated with walking for errands in urban areas, while street integration was associated with walking for commuting in rural areas. However, these results are still tentative. How walking-environment relationships differ between age groups in urban and rural areas and between weekends and weekdays has not been thoroughly examined. As noted in Collins, Al-Nakeeb, Nevill, and Lyons (2012), environments with different urbanization levels provide different types of facilities for promoting physical activities (e.g., more playgrounds and parks are available in suburban areas than in rural areas), which may influence walking differently among different age groups. Moreover, people living in urban and rural areas have different physical activity behaviors between weekdays and weekends (Collins et al., 2012). Therefore, more in depth examination is needed to analyze urban–rural differences in walking-environment associations across different age groups, distinguishing between weekdays and weekends in the analysis.

3. Data and methods

3.1. Conceptual framework

In order to address the research questions mentioned in Section 1, in this study we proposed a conceptual framework in which a refined stratified analysis was applied to gain a deeper understanding of moderating effects of age on the walking-environment associations, as shown in Fig. 1. In our framework, we mainly focused on two walking purposes: transportation walking (e.g., walking to work) and recreational walking (e.g., walking for leisure). Furthermore, we distinguished walking between weekends and weekdays and between urban and rural areas. To capture natural and built environment characteristics, we employed and calculated the following environmental variables: normalized difference vegetation index (NDVI), blue space, land-use mix, street connectivity (cul-de-sac and ≥4 crossing density), and residential building density. Meteorological conditions (temperature, wind speed, and precipitation) and individual determinants (e.g., gender and education) were also included in the framework. To examine to what extend the associations between the environmental characteristics and walking duration were moderated by age, interaction terms between environmental variables and age were included, with the youngest age group (18–44) served as reference. The regression models were stratified by walking purpose (transportation/recreation), residence (urban/rural/total), and by weekdays/weekends. This gave us totally 12 separate strata to control for these variables simultaneously to perform a detailed examination of walking-environment associations.

3.2. Study population

We selected the Netherlands as our study site. This was because 13 % of adults in the Netherlands were obese in 2017 (rising from 10 % in 2002) and 2 % of deaths were attributed to physical inactivity (OECD et al., 2019). We used self-reported, cross-sectional data taken from the Dutch National Travel Survey (NTS) (CBS, 2015). The NTS is carried out yearly based on a random sample of the population living in the Netherlands. Participants report their travel behavior on a specific day via a travel diary. The survey items cover respondents' socio-demographic characteristics (e.g., nationality, age, gender, and driving license) and travel-related information (e.g., travel purpose, trip duration, and trip origin and destination at a postcode level). To adjust for seasonal effects in transport behavior, eligible respondents were allocated to a specific day of the year. We included adults aged ≥ 18 years and maximized the sample size by pooling data from three consecutive years (i.e., 2015–2017).

3.3. Outcome variables

The outcome variables were defined as the total duration of daily walking (in minutes) within a 1000 m buffer centered on peoples' residential postal codes. Depending on the reported travel purpose, we stratified walking trips into recreational walking (e.g., for leisure) and transportation walking (e.g., for shopping or commuting). We excluded trips beyond the residential environment (>1000 m) based on their origin and destination 6-digit postal codes areas (PC6).

3.4. Natural and built environmental variables

We applied circular buffers based on the centroids of respondents' residential PC6 to approximate their walking environments. The PC6 is the most fine-grained administrative level in the Netherlands comprising 456,563 areas with, on average, only 20 (standard deviation (SD) = 243) address locations. In keeping with earlier studies (Mavoa et al., 2019; Villanueva et al., 2014), we applied three buffer sizes with radii of 300 m, 600 m, and 1000 m, respectively, to obtain the environmental covariates by means of a geographic information system (GIS).

We followed previous studies (Gao et al., 2020; Sarkar et al., 2015) in selecting covariates describing the natural and the built environment objectively. The following five measures were included: green space, blue space, land-use mix, street connectivity, and residential building density. For a description the variables, see Table 1.

3.5. Meteorological conditions

Because meteorological conditions on the day of travel have a profound influence on travel behavior (Böcker, Dijst, & Prillwitz, 2013), we adjusted for three weather conditions: 1) daily average precipitation (in mm), 2) daily average wind speed (in m/s), and 3) daily average temperature (in C). Data were obtained from the Royal Dutch

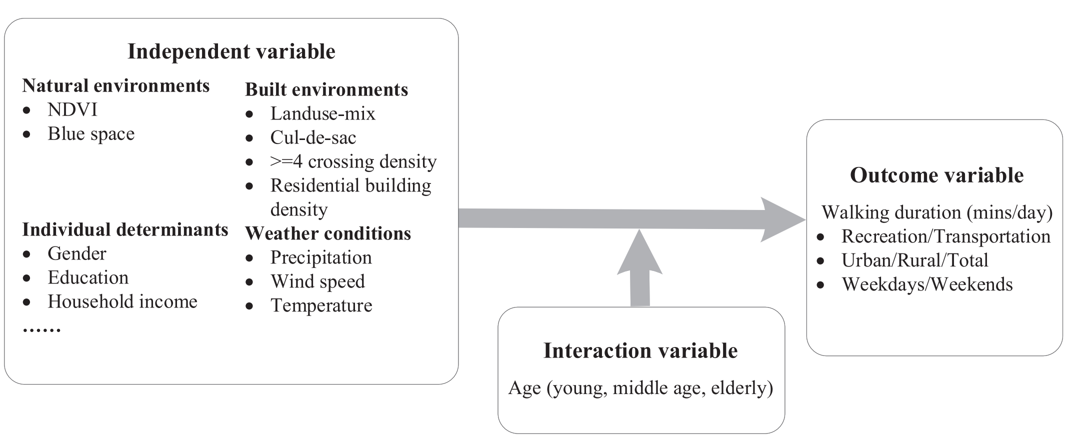


Fig. 1. Conceptual framework for analysis of moderating effects of age on walking-environment associations.

Table 1
Objective measures of natural and built environments.

Considered variables	Description
Normalized difference vegetation index (NDVI)	As a green space measure, NDVI was used to describe the level of greenness of outdoor environments. The NDVI captures the chlorophyll content in the vegetation canopy (Tucker, 1979). We used Landsat 8 satellite imagery with a 30 m resolution for 2015 as input data. The range of the index is between −1 and + 1. Higher positive NDVI values (0, 1] indicate more biomass, negative ones [−1, 0) represent water bodies. To achieve a better estimation of greenness, the latter were excluded before determining the average NDVI per buffer.
Blue space	We used the Dutch land cover database (Landelijk Grondgebruiksbestand Nederland) for 2018 with a spatial resolution of 5 m. Blue space proportion was computed as the proportion of cells classified as fresh water or saltwater within the total number of cells per buffer.
Land-use mix	We used Dutch land-use data (Bestand Bodemgebruik) for 2015 from Statistics Netherlands (CBS, 2019) to calculate land-use mix. The measure was operationalized based on the Shannon entropy. The index measures the heterogeneity in the distribution of different land-use types within each buffer (Sarkar, Gallacher, & Webster, 2013). A higher entropy value refers to greater land-use diversity.
Street connectivity	We extracted crossing data from the digital Dutch topographical base map 1:10,000 (TOP10NL) for 2016. We distinguished two types of street connectivity types: ≥ 4-way crossings and cul-de-sacs. While ≥ 4-way crossings are typical for more walkable areas, cul-de-sacs are considered as walking barriers due to their poor connectivity.
Residential building density	We used the building data from the Addresses and Buildings Registry 2016 (Basisregistratie Adressen en Gebouwen) to calculate the ratio of the area of residential building footprints relative to the buffer area.

Meteorological Institute (www.knmi.nl) as done elsewhere (Fishman et al., 2015; Gao et al., 2020). Each respondent's PC6 was allocated to the closest weather station using the Euclidean distance.

3.6. Urban and rural residence

Considering that walking behavior differs across urban and rural areas (Whitfield et al. (2019); Moreno-Llamas et al. (2021); Carlson et al. (2018)), we classified each respondent's PC6 area as either urban or rural. To maintain comparability across countries, we used the functional urban areas classification proposed by the Organisation for Economic Co-operation and Development (Dijkstra, Poelman, & Veneri, 2019). A functional urban area is composed of a densely populated city (≥ 1500 inhabitants per square kilometer) and its home–work commuting zones. A PC6 area was identified as urban if its centroid was within a functional urban area, otherwise it was regarded as rural.

3.7. Control variables

Individual-level data on demographic and socioeconomic characteristics of the respondents were obtained from the NTS. Following earlier studies (Gao et al., 2020; Gao, Kamphuis, Dijst, & Helbich, 2018), we included gender (male, female); ethnicity was dichotomized into Dutch and non-Dutch; age was grouped into three categories: 18–44 (young adults), 45–64 (middle aged), and ≥65 years (the elderly), as commonly used in other studies (An et al., 2020; Gao et al., 2018; Okoro, Hollis, Cyrus, & Griffin-Blake, 2018); education level was grouped into low, medium, and high; household income was grouped into <2,000 2,000 − 4,000, and >4,000 euros/month; driving license status was binary (no, yes), household composition was grouped into single person, couple without children, couple with children, and single parent with children; the number of cars per household was classified into no cars, 1 car, and ≥ 2 cars; number of e-bikes per household was classified into no e-bikes, 1 e-bike, and ≥ 2 e-bikes; and number of mopeds per household was classified into no mopeds, 1 moped, and ≥ 2 mopeds.

3.8. Statistical analysis

Descriptive statistics (i.e., mean and standard deviation) were used to summarize quantitative variables; percentages per category were used for categorical variables. To circumvent multicollinearity issues among the quantitative variables, we used Spearman's correlation coefficients. Correlations above ±0.8 were considered as critical.

We employed Tobit regression models to assess the linear associations between walking and the environmental variables. Tobit regressions were necessary because of left-censoring in our outcome variables (i.e., walking duration cannot take negative values) and a large portion of the respondents did not report any walking resulting in zero-inflated data. We analyzed transportation walking and recreational walking separately, as suggested elsewhere (Wang et al., 2021). The models were stratified further into weekdays and weekends as well as respondents' residence (urban, rural, and total). The environmental variables were measured based on 300 m, 600 m, and 1000 m buffers. Models were refitted with the three buffer sizes to assess model robustness concerning the definition of the geographic context. In total, we fitted 36 fully-adjusted models.

To test whether the associations between the environmental characteristics and walking duration were moderated by different age groups and differed between urban and rural areas, interaction terms between environmental variables and age were included and models were stratified by urban/rural residence. The youngest age group (18–44) served as reference. The significance of the main and interaction effects was assessed based on 95 % confidence intervals (CI). All analyses were conducted in Stata 16.

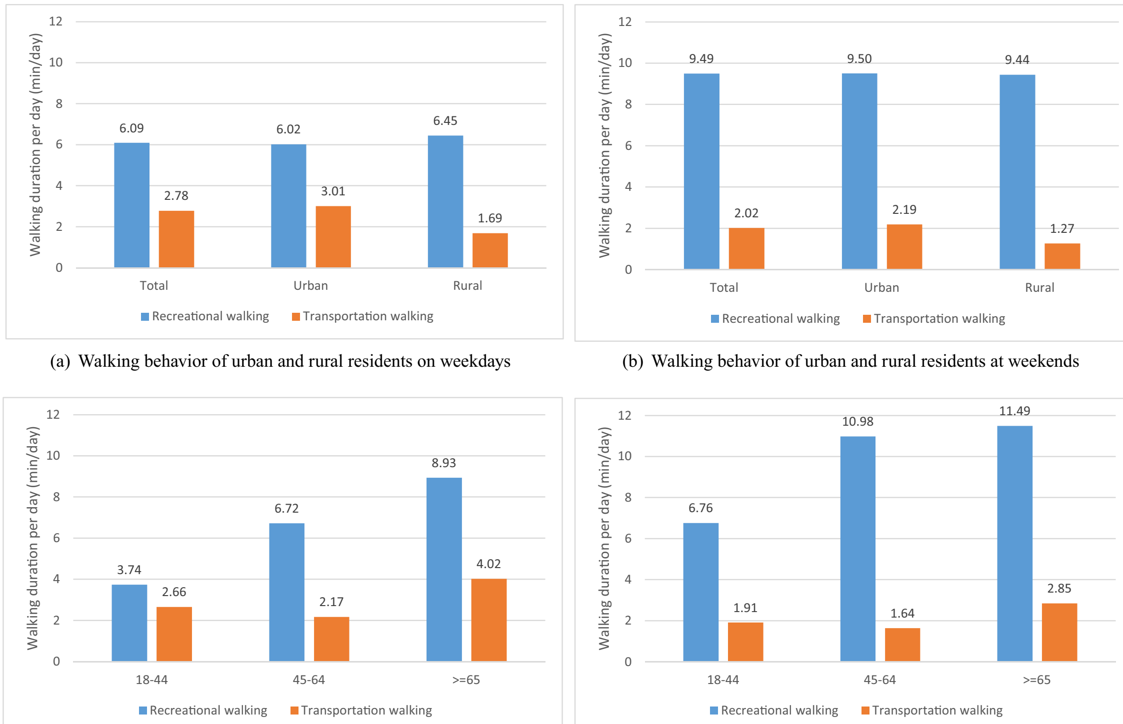
4. Results

4.1. Sample characteristics

After we excluded records with missing covariate information and trips outside respondents' residential environments (>1000 m) from the total population (N=112,706), our analytical sample comprised in total 65,785 respondents. Of these, 82 % lived in urban areas, 18 % in the countryside, 38 % were aged 18–44, 39 % between 45 and 64, 23 % were retired (aged ≥ 65 years), 35 % were highly educated, and 40 % were couples with children.

Figs. 2(a) and 2(b) show the differences in the daily walking duration between residents in urban and rural areas. People living in rural areas spent less time in transportation walking (1.69 min/day on weekdays and 1.27 min/day at weekends) than the people in urban areas (3.01 min/day on weekdays and 2.19 min/day at weekends). Regarding the differences in respondents' walking across different age groups, as shown in Fig. 2(c) and 2(d), the elderly (≥ 65) engaged in more walking than the middle -aged group (45 − 64) and the young group (18–44). While younger people spent less time on recreational walking (3.74 mins/day on weekdays and 6.76 mins/day at weekends) than the elderly, middle aged people (45–64) walked less for transportation (2.17 mins/day on weekdays and 1.64 mins/day at weekends) than the others.

Independent of the considered buffer sizes and consistently across both weekdays and weekends, land use mix, the proportions of blue space, residential building density, and both crossing density variables (cul-de-sacs and ≥4 way crossings) were higher in urban areas than in rural areas. In contrast, the average NDVI values were lower in urban areas than those measured in rural areas. Regarding the meteorological conditions, the means of daily precipitation sum, daily average wind speed, and daily average temperature were higher in urban areas than in



(a) Walking behavior of urban and rural residents on weekdays

(b) Walking behavior of urban and rural residents at weekends

(c) Walking behavior among different age groups on weekdays

(d) Walking behavior among different age groups at weekends

Fig. 2. Walking behavior in the study population.

rural areas (see Table 2).

4.2. Regression analyses

We mainly reported analysis results for the 1000 m buffer size because some similar results were observed for the other buffers and we were more interested 1000 m walking environment. Tables 3 summarizes the regression results for transportation and recreational walking within 1000 m buffers stratified by the day of the week and the urbanization level (urban vs. rural). We observed that age modified the associations between recreational/transportation walking and some natural and built environmental variables. More specifically, a negative association between green space and recreational walking on weekdays was found for younger people (*coef* $= -75.247$, $p < 0.01$), while no significant associations were found for middle-aged people and the elderly. Positive associations between land-use mix (*coef* $= 31.689$, $p < 0.05$) and $\geq$4 way crossing density (*coef* $= 24.952$, $p < 0.01$) and transportation walking at weekends were observed for younger people, However, the association of land-use mix was weaker for middle-aged people (45–64 years), and association was null for $\geq$4 way crossing density. Age also moderated the associations of blue space, and residential building density. No significant associations with recreational walking at weekends were found among younger and middle-aged groups, while those aged $\geq$65 showed a negative association with blue space in urban areas and a positive association with residential building density in rural areas (as shown in Table 3). There was no evidence for moderating effects of age with respect to cul-de-sac. In addition, precipitation was negatively associated with recreational walking at weekends among younger people (*coef* $= -32.783$, $p < -0.05$), while no significant associations were found for middle-aged people and the elderly. A similar effect was also observed for temperature (*coef* $= -10.376$, $p < 0.1$). For the analysis results concerning the other buffers (300 m and 600 m), please see Appendix A.

5. Discussion

5.1. Main findings and interpretation

In this study we assessed how objectively measured physical environmental factors correlate differently with walking across age groups. Regarding the natural environmental characteristics, age moderated the associations of green and blue spaces with walking. Specifically, the negative relationships of green space with transportation walking (both on weekdays and at weekends) were only significant for younger adults in urban areas, and no significant association was found for the elderly. This might be because neighborhoods with higher level of vegetation may have less utilitarian destinations for younger adults for transportation walking, but are attractive for the elderly who like the presence of greenery in transportation walking (Van Cauwenberg et al., 2012). Moreover, we also observed a significant negative association between blue space and recreational walking at weekends among the elderly living in urban areas, while no significant association appeared for younger adults. This may be attributed to the fact blue space is unwalkable and acts as barriers for the elderly (who are less physically functional) in their walking trips for recreation.

In line with previous studies (Cerin et al., 2017; Gao et al., 2020; Wang et al., 2021), we also found some differences in the associations of natural environments with walking between weekdays and weekends. For instance, NDVI was negatively associated walking for the younger group on weekdays, but no associations were found at weekends. This echoes the results from another study on Dutch citizens by Maas et al. (2009). A possible explanation is that green space could be a hiding place for criminal activities (Herzog & Chernick, 2000; Herzog & Flynn-Smith, 2001). This may negatively affect the perceived safety for younger people, who have less time for recreational walking on weekdays and thus mainly walk within their neighborhoods, prefer not to walk in insecure environments. But at weekends they can spend more time on outdoor physical activities and can walk outside their neighborhoods, where residential environments are not relevant.

Table 2
Descriptive statistics of the study population and the physical environmental characteristics of their residential PC6.

Indicators	Overall	Weekdays			Weekends		
	$N = 65,785$	Urban	Rural	Total	Urban	Rural	Total
		$N = 39,780$ (82.3 %)	$N = 8573$ (17.7 %)	$N = 48,353$ (73.5 %)	$N = 14,277$ (82.0 %)	$N = 3155$ (18.0 %)	$N = 17,432$ (26.5 %)
Gender							
Male	31,543 (47.9 %)	19,122 (48.1 %)	4169 (48.6 %)	23,291 (48.2 %)	6725 (47.1 %)	1527 (48.4 %)	8252 (47.3 %)
Female	34,242 (52.1 %)	20,658 (51.9 %)	4404 (51.4 %)	25,062 (51.8 %)	7552 (52.9 %)	1628 (51.6 %)	9180 (52.7 %)
Nationality							
Non-Dutch	10,378 (15.8 %)	6868 (17.3 %)	760 (8.9 %)	7628 (15.8 %)	2475 (17.3 %)	275 (8.7 %)	2750 (15.8 %)
Dutch	55,407 (84.2 %)	32,912 (82.7 %)	7813 (91.1 %)	40,725 (84.2 %)	11,802 (82.7 %)	2880 (91.3 %)	14,682 (84.2 %)
Age							
18–44	25,026 (38.0 %)	15,267 (38.4 %)	3107 (36.2 %)	18,374 (38.0 %)	5511 (38.6 %)	1141 (36.2 %)	6652 (38.2 %)
45–64	25,608 (38.9 %)	15,475 (38.9 %)	3397 (39.6 %)	18,872 (39.0 %)	5490 (38.5 %)	1246 (39.5 %)	6736 (38.6 %)
65+	15,151 (23.0 %)	9038 (22.7 %)	2069 (24.1 %)	11,107 (23.0 %)	3276 (22.9 %)	768 (24.3 %)	4044 (23.2 %)
Education							
Low	16,928 (25.7 %)	9957 (25.0 %)	2594 (30.3 %)	12,551 (26.0 %)	3457 (24.2 %)	920 (29.2 %)	4377 (25.1 %)
Medium	25,375 (38.6 %)	15,012 (37.7 %)	3609 (42.1 %)	18,621 (38.5 %)	5368 (37.6 %)	1386 (43.9 %)	6754 (38.7 %)
High	23,482 (35.7 %)	14,811 (37.2 %)	2370 (27.6 %)	17,181 (35.5 %)	5452 (38.2 %)	849 (26.9 %)	6301 (36.1 %)
Driving licensee							
No	7780 (11.8 %)	5007 (12.6 %)	747 (8.7 %)	5754 (11.9 %)	1763 (12.3 %)	263 (8.3 %)	2026 (11.6 %)
Yes	58,005 (88.2 %)	34,773 (87.4 %)	7826 (91.3 %)	42,599 (88.1 %)	12,514 (87.7 %)	2892 (91.7 %)	15,406 (88.4 %)
Household income							
< 20.000	15,533 (23.6 %)	9406 (23.6 %)	2022 (23.6 %)	11,428 (23.6 %)	3363 (23.6 %)	742 (23.5 %)	4105 (23.5 %)
20.000–40.000	39,139 (59.5 %)	23,382 (58.8 %)	5435 (63.4 %)	28,817 (59.6 %)	8342 (58.4 %)	1980 (62.8 %)	10,322 (59.2 %)
> 40.000	11,113 (16.9 %)	6992 (17.6 %)	1116 (13.0 %)	8108 (16.8 %)	2572 (18.0 %)	433 (13.7 %)	3005 (17.2 %)
Household composition							
Single person	12,725 (19.3 %)	8112 (20.4 %)	1318 (15.4 %)	9430 (19.5 %)	2831 (19.8 %)	464 (14.7 %)	3295 (18.9 %)
Couple without children	23,714 (36.0 %)	14,135 (35.5 %)	3242 (37.8 %)	17,377 (35.9 %)	5107 (35.8 %)	1230 (39.0 %)	6337 (36.4 %)
Couple with children	25,818 (39.2 %)	15,303 (38.5 %)	3651 (42.6 %)	18,954 (39.2 %)	5564 (39.0 %)	1300 (41.2 %)	6864 (39.4 %)
Single parent with children	3528 (5.4 %)	2230 (5.6 %)	362 (4.2 %)	2592 (5.4 %)	775 (5.4 %)	161 (5.1 %)	936 (5.4 %)
Number of cars							
No car	8037 (12.2 %)	5408 (13.6 %)	570 (6.6 %)	5978 (12.4 %)	1871 (13.1 %)	188 (6.0 %)	2059 (11.8 %)
1 car	34,149 (51.9 %)	20,785 (52.2 %)	4290 (50.0 %)	25,075 (51.9 %)	7477 (52.4 %)	1597 (50.6 %)	9074 (52.1 %)
2 or more cars	23,599 (35.9 %)	13,587 (34.2 %)	3713 (43.3 %)	17,300 (35.8 %)	4929 (34.5 %)	1370 (43.4 %)	6299 (36.1 %)
Number of *E*-bikes							
No E-bikes	51,959 (79.0 %)	31,846 (80.1 %)	6396 (74.6 %)	38,242 (79.1 %)	11,411 (79.9 %)	2306 (73.1 %)	13,717 (78.7 %)
1 E-bike	8193 (12.5 %)	4804 (12.1 %)	1242 (14.5 %)	6046 (12.5 %)	1693 (11.9 %)	454 (14.4 %)	2147 (12.3 %)
2 or more E-bikes	5633 (8.6 %)	3130 (7.9 %)	935 (10.9 %)	4065 (8.4 %)	1173 (8.2 %)	395 (12.5 %)	1568 (9.0 %)
Number of mopeds							
No moped	60,334 (91.7 %)	36,574 (91.9 %)	7715 (90.0 %)	44,289 (91.6 %)	13,213 (92.5 %)	2832 (89.8 %)	16,045 (92.0 %)
1 moped	4596 (7.0 %)	2709 (6.8 %)	705 (8.2 %)	3414 (7.1 %)	921 (6.5 %)	261 (8.3 %)	1182 (6.8 %)
2 or more mopeds	855 (1.3 %)	497 (1.2 %)	153 (1.8 %)	650 (1.3 %)	143 (1.0 %)	62 (2.0 %)	205 (1.2 %)
Built and natural characteristics							
NDVI 300 m	0.425 (0.107)	0.413 (0.104)	0.480 (0.104)	0.425 (0.107)	0.413 (0.105)	0.480 (0.104)	0.425 (0.108)
Land use mix 300 m	0.471 (0.188)	0.479 (0.184)	0.443 (0.202)	0.472 (0.188)	0.475 (0.185)	0.442 (0.204)	0.469 (0.189)
Proportion of blue space 300 m	0.0414 (0.0678)	0.0441 (0.0687)	0.0295 (0.0601)	0.0415 (0.0675)	0.0445 (0.0707)	0.0268 (0.0560)	0.0413 (0.0686)
Residential building density 300 m		0.313 (0.274)	0.254 (0.274)	0.303 (0.275)	0.314 (0.275)	0.253 (0.274)	0.303 (0.276)

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Table 2 (*continued*)

Indicators	Overall	Weekdays			Weekends		
	N = 65, 785	Urban	Rural	Total	Urban	Rural	Total
		N = 39,780 (82.3 %)	N = 8573 (17.7 %)	N = 48,353 (73.5 %)	N = 14,277 (82.0 %)	N = 3155 (18.0 %)	N = 17,432 (26.5 %)
	0.303 (0.275)						
Cul-de-sac 300 m (100 crossings/km^2)	0.253 (0.204)	0.259 (0.206)	0.230 (0.195)	0.254 (0.204)	0.255 (0.203)	0.230 (0.194)	0.250 (0.201)
≥4-way crossing density 300 m (100 crossings/km^2)	0.367 (0.316)	0.396 (0.325)	0.236 (0.228)	0.368 (0.316)	0.394 (0.326)	0.233 (0.221)	0.365 (0.316)
NDVI 600 m	0.443 (0.104)	0.430 (0.101)	0.502 (0.0952)	0.443 (0.103)	0.431 (0.102)	0.503 (0.0957)	0.444 (0.105)
Land use mix 600 m	0.594 (0.170)	0.604 (0.161)	0.549 (0.202)	0.595 (0.170)	0.601 (0.160)	0.547 (0.202)	0.591 (0.170)
Proportion of blue space 600 m	0.0503 (0.0703)	0.0529 (0.0708)	0.0375 (0.0642)	0.0502 (0.0699)	0.0538 (0.0729)	0.0355 (0.0618)	0.0505 (0.0714)
Residential building density 600 m	0.272 (0.277)	0.281 (0.275)	0.225 (0.276)	0.271 (0.276)	0.283 (0.278)	0.225 (0.279)	0.273 (0.279)
Cul-de-sac 600 m (100 crossings/km^2)	0.218 (0.136)	0.225 (0.137)	0.189 (0.127)	0.219 (0.136)	0.222 (0.136)	0.189 (0.127)	0.216 (0.135)
≥4-way crossing density 600 m (100 crossings/km^2)	0.330 (0.240)	0.359 (0.244)	0.200 (0.166)	0.330 (0.240)	0.356 (0.247)	0.201 (0.165)	0.328 (0.241)
NDVI 1000 m	0.460 (0.102)	0.447 (0.0995)	0.522 (0.0880)	0.460 (0.102)	0.447 (0.101)	0.523 (0.0882)	0.461 (0.103)
Land use mix 1000 m	0.640 (0.177)	0.656 (0.164)	0.571 (0.216)	0.641 (0.177)	0.654 (0.164)	0.568 (0.215)	0.638 (0.178)
Proportion of blue space 1000 m	0.0585 (0.0745)	0.0607 (0.0738)	0.0464 (0.0735)	0.0582 (0.0739)	0.0625 (0.0764)	0.0459 (0.0733)	0.0595 (0.0761)
Residential building density 1000 m	0.251 (0.288)	0.261 (0.286)	0.204 (0.290)	0.251 (0.288)	0.260 (0.285)	0.205 (0.293)	0.250 (0.287)
Cul-de-sac 1000 m (100 crossings/km^2)	0.186 (0.102)	0.194 (0.102)	0.153 (0.0922)	0.187 (0.102)	0.191 (0.101)	0.152 (0.0934)	0.184 (0.101)
≥4-way crossing density 1000 m (100 crossings/km^2)	0.291 (0.209)	0.319 (0.212)	0.163 (0.131)	0.292 (0.209)	0.318 (0.214)	0.163 (0.131)	0.290 (0.210)
Weather conditions							
Daily precipitation sum (mm)	2.34 (0.259)	2.35 (0.221)	2.28 (0.380)	2.34 (0.258)	2.35 (0.225)	2.28 (0.385)	2.34 (0.263)
Daily average wind speed (m/s)	4.33 (0.913)	4.37 (0.916)	4.14 (0.870)	4.33 (0.912)	4.39 (0.918)	4.15 (0.880)	4.34 (0.916)
Daily average temperature (°C)	10.7 (0.666)	10.7 (0.546)	10.4 (0.987)	10.7 (0.661)	10.7 (0.567)	10.4 (0.995)	10.7 (0.680)

Concerning the built environmental variables, the associations between land-use mix and transportation walking were also modified by age. While a positive association with transportation walking at weekends was found for younger people, a negative association was observed for middle-aged group. A possible explanation is that environments with a higher land-use diversity may attract younger people to walk more, but are less attractive for middle-aged people (who do not have to work at weekends), which results in less transportation walking. Furthermore, we found that street connectivity (≥4 way crossing density) supported transportation walking on weekdays and at weekends, especially for younger people, which is in line with earlier work (Shigematsu et al., 2009). Another key finding is that residential building density was positively associated with recreational walking (at weekends) in the elderly in rural areas, but not for those living in urban areas. This may be because environments with a higher residential density may provide more opportunities for elderly people in rural areas to access recreational facilities, which attract the elderly to engage in more recreational walking (Hajna et al., 2015; Saelens et al., 2012; Saelens & Handy, 2008). But in urban areas more recreational facilities can be easily accessible, irrespective of residential density. This may result in the lack of significance for the elderly in urban areas.

With respect to weather conditions, moderating effects of age on the associations of some meteorological variables with recreational walking were also observed, which is consistent with previous results (Dunn, Shaw, & Trousdale, 2012). The negative associations between less precipitation, lower temperature and longer recreational walking were only significant in younger people. This may imply that increased temperate and more precipitation could make younger people less active, resulting in less walking for recreation. We didn't find any significant associations for older adults, as found elsewhere (Prins & Van Lenthe, 2015).

Another striking result is that the effects of age varied across different buffer sizes (See Appendix A). For the smaller buffers, the interaction effects reached a higher level of statistical significance, which aligns with the work conducted by Etman et al. (2014). This may be partly because different age groups differ in physical activities and stamina (Azmi, Karim, & Amin, 2012), which results in different walking distances and distinct walking environments. Compared to younger adults, elderly people are less functionally fit and less likely to walk far from home. Therefore, the elderly are more restricted by their immediate living environments than by the larger environments (Amagasa et al., 2019). We also observed more significant interaction effects in urban areas than in rural areas. This is consistent with Carlson et al. (2018) and provides another evidence of urban-rural differences in the walking–environment associations.

5.2. Strengths and limitations

A strength of our analysis was the use of a nationally-representative travel survey, rather than data for a single city (Zhang, Melbourne, Sarkar, Chiaradia, & Webster, 2020). The survey data contained detailed information of respondents' travel behaviors and covered the full spectrum of age groups. The large number of participants provided sufficient statistical power to fit stratified models including walking purpose (recreation vs. transportation), day of the week (weekday vs. weekend), urbanicity (urban vs. rural), and age (young, middle-age, and old people). Since our survey data were geocoded at the smallest postal code level available, we were able to use multiple buffers to represent walking environments rather than the more crude administrative levels used previously in Gao et al. (2020). In this way we minimized the risk of misrepresentation of the walking environment. In relation to this, our

Table 3
Regression results of age as effect modifier on walking-physical environment associations using 1000 m buffer stratified by recreational walking and transportation walking in urban and rural areas.

	Weekdays						Weekends					
	Recreational walking on weekdays			Transportation walking on weekdays			Recreational walking at weekends			Transportation walking at weekends		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
Age:45–64 (ref. = 18–44)	−23.685	−249.478	−26.567	3.043	65.441	11.325	−85.121	−59.334	−106.225	28.221	−115.049	6.747
	(67.473)	(173.612)	(60.557)	(37.103)	(99.571)	(33.655)	(113.320)	(246.635)	(99.897)	(61.444)	(187.650)	(56.604)
Age:≥65	−10.401	−222.964	−6.684	−35.118	133.057	−9.157	−23.612	−349.001	−67.007	−12.425	−61.714	−1.042
	(74.405)	(188.119)	(66.212)	(39.808)	(104.204)	(35.603)	(128.049)	(283.053)	(111.963)	(66.079)	(194.544)	(59.162)
NDVI	−75.247**	−10.616	−69.856**	−36.221**	−85.599*	−43.661**	3.401	−40.444	0.455	−71.135**	−75.385	−70.538**
	(27.346)	(68.229)	(25.203)	(13.789)	(35.883)	(12.838)	(47.012)	(94.178)	(41.799)	(22.949)	(66.907)	(21.596)
Land-use mix	−3.672	3.877	−0.893	17.855**	23.862	18.781**	38.910	10.865	37.785*	31.689*	7.497	27.302*
	(12.599)	(26.220)	(11.134)	(6.822)	(14.498)	(6.106)	(22.138)	(36.230)	(18.647)	(12.522)	(26.575)	(11.105)
Proportion of blue space	−26.252	1.279	−21.400	−8.385	−26.543	−11.353	61.360	−63.559	38.889	−9.577	50.240	−1.425
	(23.024)	(53.003)	(21.015)	(11.925)	(27.780)	(10.976)	(36.058)	(73.302)	(32.264)	(19.369)	(47.267)	(17.829)
Residential building density	−5.814	−6.227	−5.818	−2.351	−4.693	−2.316	−6.073	−8.851	−5.987	−1.235	14.734	1.565
	(5.522)	(11.722)	(4.989)	(2.901)	(6.721)	(2.673)	(9.243)	(15.608)	(8.001)	(5.138)	(10.018)	(4.572)
Cul-de-sac	−19.663	15.493	−13.633	7.814	13.194	8.918	−50.690	109.716	−30.271	17.347	61.696	18.761
	(15.592)	(48.992)	(14.568)	(7.729)	(25.110)	(7.254)	(27.094)	(69.321)	(24.349)	(12.938)	(44.921)	(12.132)
≥4 crossing density	−7.989	18.583	−5.218	19.216**	−20.715	17.371**	2.152	−44.131	−1.709	24.952**	6.015	23.422**
	(10.690)	(38.678)	(10.056)	(5.286)	(20.071)	(4.981)	(17.830)	(57.196)	(16.294)	(8.418)	(38.084)	(8.030)
Precipitation	−10.324	−70.351*	−16.086	−2.741	8.158	0.167	−41.240**	3.795	−32.783**	5.491	−8.415	2.486
	(8.166)	(20.568)	(7.081)	(4.243)	(10.648)	(3.685)	(13.623)	(26.840)	(11.476)	(7.122)	(19.761)	(6.278)
Wind speed	−3.216	0.387	−2.291	0.259	2.717	0.576	1.493	−1.083	0.855	−1.364	−4.201	−1.494
	(1.825)	(4.021)	(1.652)	(0.918)	(2.111)	(0.845)	(2.955)	(5.723)	(2.620)	(1.529)	(4.413)	(1.434)
Temperature	−5.262	−26.514**	−6.548*	−1.175	2.521	−0.594	−10.345*	−0.263	−10.376*	2.350	−2.813	1.844
	(3.136)	(7.995)	(2.661)	(1.658)	(4.037)	(1.390)	(5.141)	(10.403)	(4.248)	(2.713)	(7.850)	(2.357)
NDVI*Age 45–64	61.283	−34.272	49.869	−26.138	79.676	−13.710	47.365	73.782	50.071	−18.915	48.650	−12.067
	(37.112)	(88.548)	(33.985)	(20.200)	(50.887)	(18.731)	(63.410)	(129.628)	(56.641)	(32.893)	(96.088)	(30.991)
NDVI*Age ≥ 65	35.417	−87.523	22.041	−20.694	12.237	−20.818	−111.938	130.035	−66.876	20.176	−70.262	3.629
	(40.974)	(94.750)	(37.266)	(21.690)	(51.659)	(19.971)	(71.623)	(141.908)	(63.634)	(35.801)	(93.384)	(33.113)
Land-use mix*Age 45–64	16.688	9.986	14.877	−4.814	18.610	−2.996	−6.616	9.418	−2.201	−40.900*	9.719	−34.194*
	(16.763)	(33.929)	(14.709)	(9.857)	(20.545)	(8.767)	(29.402)	(49.159)	(24.984)	(17.390)	(37.960)	(15.530)
Land-use mix*Age ≥ 65	−2.933	−10.298	−0.584	3.569	−15.231	−0.438	−60.708	40.362	−48.062	−16.575	0.679	−13.037
	(18.754)	(35.774)	(16.226)	(10.716)	(20.621)	(9.391)	(33.319)	(54.668)	(28.044)	(18.598)	(37.876)	(16.338)
Proportion of blue space*Age 45–64	−11.967	14.190	−6.363	−4.789	58.138	5.824	−84.902	109.853	−46.821	−0.194	−34.368	−5.233
	(30.687)	(65.946)	(27.587)	(16.975)	(36.636)	(15.399)	(49.411)	(102.655)	(44.314)	(27.567)	(72.751)	(25.621)
Proportion of blue space*Age ≥ 65	30.102	2.460	29.239	−11.841	45.869	−0.789	−124.773*	113.434	−76.276	1.907	−138.178	−21.795
	(33.661)	(71.449)	(30.143)	(18.778)	(38.440)	(16.836)	(56.292)	(99.224)	(48.428)	(29.662)	(70.653)	(27.008)
Residential building density*Age 45–64	−9.328	15.348	−4.197	−0.315	−0.481	−0.820	10.682	3.092	9.213	1.791	−13.040	−1.004
	(7.271)	(14.528)	(6.485)	(4.164)	(9.066)	(3.805)	(12.097)	(21.262)	(10.560)	(7.088)	(14.908)	(6.397)
Residential building density*Age ≥ 65	4.562	19.768	7.351	6.175	11.652	6.793	9.139	45.040*	16.407	−1.226	−15.619	−3.780
	(7.868)	(16.015)	(7.052)	(4.309)	(9.272)	(3.930)	(13.678)	(22.689)	(11.791)	(7.515)	(15.676)	(6.770)
Cul-de-sac*Age 45–64	3.604	33.011	2.587	−11.440	−12.158	−13.442	8.503	−145.648	−4.286	−0.843	−70.568	−6.017
	(21.047)	(63.896)	(19.642)	(11.245)	(35.931)	(10.562)	(37.041)	(92.895)	(33.472)	(18.588)	(65.306)	(17.553)
Cul-de-sac*Age ≥ 65	−26.857	−10.199	−24.618	14.065	3.108	13.475	56.940	−193.652	20.816	−11.887	−37.485	−13.210
	(23.072)	(69.690)	(21.556)	(11.704)	(36.565)	(10.982)	(40.483)	(104.226)	(36.774)	(19.833)	(65.511)	(18.655)
≥4 crossing density*Age 45–64	−0.231	−93.611	−9.002	3.697	13.416	5.980	−16.261	95.882	−6.373	8.208	18.046	10.325
	(14.459)	(52.485)	(13.578)	(7.669)	(29.012)	(7.224)	(24.678)	(77.231)	(22.660)	(12.305)	(54.633)	(11.775)
≥4 crossing density*Age ≥ 65	7.458	−33.659	−0.072	3.951	52.315	5.778	−20.886	40.099	−13.306	−3.174	−42.904	−8.552
	(16.099)	(55.044)	(15.080)	(8.272)	(28.861)	(7.762)	(28.104)	(83.488)	(25.672)	(13.551)	(53.958)	(12.808)
Precipitation*Age 45–64	−9.082	45.340	−5.224	2.222	−22.368	−2.337	30.878	−5.363	21.877	−4.853	9.220	−1.892
	(10.827)	(26.215)	(9.368)	(6.059)	(15.036)	(5.284)	(18.314)	(37.157)	(15.527)	(10.280)	(27.800)	(9.066)
Precipitation*Age ≥ 65	0.687	39.782	0.157	8.297	−14.409	5.979	34.144	42.537	27.568	−2.283	18.579	5.211
	(11.980)	(28.721)	(10.313)	(6.488)	(15.918)	(5.615)	(20.969)	(42.639)	(17.571)	(11.076)	(29.120)	(9.515)
Wind speed*Age 45–64	2.838	−2.356	1.946	0.469	−0.328	0.512	−2.570	3.299	−1.477	−0.500	−0.185	−0.520

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Table 3 (*continued*)

	Weekdays						Weekends					
	Recreational walking on weekdays			Transportation walking on weekdays			Recreational walking at weekends			Transportation walking at weekends		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
	(2.368)	(5.317)	(2.151)	(1.299)	(3.032)	(1.196)	(3.970)	(7.571)	(3.515)	(2.169)	(6.006)	(2.029)
Wind speed*Age ≥ 65	3.900	7.676	4.342	−1.958	−5.094	−2.304	0.920	−2.783	0.120	−1.406	7.303	−0.484
	(2.594)	(5.637)	(2.343)	(1.385)	(3.189)	(1.272)	(4.457)	(8.919)	(3.966)	(2.328)	(6.162)	(2.158)
Temperature*Age 45–64	1.846	19.538	2.389	0.390	−6.525	−0.053	3.646	2.976	6.267	1.705	6.993	2.428
	(4.141)	(10.218)	(3.517)	(2.314)	(5.757)	(1.973)	(6.800)	(14.340)	(5.695)	(3.955)	(11.048)	(3.442)
Temperature*Age ≥ 65	1.181	18.211	1.287	3.660	−7.538	2.072	5.418	19.591	8.508	3.292	4.938	1.002
	(4.543)	(11.057)	(3.816)	(2.506)	(6.052)	(2.085)	(7.748)	(16.772)	(6.483)	(4.314)	(11.381)	(3.544)
logsigma	4.637**	4.590**	4.630**	4.038**	3.893**	4.024**	4.760**	4.593**	4.734**	3.932**	3.886**	3.930**
	(0.012)	(0.026)	(0.011)	(0.011)	(0.032)	(0.011)	(0.017)	(0.037)	(0.016)	(0.023)	(0.063)	(0.021)
Constant	−11.974	287.994*	5.968	−38.061	−83.005	−49.764*	33.997	−113.799	21.981	−83.834*	21.075	−68.989
	(50.494)	(135.262)	(45.591)	(25.816)	(70.564)	(23.436)	(84.444)	(180.343)	(74.193)	(42.688)	(134.740)	(39.410)
Log Likelihood	−37,540.990	−8370.139	−45,936.820	−36,103.620	−5021.865	−41,157.920	−17,920.610	−4093.125	−22,045.040	−9915.099	−1390.138	−11,321.520
Akaike Inf. Crit.	75,175.970	16,834.280	91,967.640	72,301.250	10,137.730	82,409.830	35,935.230	8280.251	44,184.080	19,924.200	2874.276	22,737.040

$^*p<0.05$; $^{**}p<0.01$.

All models were adjusted for gender, nationality, education, driving license, household income, household composition, number of cars, number of e-bikes, and number of mopeds.

buffer approach supported sensitivity analyses across multiple scales representing the immediate and more distant environments.

Despite these promising results, a few limitations must be acknowledged. First, the walking data were cross-sectional, which prevented us from establishing causality. Residential self-selection also remains possible (Guan, Wang, & Jason Cao, 2020)–a problem faced by many other studies (Gao et al., 2018; Nello-Deakin & Harms, 2019). Second, as found in previous studies (Gao et al., 2020; McCormack et al., 2019), self-reported walking may not represent the actual walking duration accurately, while short daily walking trips may be affected by underreporting (Gao et al., 2020; Rietveld, 2000). How both limitations affected the reported associations remains unclear. Third, for pragmatic reasons, we included only an urban and a rural strata, while continuous transitions from urban to rural areas are likely. This simplification may have resulted in some misclassification, particularly in suburban areas, and we cannot exclude any influence on our findings regarding urban and rural walking behaviors. Fourth, we lacked detailed movement data based on Global Positioning System as used in a few studies (Carlson et al., 2015; Chaix et al., 2016; Hahm, Yoon, & Choi, 2019; Helbich, 2017). It was therefore impossible to assess how the physical environment beyond the residential neighborhood (e.g., at the work-place) may play a role for people's walking. Finally, secondary data, such as ours, are intrinsically constrained by the available variables. A few variables such as travel attitudes, subjective measures, and social environmental characteristics were lacking in the NTS. Some environmental datasets (e.g., the land cover data) were also not annually available, and thus we cannot exclude that our associations were biased.

6. Conclusions and policy implications

Based on the data from a large Dutch sample, in this paper we examined to what extent age was an effect modifier of the associations between the neighborhood physical environment and transportation and recreational walking, considering day of the week (weekdays/weekends) and urbanization levels (urban/rural). The analysis results showed that the moderating effects of age on the walking-environment relationships (such as green space) differed between weekday and weekends. We also found that certain natural and built environment characteristics (like residential density and blue space) correlated with walking differently across urban and rural areas.

Our findings provide urban planners not only in the Netherlands but also worldwide with a deeper understating of walking-environment interactions and suggest that urban planners should take into account urban-rural differences while developing new interventions to promote walking. For example, implementing community strategies where people can easily access recreational facilities to promote walking is more effective in rural areas than in urban areas. To promote increased recreational walking among older adults in urban areas, future policies are advised to address blue space barriers.

The findings also highlight the importance of tailoring interventions for the targeted age groups. For instance, enhancing communities with diverse land use and well-connected streets would encourage transportation walking among younger people, but may discourage or have no effect on transportation walking among the middle aged and elderly. It should be noted that urban planners should also consider weekday-weekend differences and the interventions could have different impact on walking between weekdays and weekends. For example, urban planners may consider intervening in green space (which has potential to hinder people from doing physical activities) to encourage increased participation in recreational walking among younger adults. This intervention may not be effective for weekends, as the younger group could participate in walking outside their neighborhoods during weekends. More in-depth investigation of walking behaviors on weekdays and at weekends is needed.

CRediT authorship contribution statement

Zhiyong Wang: Methodology, Formal analysis, Data curation, Writing – original draft, Visualization. **Marco Helbich:** Conceptualization, Data curation, Writing – review & editing. **Dick Ettema:** Conceptualization, Writing – review & editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A

Table A.1
Regression results of age as effect modifier on walking-physical environment associations using 300 m buffer stratified by recreational walking and transportation walking in urban and rural areas.

	Weekdays						Weekends					
	Recreational walking on weekdays			Transportation walking on weekdays			Recreational walking at weekends			Transportation walking at weekends		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
Age:45–64 (ref. = 18–44)	26.539	−212.167	24,402	6.992	116.937	18.209	−109.269	4.671	−116.654	19.186	−42.796	9.969
	(60.967)	(164.315)	−54,329	(33.706)	(93.944)	(30.331)	(101.943)	(232.708)	(89.383)	(55.338)	(176.689)	(50.504)
Age:≥65	10.061	−225.245	16,828	−25.230	95.513	−16.939	−94.988	−283.995	−124.312	28.168	−8.336	47.602
	(66.642)	(179.081)	−59,047	(35.784)	(98.780)	(31.845)	(115.598)	(268.475)	(100.453)	(59.967)	(184.480)	(53.143)
NDVI	−55.469**	−21.357	−54.952**	−70.530**	−98.368**	−76.474**	−72.460*	−42.337	−66.156*	−71.863**	−53.931	−70.435**
	(18.223)	(40.614)	−16,351	(9.529)	(21.951)	(8.663)	(30.382)	(58.345)	(26.703)	(15.629)	(40.932)	(14.469)
Land-use mix	−2.328	20.602	1410	10.086*	8.514	10.012*	26.412	31.523	27.600*	16.409*	10.611	15.472*
	(8.330)	(17.732)	−7506	(4.291)	(9.433)	(3.927)	(14.072)	(24.726)	(12.284)	(7.162)	(17.053)	(6.607)
Proportion of blue space	−33.399	−21.737	−30,901	−44.000**	−7.692	−39.967**	0.620	−147.809	−16.566	−7.160	120.074*	3.517
	(24.162)	(68.242)	−22,643	(12.929)	(31.274)	(11.982)	(39.217)	(118.882)	(36.757)	(19.535)	(57.011)	(18.358)
Residential building density	−2.103	−2.281	−1960	5.178	−0.418	4.461	−1.729	−7.483	−2.803	6.176	18.502	8.052
	(5.769)	(12.242)	−5218	(2.957)	(6.934)	(2.728)	(9.662)	(17.284)	(8.467)	(4.905)	(10.850)	(4.488)
Cul-de-sac	−1.637	16.263	1010	1.479	10.720	2.640	−16.785	24.963	−8.179	3.629	26.909	6.475
	(7.205)	(16.989)	−6568	(3.698)	(8.810)	(3.397)	(12.475)	(23.830)	(10.961)	(6.122)	(16.187)	(5.680)
≥4 crossing density	−3.285	−7.369	−3526	6.314**	−13.808	5.504*	−14.539	2.379	−12.972	9.707**	23.618	10.809**
	(5.052)	(16.037)	−4773	(2.418)	(8.526)	(2.297)	(8.320)	(22.552)	(7.674)	(3.740)	(14.236)	(3.595)
Precipitation	−9.217	−68.011*	−14.202*	−0.335	7.793	2.331	−39.995**	3.629	−32.770**	12.018	−9.182	8.828
	(7.981)	(20.372)	−6898	(4.142)	(10.605)	(3.593)	(13.319)	(26.575)	(11.219)	(6.880)	(19.431)	(6.069)
Wind speed	−2.940	0.357	−2080	0.220	2.228	0.483	1.379	−0.323	0.668	−1.265	−5.274	−1.393
	(1.806)	(3.993)	−1638	(0.911)	(2.105)	(0.839)	(2.929)	(5.695)	(2.603)	(1.515)	(4.430)	(1.422)
Temperature	−4.745	−25.515**	−5.865*	−0.860	2.159	−0.058	−10.802*	0.475	−10.916**	4.281	−2.292	4.270
	(3.097)	(7.923)	−2604	(1.625)	(4.017)	(1.355)	(5.043)	(10.229)	(4.142)	(2.638)	(7.743)	(2.277)
NDVI*Age 45–64	18.049	−34.050	13,438	−32.962*	15.503	−26.247*	117.659**	27.981	93.716**	−40.735	−55.930	−42.049*
	(24.269)	(52.295)	−21,718	(13.755)	(30.546)	(12.488)	(40.694)	(79.079)	(35.886)	(22.329)	(58.209)	(20.673)
NDVI*Age ≥ 65	11.766	−56.531	4037	−42.773**	23.439	−33.877*	−5.704	93.713	21.276	−20.467	−83.608	−31.173
	(26.587)	(56.914)	−23,795	(14.542)	(31.455)	(13.156)	(46.115)	(83.589)	(40.078)	(24.073)	(57.608)	(21.964)
Land-use mix*Age 45–64	7.480	−13.827	5179	−1.946	10.238	−0.100	11.515	−30.735	2.490	7.642	−2.185	6.644
	(11.107)	(22.625)	−9930	(6.249)	(13.266)	(5.686)	(19.101)	(32.935)	(16.634)	(10.385)	(24.202)	(9.559)
Land-use mix*Age ≥ 65	−2.359	−14.304	−2436	9.571	13.445	9.632	−45.096*	−2.536	−35.305	−5.785	−2.609	−5.770
	(12.274)	(24.352)	−10,913	(6.687)	(13.702)	(6.051)	(21.390)	(36.042)	(18.487)	(11.087)	(24.485)	(10.088)
Proportion of blue space*Age 45–64	−8.232	32.129	−0.156	5.140	−2.485	5.953	−98.039	−0.710	−87.273	−36.032	−189.663	−46.318
	(31.832)	(79.400)	−29,170	(17.999)	(41.473)	(16.578)	(55.321)	(153.821)	(51.379)	(28.497)	(101.773)	(27.099)
Proportion of blue space*Age ≥ 65	9.717	−24.869	3123	−10.186	−14.007	−10.026	−25.167	188.903	1.801	−28.500	−197.118*	−44.698
	(34.098)	(84.250)	−31,273	(19.907)	(43.703)	(18.186)	(54.793)	(136.079)	(49.531)	(29.305)	(83.167)	(27.431)
Residential building density*Age 45–64	−13.437	9.959	−8859	−2.482	2.892	−1.741	7.231	−4.766	5.844	−0.996	−17.770	−3.172
	(7.706)	(15.536)	−6898	(4.285)	(9.481)	(3.927)	(12.811)	(23.758)	(11.303)	(7.016)	(16.807)	(6.478)
Residential building density*Age ≥ 65	8.865	11.201	8962	2.737	12.890	4.332	11.908	40.604	17.631	−0.882	−7.591	−1.991
	(8.319)	(17.231)	−7494	(4.496)	(9.761)	(4.109)	(14.360)	(25.392)	(12.558)	(7.508)	(16.960)	(6.880)
Cul-de-sac*Age 45–64	−11.817	−4.459	−9186	−0.839	−5.680	−1.447	16.384	17.607	17.504	−5.103	−8.976	−5.660
	(9.720)	(21.713)	−8790	(5.349)	(12.456)	(4.908)	(16.773)	(31.381)	(14.713)	(8.964)	(21.719)	(8.233)
Cul-de-sac*Age ≥ 65	−16.973	−37.375	−18.939	5.831	1.536	5.392	28.377	−33.461	13.815	5.854	2.970	5.439
	(10.659)	(24.793)	−9717	(5.656)	(13.137)	(5.192)	(19.122)	(37.303)	(16.945)	(9.541)	(23.848)	(8.809)
≥4 crossing density*Age 45–64	−8.525	−16.646	−9997	2.625	18.954	3.428	18.547	15.235	19.303	−0.928	−23.775	−1.887
	(7.030)	(21.398)	−6617	(3.600)	(11.722)	(3.405)	(11.889)	(32.013)	(10.971)	(5.771)	(21.957)	(5.551)
≥4 crossing density*Age ≥ 65	0.902	8.886	0.395	0.401	26.960*	2.198	6.848	−10.660	5.351	0.876	−33.399	−1.996
	(7.764)	(23.087)	−7289	(3.881)	(12.047)	(3.656)	(13.606)	(34.973)	(12.497)	(6.281)	(22.022)	(5.988)
	−10.271	40.009	−8057	1.217	−25.403	−3.234	24.928	−7.316	17.997	−6.576	9.622	−3.383

(*continued on next page*)

Table A.1 (*continued*)

	Weekdays						Weekends					
	Recreational walking on weekdays			Transportation walking on weekdays			Recreational walking at weekends			Transportation walking at weekends		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
Precipitation*Age 45–64	(10.572)	(25.995)	−9133	(5.922)	(15.024)	(5.164)	(17.893)	(36.808)	(15.155)	(9.982)	(27.680)	(8.802)
Precipitation*Age ≥ 65	−0.380	37.326	−1606	8.579	−11.910	7.502	29.911	39.675	24.889	−8.715	13.425	−1.541
	(11.712)	(28.611)	−10,061	(6.344)	(15.923)	(5.496)	(20.558)	(42.170)	(17.243)	(10.807)	(29.024)	(9.307)
Wind speed*Age 45–64	2.316	−2.004	1483	0.435	0.264	0.503	−2.829	2.558	−1.562	−0.347	0.673	−0.506
	(2.350)	(5.252)	−2136	(1.292)	(3.009)	(1.190)	(3.941)	(7.508)	(3.493)	(2.162)	(5.968)	(2.022)
Wind speed*Age ≥ 65	4.173	8.030	4.574*	−2.045	−4.472	−2.243	1.411	−4.019	0.395	−1.146	7.587	−0.358
	(2.571)	(5.586)	−2326	(1.379)	(3.150)	(1.267)	(4.432)	(8.788)	(3.946)	(2.323)	(6.125)	(2.156)
Temperature*Age 45–64	0.954	17.484	1167	0.098	−7.316	−0.330	2.451	1.044	5.179	1.206	5.716	1.665
	(4.080)	(10.114)	−3437	(2.271)	(5.721)	(1.924)	(6.683)	(14.121)	(5.556)	(3.862)	(10.939)	(3.336)
Temperature*Age ≥ 65	0.431	17.228	0.300	3.592	−6.173	2.727	5.437	17.727	8.304	1.107	0.451	−1.968
	(4.460)	(11.017)	−3719	(2.445)	(6.038)	(2.028)	(7.643)	(16.516)	(6.342)	(4.238)	(11.261)	(3.452)
logsigma	4.637**	4.590**	4.630**	4.037**	3.894**	4.024**	4.759**	4.590**	4.733**	3.935**	3.875**	3.932**
	(0.012)	(0.026)	(0.011)	(0.011)	(0.032)	(0.011)	(0.017)	(0.037)	(0.016)	(0.023)	(0.063)	(0.021)
Constant	−39.321	271.719*	−21,012	−23.817	−68.299	−37.995	83.087	−130.947	69.315	−102.213**	1.525	−97.336**
	(45.966)	(128.090)	−41,104	(23.581)	(65.902)	(21.188)	(75.611)	(169.807)	(66.362)	(38.014)	(126.753)	(34.891)
Log Likelihood	−37,538.450	−8362.446	−45,924.480	−36,038.340	−5011.681	−41,084.190	−17,914.020	−4090.565	−22,036.440	−9919.352	−1376.171	−11,313.850
Akaike Inf. Crit.	75,170.900	16,818.890	91,942.960	72,170.680	10,117.360	82,262.390	35,922.030	8275.131	44,166.880	19,932.710	2846.343	22,721.700

*$p<0.05$; **$p<0.01$.

All models were adjusted for gender, nationality, education, driving license, household income, household composition, number of cars, number of e-bikes, and number of mopeds.

Table A.2

Regression results of age as effect modifier on walking-physical environment associations using 600 m buffer stratified by recreational walking and transportation walking in urban and rural areas.

	Weekdays						Weekends					
	Recreational walking on weekdays			Transportation walking on weekdays			Recreational walking at weekends			Transportation walking at weekends		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
Age:45–64 (ref. = 18–44)	9.972	−243.103	4.445	3.282	82.231	11.601	−120.210	−23.473	−127.614	19.096	−29.151	9.744
	(63.473)	(168.041)	(56.904)	(34.854)	(96.222)	(31.582)	(106.437)	(238.590)	(93.812)	(57.527)	(180.121)	(52.811)
Age:≥65	−10.575	−210.283	1.680	−27.956	111.519	−11.571	−68.162	−313.086	−105.460	−3.068	−36.044	13.003
	(69.842)	(182.503)	(62.088)	(37.283)	(101.065)	(33.340)	(120.196)	(273.963)	(104.990)	(62.135)	(186.660)	(55.340)
NDVI	−56.330*	−35.218	−56.955**	−62.845**	−94.559**	−68.755**	−45.781	−33.675	−40.790	−73.649**	−58.804	−71.721**
	(22.165)	(54.152)	(20.296)	(11.271)	(28.644)	(10.413)	(37.952)	(76.694)	(33.720)	(18.670)	(52.380)	(17.413)
Land-use mix	−5.530	6.712	−2.973	11.681*	14.036	12.298*	46.176*	29.292	43.413**	22.439*	20.790	22.129*
	(10.658)	(21.886)	(9.495)	(5.610)	(12.137)	(5.097)	(18.618)	(29.979)	(15.851)	(9.740)	(21.815)	(8.864)
Proportion of blue space	−31.140	−22.999	−28.893	−33.248**	−36.821	−33.969**	15.198	−159.061	−8.190	−6.615	65.056	−0.075
	(23.349)	(60.023)	(21.663)	(12.304)	(30.887)	(11.456)	(37.695)	(96.051)	(34.811)	(19.318)	(56.541)	(18.223)
Residential building density	−3.433	−11.874	−4.548	1.169	−1.863	0.829	−5.680	−6.318	−5.275	1.517	10.960	3.027
	(5.702)	(12.466)	(5.181)	(2.969)	(6.954)	(2.742)	(9.528)	(16.203)	(8.273)	(5.055)	(10.916)	(4.600)
Cul-de-sac	−4.019	1.742	−2.254	4.934	10.389	6.166	−27.167	59.578	−13.249	10.627	37.579	13.213
	(11.017)	(29.601)	(10.132)	(5.596)	(15.047)	(5.166)	(19.166)	(40.874)	(16.929)	(9.318)	(27.315)	(8.651)
≥4 crossing density	−1.575	5.005	−0.865	13.754**	−5.587	13.060**	−9.443	−21.382	−10.321	22.677**	20.598	22.581**
	(7.938)	(25.752)	(7.476)	(3.850)	(12.979)	(3.638)	(13.125)	(38.486)	(12.081)	(6.019)	(25.057)	(5.781)
Precipitation	−9.334	−69.291**	−14.737*	−1.851	7.234	0.709	−41.536**	5.682	−33.169**	6.654	−8.982	3.794
	(8.066)	(20.491)	(6.985)	(4.184)	(10.668)	(3.635)	(13.481)	(26.672)	(11.353)	(7.028)	(19.553)	(6.185)
Wind speed	−3.053	0.535	−2.195	0.165	2.706	0.471	1.443	−0.336	0.818	−1.368	−4.808	−1.522
	(1.810)	(4.004)	(1.641)	(0.911)	(2.102)	(0.838)	(2.934)	(5.721)	(2.606)	(1.516)	(4.409)	(1.423)
Temperature	−4.838	−25.793**	−6.137*	−1.313	2.026	−0.657	−10.813*	0.717	−10.613*	3.052	−2.478	2.673
	(3.120)	(7.953)	(2.636)	(1.638)	(4.038)	(1.371)	(5.083)	(10.291)	(4.194)	(2.689)	(7.771)	(2.322)
NDVI*Age 45–64	31.663	−35.293	25.174	−29.918	53.403	−19.881	107.602*	38.352	90.962*	−33.280	−45.845	−33.467
	(29.994)	(70.929)	(27.372)	(16.394)	(40.836)	(15.132)	(51.261)	(105.645)	(45.774)	(26.501)	(75.241)	(24.766)
NDVI*Age ≥ 65	22.698	−86.764	7.942	−34.576*	12.830	−29.787	−44.973	150.163	−5.434	10.055	−69.212	−2.227
	(33.170)	(76.412)	(30.144)	(17.621)	(41.829)	(16.182)	(57.917)	(114.786)	(51.321)	(28.975)	(74.442)	(26.672)
Land-use mix*Age 45–64	14.664	2.167	14.002	−3.323	20.705	−0.310	8.934	−8.039	7.041	−17.276	−31.352	−20.046
	(14.140)	(28.252)	(12.522)	(8.121)	(17.306)	(7.343)	(24.947)	(40.943)	(21.380)	(13.941)	(30.937)	(12.684)
Land-use mix*Age ≥ 65	13.651	−24.324	7.781	7.514	−3.547	4.253	−76.009**	42.612	−50.902*	−6.842	−14.654	−7.443
	(15.877)	(30.083)	(13.893)	(8.847)	(17.572)	(7.920)	(28.058)	(44.926)	(23.811)	(15.044)	(31.740)	(13.499)
Proportion of blue space*Age 45–64	−11.896	15.104	−6.806	3.063	38.185	8.854	−60.758	121.505	−33.975	−20.038	−71.950	−23.614
	(31.100)	(73.496)	(28.412)	(17.369)	(40.906)	(16.007)	(51.800)	(128.711)	(47.657)	(27.716)	(86.009)	(26.216)
Proportion of blue space*Age ≥ 65	21.983	17.382	25.991	−13.977	34.065	−5.942	−69.220	231.227*	−22.461	−10.580	−160.438	−28.447
	(33.888)	(76.134)	(30.560)	(19.426)	(41.355)	(17.594)	(55.970)	(117.880)	(49.551)	(29.454)	(84.860)	(27.526)
Residential building density*Age 45–64	−10.811	18.306	−5.519	−0.787	−0.814	−0.909	14.379	0.526	11.781	1.818	−17.875	−0.953
	(7.561)	(15.509)	(6.782)	(4.271)	(9.496)	(3.917)	(12.449)	(22.337)	(10.918)	(7.065)	(16.892)	(6.503)

(*continued on next page*)

Table A.2 (*continued*)

	Weekdays						Weekends					
	Recreational walking on weekdays			Transportation walking on weekdays			Recreational walking at weekends			Transportation walking at weekends		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
Residential building density*Age ≥ 65	5.532	25.063	8.541	5.078	11.729	6.154	15.961	42.179	20.728	0.553	−6.040	−0.735
	(8.194)	(17.036)	(7.377)	(4.473)	(9.714)	(4.088)	(14.068)	(24.192)	(12.230)	(7.570)	(16.815)	(6.910)
Cul-de-sac*Age 45–64	−7.796	30.830	−3.724	−3.135	2.348	−3.578	12.882	−37.893	8.854	−3.694	−14.474	−6.319
	(14.810)	(38.151)	(13.574)	(8.052)	(21.450)	(7.445)	(25.842)	(54.597)	(22.928)	(13.389)	(38.237)	(12.444)
Cul-de-sac*Age ≥ 65	−26.304	−27.390	−24.832	14.015	11.688	12.987	37.807	−94.923	13.196	2.534	5.396	1.655
	(16.266)	(42.536)	(14.967)	(8.434)	(22.070)	(7.792)	(28.815)	(63.519)	(25.782)	(14.310)	(40.668)	(13.290)
≥4 crossing density*Age 45–64	−4.372	−60.705	−10.405	0.678	10.415	1.688	−0.412	43.577	4.982	−3.165	−17.556	−2.993
	(10.819)	(34.772)	(10.171)	(5.665)	(18.796)	(5.348)	(18.445)	(52.153)	(16.993)	(8.958)	(35.744)	(8.604)
≥4 crossing density*Age ≥ 65	−6.842	−6.591	−9.179	2.489	21.644	3.434	−0.414	10.914	0.912	−0.259	−40.150	−3.977
	(12.047)	(37.081)	(11.294)	(6.094)	(19.319)	(5.735)	(21.035)	(58.172)	(19.335)	(9.824)	(37.241)	(9.352)
Precipitation*Age 45–64	−10.480	44.443	−7.382	2.017	−23.518	−2.311	28.736	−6.642	20.364	−3.624	8.120	−1.031
	(10.695)	(26.126)	(9.249)	(5.981)	(15.067)	(5.218)	(18.095)	(37.011)	(15.340)	(10.137)	(27.713)	(8.935)
Precipitation*Age ≥ 65	0.933	38.807	−0.354	7.757	−11.991	6.337	34.923	35.495	27.584	−4.665	16.491	2.628
	(11.848)	(28.638)	(10.182)	(6.413)	(15.938)	(5.553)	(20.747)	(42.495)	(17.395)	(10.967)	(28.936)	(9.409)
Wind speed*Age 45–64	2.462	−2.360	1.669	0.470	−0.133	0.532	−2.461	2.650	−1.454	−0.184	0.056	−0.326
	(2.353)	(5.282)	(2.138)	(1.289)	(3.021)	(1.188)	(3.945)	(7.540)	(3.496)	(2.154)	(5.962)	(2.015)
Wind speed*Age ≥ 65	4.146	7.817	4.514	−1.988	−5.046	−2.239	1.139	−4.482	0.235	−1.359	7.386	−0.522
	(2.575)	(5.612)	(2.329)	(1.376)	(3.164)	(1.265)	(4.429)	(8.878)	(3.947)	(2.318)	(6.134)	(2.151)
Temperature*Age 45–64	1.055	19.064	1.520	0.354	−6.715	−0.063	3.248	2.220	5.732	1.597	5.798	2.230
	(4.114)	(10.163)	(3.483)	(2.287)	(5.753)	(1.948)	(6.733)	(14.233)	(5.624)	(3.914)	(10.972)	(3.389)
Temperature*Age ≥ 65	1.176	17.407	1.038	3.464	−6.331	2.321	6.133	16.597	8.647	2.311	2.709	−0.355
	(4.505)	(11.016)	(3.772)	(2.472)	(6.051)	(2.056)	(7.683)	(16.699)	(6.408)	(4.299)	(11.272)	(3.502)
logsigma	4.637**	4.589**	4.630**	4.036**	3.894**	4.023**	4.759**	4.591**	4.734**	3.932**	3.881**	3.930**
	(0.012)	(0.026)	(0.011)	(0.011)	(0.032)	(0.011)	(0.017)	(0.037)	(0.016)	(0.023)	(0.063)	(0.021)
Constant	−33.504	293.296*	−11.211	−21.491	−71.374	−34.259	61.116	−140.763	44.031	−85.838*	3.588	−76.696*
	(47.726)	(130.780)	(42.941)	(24.353)	(67.823)	(22.030)	(78.947)	(173.494)	(69.522)	(39.681)	(128.279)	(36.565)
Log Likelihood	−37,544.640	−8367.461	−45,936.810	−36,048.860	−5015.130	−41,094.160	−17,913.840	−4090.515	−22,037.420	−9909.345	−1384.938	−11,309.690
Akaike Inf. Crit.	75,183.280	16,828.920	91,967.620	72,191.710	10,124.260	82,282.310	35,921.680	8275.029	44,168.840	19,912.690	2863.876	22,713.380

*$p<0.05$; **$p<0.01$.
All models were adjusted for gender, nationality, education, driving license, household income, household composition, number of cars, number of e-bikes, and number of mopeds.

References

Alvdv, A., Ac, B., & Js, C. (2022). The influence of travel attitudes on perceived walking accessibility and walking behaviour. *Travel Behaviour and Society, 27*, 47–56.

Amagasa, S., Inoue, S., Fukushima, N., Kikuchi, H., Nakaya, T., Hanibuchi, T., Sallis, J. F., & Owen, N. (2019). Associations of neighborhood walkability with intensity-and bout-specific physical activity and sedentary behavior of older adults in Japan. *Geriatrics & Gerontology International, 19*(9), 861–867.

An, H.-Y., Chen, W., Wang, C.-W., Yang, H.-F., Huang, W.-T., & Fan, S.-Y. (2020). The relationships between physical activity and life satisfaction and happiness among young, middle-aged, and older adults. *International Journal of Environmental Research and Public Health, 17*(13), 4817.

Azmi, D. I., Karim, H. A., & Amin, M. Z. M. (2012). Comparing the walking behaviour between urban and rural residents. *Procedia-Social and Behavioral Sciences, 68*, 406–416.

Barnett, D. W., Barnett, A., Nathan, A., Van Cauwenberg, J., & Cerin, E. (2017). Built environmental correlates of older adults'total physical activity and walking: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 103.

Barton, H., & Tsourou, C. (2013). *Healthy urban planning*. Routledge.

Besser, L. M., & Mitsova, D. P. (2021). Neighborhood green land cover and neighborhood-based walking in us older adults. *American Journal of Preventive Medicine, 61*(1), e13–e20.

Böcker, L., Dijst, M., & Prillwitz, J. (2013). Impact of everyday weather on individual daily travel behaviours in perspective: A literature review. *Transport Reviews, 33*(1), 71–91.

Böcker, L., van Amen, P., & Helbich, M. (2017). Elderly travel frequencies and transport mode choices in Greater Rotterdam, the Netherlands. *Transportation, 44*(4), 831–852.

Brooke, H. L., Corder, K., Atkin, A. J., & van Sluijs, E. M. (2014). A systematic literature review with meta-analyses of within-and between-day differences in objectively measured physical activity in school-aged children. *Sports Medicine, 44*(10), 1427–1438.

Bürgi, R., & De Bruin, E. D. (2016). Differences in spatial physical activity patterns between weekdays and weekends in primary school children: A cross-sectional study using accelerometry and global positioning system. *Sports, 4*(3), 36.

Carlson, J. A., Saelens, B. E., Kerr, J., Schipperijn, J., Conway, T. L., Frank, L. D., Chapman, J. E., Glanz, K., Cain, K. L., & Sallis, J. F. (2015). Association between neighborhood walkability and gps-measured walking, bicycling and vehicle time in adolescents. *Health & Place, 32*, 1–7.

Carlson, S. A., Whitfield, G. P., Peterson, E. L., Ussery, E. N., Watson, K. B., Berrigan, D., & Fulton, J. E. (2018). Geographic and urban–rural differences in walking for leisure and transportation. *American Journal of Preventive Medicine, 55*(6), 887–895.

CBS. (2015). *Onderzoek verplaatsingen in nederland 2015*. Den Haag, The Netherlands: CBS—Statistics Netherlands.

CBS. (2019). Bestand bodemgebruik. https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/natuur-en-milieu/bestand-bodemgebruik [Online; accessed 12-05-2020].

Cerin, E., Mitáš, J., Cain, K. L., Conway, T. L., Adams, M. A., Schofield, G., Sarmiento, O. L., Reis, R. S., Schipperijn, J., Davey, R., et al. (2017). Do associations between objectively-assessed physical activity and neighbourhood environment attributes vary by time of the day and day of the week? Ipen adult study. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 1–16.

Chaix, B., Kestens, Y., Duncan, D. T., Brondeel, R., Méline, J., El Aarbaoui, T., Pannier, B., & Merlo, J. (2016). A GPS-based methodology to analyze environment-health associations at the trip level: Case-crossover analyses of built environments and walking. *American Journal of Epidemiology, 184*(8), 579–589.

Cole, R., Koohsari, M. J., Carver, A., Owen, N., & Sugiyama, T. (2019). Are neighborhood environmental attributes more important for older than for younger adults' walking? Testing effect modification by age. *Journal of Aging and Physical Activity, 27*(3), 354–359.

OECD. (2019). *The heavy burden of obesity*.

OECD, o. H. S., & E. O. (2019). *Netherlands: Country Health Profile 2019*.

Collins, P., Al-Nakeeb, Y., Nevill, A., & Lyons, M. (2012). The impact of the built environment on young people's physical activity patterns: A suburban-rural comparison using gps. *International Journal of Environmental Research and Public Health, 9*(9), 3030–3050.

Dijkstra, L., Poelman, H., & Veneri, P. (2019). *The eu-oecd definition of a functional urban area*.

Dunn, R. A., Shaw, W. D., & Trousdale, M. A. (2012). The effect of weather on walking behavior in older adults. *Journal of Aging and Physical Activity, 20*(1), 80–92.

Etman, A., Kamphuis, C. B., Prins, R. G., Burdorf, A., Pierik, F. H., & van Lenthe, F. J. (2014). Characteristics of residential areas and transportational walking among frail and non-frail dutch elderly: Does the size of the area matter? *International Journal of Health Geographics, 13*(1), 1–7.

Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. *Journal of the American Planning Association, 76*(3), 265–294.

Ferrer, S., Ruiz, T., & Mars, L. (2015). A qualitative study on the role of the built environment for short walking trips. *Transportation Research Part F: Traffic Psychology and Behaviour, 33*, 141–160.

Fishman, E., Böcker, L., & Helbich, M. (2015). Adult active transport in the Netherlands: An analysis of its contribution to physical activity requirements. *PloS one, 10*(4).

Forsyth, A., Oakes, J. M., Lee, B., & Schmitz, K. H. (2009). The built environment, walking, and physical activity: Is the environment more important to some people than others? *Transportation Research Part D: Transport and Environment, 14*(1), 42–49.

Gao, J., Kamphuis, C. B., Dijst, M., & Helbich, M. (2018). The role of the natural and built environment in cycling duration in the Netherlands. *International Journal of Behavioral Nutrition and Physical Activity, 15*(1), 82.

Gao, J., Kamphuis, C., Ettema, D., & Helbich, M. (2019). Longitudinal changes in transport-related and recreational walking: The role of life events. *Transportation Research Part D Transport and Environment, 77*, 243–251.

Gao, J., Kamphuis, C. B., Helbich, M., & Ettema, D. (2020). What is 'neighborhood walkability'? How the built environment differently correlates with walking for different purposes and with walking on weekdays and weekends. *Journal of Transport Geography, 88*, Article 102860.

Ghani, F., Rachele, J. N., Washington, S., & Turrell, G. (2016). Gender and age differences in walking for transport and recreation: Are the relationships the same in all neighborhoods? *Preventive Medicine Reports, 4*, 75–80.

Ghani, F., Rachele, J. N., Loh, V. H., Washington, S., & Turrell, G. (2018). Do differences in built environments explain age differences in transport walking across neighbourhoods? *Journal of Transport & Health, 9*, 83–95.

Guan, X., Wang, D., & Jason Cao, X. (2020). The role of residential self-selection in land use-travel research: A review of recent findings. *Transport Reviews, 40*(3), 267–287.

Hahm, Y., Yoon, H., & Choi, Y. (2019). The effect of built environments on the walking and shopping behaviors of pedestrians; a study with GPS experiment in Sinchon retail district in Seoul, South Korea. *Cities, 89*, 1–13.

Hajna, S., Ross, N. A., Brazeau, A.-S., Bélisle, P., Joseph, L., & Dasgupta, K. (2015). Associations between neighbourhood walkability and daily steps in adults: A systematic review and meta-analysis. *BMC Public Health, 15*(1), 1–8.

Haskell, W. L., Lee, I.-M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., Macera, C. A., Heath, G. W., Thompson, P. D., & Bauman, A. (2007). Physical activity and public health: Updated recommendation for adults from the american college of sports medicine and the american heart association. *Circulation, 116*(9), 1081.

Helbich, M. (2017). Children's school commuting in the Netherlands: Does it matter how urban form is incorporated in mode choice models? *International Journal of Sustainable Transportation, 11*(7), 507–517.

Herzog, T. R., & Chernick, K. K. (2000). Tranquility and danger in urban and natural settings. *Journal of Environmental Psychology, 20*(1), 29–39.

Herzog, T. R., & Flynn-Smith, J. A. (2001). Preference and perceived danger as a function of the perceived curvature, length, and width of urban alleys. *Environment & Behavior, 33*(5), 653.

Kang, C.-D. (2018). The S+ 5Ds: Spatial access to pedestrian environments and walking in Seoul, Korea. *Cities, 77*, 130–141.

Koohsari, M. J., Sugiyama, T., Shibata, A., Ishii, K., Liao, Y., Hanibuchi, T., Owen, N., & Oka, K. (2017). Associations of street layout with walking and sedentary behaviors in an urban and a rural area of Japan. *Health & Place, 45*, 64–69.

Koolhaas, C. M., Dhana, K., Schoufour, J. D., Ikram, M. A., Kavousi, M., & Franco, O. H. (2017). Impact of physical activity on the association of overweight and obesity with cardiovascular disease: The Rotterdam study. *European Journal of Preventive Cardiology, 24*(9), 934–941.

Larrañaga, A. M., Rizzi, L. I., Arellana, J., Strambi, O., & Cybis, H. B. B. (2016). The influence of built environment and travel attitudes on walking: A case study of Porto Alegre, Brazil. *International Journal of Sustainable Transportation, 10*(4), 332–342.

Li, F., Fisher, K. J., Brownson, R. C., & Bosworth, M. (2005). Multilevel modelling of built environment characteristics related to neighbourhood walking activity in older adults. *Journal of Epidemiology & Community Health, 59*(7), 558–564.

Li, J., Wu, S., Luo, Z., Hou, J., Zhang, W., Chen, X., Su, J., & Ying, S. (2021). Evaluating the friendliness of pedestrian footbridges using visibility analysis: A case study in Wuhan. *Journal of Geovisualization and Spatial Analysis, 5*(1), 1–10.

Lin, L., & Moudon, A. V. (2010). Objective versus subjective measures of the built environment, which are most effective in capturing associations with walking? *Health & Place, 16*(2), 339–348.

Maas, J., Spreeuwenberg, P., Winsum-Westra, V., Marijke, V., Robert, A., Vries, D., & S.. (2009). Is green space in the living environment associated with people's feelings of social safety? *Environment & Planning A, 41*(7), 1763–1777.

Mavoa, S., Bagheri, N., Koohsari, M. J., Kaczynski, A. T., Lamb, K. E., Oka, K., O'sullivan, D., & Witten, K. (2019). How do neighbourhood definitions influence the associations between built environment and physical activity? *International Journal of Environmental Research and Public Health, 16*(9), 1501.

McCormack, G. R., Koohsari, M. J., Turley, L., Nakaya, T., Shibata, A., Ishii, K., Yasunaga, A., & Oka, K. (2019). Evidence for urban design and public health policy and practice: Space syntax metrics and neighborhood walking. *Health & Place, 67*, 1–5.

Moreno-Llamas, A., García-Mayor, J., & De la Cruz-Sánchez, E. (2021). Urban-rural differences in trajectories of physical activity in Europe from 2002 to 2017. *Health & Place, 69*, Article 102570.

Nagel, C. L., Carlson, N. E., Bosworth, M., & Michael, Y. L. (2008). The relation between neighborhood built environment and walking activity among older adults. *American Journal of Epidemiology, 168*(4), 461–468.

Nello-Deakin, S., & Harms, L. (2019). Assessing the relationship between neighbourhood characteristics and cycling: Findings from Amsterdam. *Transportation Research Procedia, 41*, 17–36.

Okoro, C. A., Hollis, N. D., Cyrus, A. C., & Griffin-Blake, S. (2018). Prevalence of disabilities and health care access by disability status and type among adults—United States, 2016. *Morbidity and Mortality Weekly Report, 67*(32), 882.

Oyeyemi, A. L., Adegoke, B. O., Oyeyemi, A. Y., & Sallis, J. F. (2011). Perceived environmental correlates of physical activity and walking in African young adults. *American Journal of Health Promotion, 25*(5), e10–e19.

Oyeyemi, A. L., Kolo, S. M., Oyeyemi, A. Y., & Omotara, B. A. (2019). Neighborhood environmental factors are related to health-enhancing physical activity and walking among community dwelling older adults in Nigeria. *Physiotherapy Theory and Practice, 35*(3), 288–297.

Pan, K.-Y., Kok, A. A., Eikelenboom, M., Horsfall, M., Jörg, F., Luteijn, R. A., Rhebergen, D., van Oppen, P., Giltay, E. J., & Penninx, B. W. (2021). The mental health impact of the covid-19 pandemic on people with and without depressive, anxiety, or obsessive-compulsive disorders: A longitudinal study of three dutch case-control cohorts. *The Lancet Psychiatry, 8*(2), 121–129.

Pateman, T. (2011). Rural and urban areas: Comparing lives using rural/urban classifications. *Regional Trends, 43*(1), 11–86.

Pelclová, J., Frömel, K., Bláha, L., Zajac-Gawlak, I., Tluáková, L., et al. (2012). Neighborhood environment and walking for transport and recreation in central european older adults. *Acta Gymnica, 42*(4), 49–56.

Prins, R. G., & Van Lenthe, F. (2015). The hour-to-hour influence of weather conditions on walking and cycling among dutch older adults. *Age and Ageing, 44*(5), 886–890.

Rietveld, P. (2000). Non-motorised modes in transport systems: A multimodal chain perspective for the Netherlands. *Transportation Research Part D: Transport and Environment, 5*(1), 31–36.

Saelens, B. E., & Handy, S. L. (2008). Built environment correlates of walking: A review. *Medicine and Science in Sports and Exercise, 40*(7 Suppl), S550.

Saelens, B. E., Sallis, J. F., Frank, L. D., Cain, K. L., Conway, T. L., Chapman, J. E., Slymen, D. J., & Kerr, J. (2012). Neighborhood environment and psychosocial correlates of adults'physical activity. *Medicine and Science in Sports and Exercise, 44*(4), 637–646.

Santos, M., Vale, M., Miranda, L., & Mota, J. (2009). Socio-demographic and perceived environmental correlates of walking in Portuguese adults—a multilevel analysis. *Health & Place, 15*(4), 1094–1099.

Sarkar, C., Gallacher, J., & Webster, C. (2013). Built environment configuration and change in body mass index: The caerphilly prospective study (caps). *Health & Place, 19*, 33–44.

Sarkar, C., Webster, C., Pryor, M., Tang, D., Melbourne, S., Zhang, X., & Jianzheng, L. (2015). Exploring associations between urban green, street design and walking: Results from the Greater London boroughs. *Landscape and Urban Planning, 143*, 112–125.

Shigematsu, R., Sallis, J. F., Conway, T. L., Saelens, B. E., Frank, L. D., Cain, K. L., Chapman, J. E., & King, A. C. (2009). Age differences in the relation of perceived neighborhood environment to walking. *Medicine and Science in Sports and Exercise, 41*(2), 314.

Shimura, H., Sugiyama, T., Winkler, E., & Owen, N. (2012). High neighborhood walkability mitigates declines in middle-to-older aged adults'walking for transport. *Journal of Physical Activity and Health, 9*(7), 1004–1008.

Siegel, P. Z., Brackbill, R. M., & Heath, G. W. (1995). The epidemiology of walking for exercise: Implications for promoting activity among sedentary groups. *American Journal of Public Health, 85*(5), 706–710.

Szanton, S. L., Walker, R. K., Roberts, L., Thorpe, R. J., Jr., Wolff, J., Agree, E., … Seplaki, C. (2015). Older adults'favorite activities are resoundingly active: Findings from the NHATS study. *Geriatric Nursing, 36*(2), 131–135.

Thorell, L. B., Skoglund, C., de la Peña, A. G., Baeyens, D., Fuermaier, A. B., Groom, M. J., Mammarella, I. C., Van der Oord, S., van den Hoofdakker, B. J., Luman, M., et al. (2021). Parental experiences of homeschooling during the covid-19 pandemic: Differences between seven European countries and between children with and without mental health conditions. *European Child & Adolescent Psychiatry*, 1–13.

Thornton, C. M., Kerr, J., Conway, T. L., Saelens, B. E., Sallis, J. F., Ahn, D. K., Frank, L. D., Cain, K. L., & King, A. C. (2017). Physical activity in older adults: An ecological approach. *Annals of Behavioral Medicine, 51*(2), 159–169.

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment, 8*(2), 127–150.

Ussery, E. N., Carlson, S. A., Whitfield, G. P., Watson, K. B., Berrigan, D., & Fulton, J. E. (2018). Transportation and leisure walking among us adults: Trends in reported prevalence and volume, national health interview survey 2005–2015. *American Journal of Preventive Medicine, 55*(4), 533–540.

Van Cauwenberg, J., Van Holle, V., Simons, D., Deridder, R., Clarys, P., Goubert, L., Nasar, J., Salmon, J., De Bourdeaudhuij, I., & Deforche, B. (2012). Environmental factors influencing older adults'walking for transportation: A study using walk-along interviews. *International Journal of Behavioral Nutrition and Physical Activity, 9*(1), 1–11.

Van Dyck, D., Cerin, E., Conway, T. L., De Bourdeaudhuij, I., Owen, N., Kerr, J., Cardon, G., Frank, L. D., Saelens, B. E., & Sallis, J. F. (2013). Perceived neighborhood environmental attributes associated with adults'leisure-time physical activity: Findings from Belgium, Australia and the USA. *Health & Place, 19*, 59–68.

Villanueva, K., Knuiman, M., Nathan, A., Giles-Corti, B., Christian, H., Foster, S., & Bull, F. (2014). The impact of neighborhood walkability on walking: Does it differ across adult life stage and does neighborhood buffer size matter? *Health & Place, 25*, 43–46.

Wang, Y., Chau, C. K., Ng, W., & Leung, T. (2016). A review on the effects of physical built environment attributes on enhancing walking and cycling activity levels within residential neighborhoods. *Cities, 50*, 1–15.

Wang, Z., Ettema, D., & Helbich, M. (2021). Objective environmental exposures correlate differently with recreational and transportation walking: A cross-sectional national study in the Netherlands. *Environmental Research, 194*, Article 110591.

Whitfield, G. P., Carlson, S. A., Ussery, E. N., Watson, K. B., Berrigan, D., & Fulton, J. E. (2019). National-level environmental perceptions and walking among urban and rural residents: Informing surveillance of walkability. *Preventive Medicine, 123*, 101–108.

Yang, Y., He, D., Gou, Z., Wang, R., Liu, Y., & Lu, Y. (2019). Association between street greenery and walking behavior in older adults in Hong Kong. *Sustainable Cities and Society, 51*, Article 101747.

Yu, Y.-C., Lai, T.-F., Lin, C.-Y., Hsueh, M.-C., Liao, Y., Yang, L.-T., & Chang, S.-H. (2022). Associations of the audited residential neighborhood built-environment attributes with objectively-measured sedentary time among adults: A systematic review. *International Journal of Environmental Health Research*, 1–15.

Yun, H. Y. (2019). Environmental factors associated with older adult's walking behaviors: A systematic review of quantitative studies. *Sustainability, 11*(12), 3253.

Zhang, X., Melbourne, S., Sarkar, C., Chiaradia, A., & Webster, C. (2020). Effects of green space on walking: Does size, shape and density matter? *Urban Studies, 57*(16), 3402–3420.