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Objective environmental exposures correlate differently with recreational and transportation walking: A cross-sectional national study in the Netherlands

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ABSTRACT

Background Walking is a good and simple way to increase people's energy expenditure, but there is limited evidence whether the neighborhood environment correlates differently with recreational and transportation walking. AimTo investigate how recreational walking and transportation walking are associated with the natural and built environmental characteristics of the living environment in the Netherlands, and examine the differences in their associations between weekdays and weekends. Method and data We extracted the total duration of daily walking (in minutes per person) for recreation and transportation of adults aged 18 years and above from the Dutch National Travel Survey 2015–2017 (N = 65,785) and analyzed it as an outcome variable. Objective measures of the natural (i.e., normalized difference vegetation index (NDVI), blue space and meteorological conditions) and built environment (i.e., crossing density, land-use mix, and residential building density) around respondents' home addresses were determined for buffers with 300, 600, and 1000 m radii using a geographic information system. To assess associations between recreational and transportation walking and the environmental exposures separately, we fitted Tobit regression models to the walking data, adjusted for multiple confounders. ResultsOn weekdays, people living in areas with less NDVI, higher land-use mix, and higher crossing density were more likely to engage in transportation walking. Recreational walking was negatively associated with NDVI, blue space, crossing density, precipitation and daily average temperature. At weekends, land-use mix supports both recreational and transportation walking. A negative association appeared for NDVI and transportation walking. Daily average rainfall and temperature were inversely correlated with recreational walking. Sensitivity tests indicated that some associations depend on the buffer size. ConclusionsOur findings suggest that the built and natural environments are differently associated with people's recreational and transportation walking. We also found differences in the walking-environment associations between weekdays and weekends. Place-based policies to design walking-friendly neighborhoods may have different implications for different types of walking.

1. Introduction

Sedentary behavior and physical inactivity are well-known risk factors for developing chronic disease, and both threaten people's physical and mental health (Thorp et al., 2011). Among the different ways to be physically active, walking is the most popular and results in a range of health benefits (e.g., lower risk of type II diabetes and cardiovascular disease) (Ferdman, 2019; Tschentscher et al., 2013). In the Netherlands, the daily average distance walked by people is around 800 m (Centraal Bureau voor de Statistiek, 2017), although it varies significantly across municipalities, which can to a certain extent be attributed to differences in the environment.

Evidence is mounting that walking in the residential surroundings is influenced not only by people's demographic and socioeconomic characteristics (e.g., age, gender, and income), but also by the natural and built environments (green space, water bodies, air quality, etc.) (Yun, 2019; Saelens and Handy, 2008; Barnett et al., 2017; Gao et al., 2020). Previous research showed that the availability of green space (e.g., parks) and blue space (e.g., canals) is positively associated with people's walking behavior (Sarkar et al., 2015; James et al., 2017). Built environment factors include land use diversity and urban design features, such as street connectivity, building density, and accessibility (Ewing

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and Cervero, 2010). While a few studies found positive associations between walking and land-use diversity, design (street density and intersection types), and access to recreational and commercial places (Helbich, 2017; Clifton and Dill, 2005; Zhang et al., 2014), other environmental characteristics (e.g., traffic noise and accident risk) were reported to be inversely correlated with walking (Oyeyemi et al., 2019; Van Cauwenberg et al., 2012).

However, these associations between environmental exposures and walking were not consistently found across studies. For example, while Rosenbloom (2004), De Bourdeaudhuij et al. (2005), and Thornton et al. (2017) found that land use mix was positively associated with walking, Zhang et al. (2014) found a negative association. Results were also inconsistent for crossing density (Gómez et al., 2010; Thornton et al., 2017). These inconsistencies can to a certain extent be attributed to, first, the difference between using perceived and objective measures (Yun, 2019). While perceived measures were mainly derived from surveys or interviews, which were possibly affected by a recall bias, objective measures were obtained based on geographical information system (GIS) technologies. Second, it is common to use larger administrative areas (e.g., census tracts) to delimit people's neighborhood environments. This approach, however, has been conceptually and methodologically criticized (James et al., 2014). Refined exposure assessments are achieved through GIS-based buffers centered on people's residential home locations (Hanibuchi et al., 2011; Su et al., 2019). While the use of buffers circumvents many limitations of administrative areas, there is a lack of consensus on the appropriate buffer size. Earlier studies used ad hoc selected buffer radii ranging from 200 m to 2000 m (Wong et al., 2011; Mavoa et al., 2019). Third, different kinds of data sources were used in previous studies to incorporate environmental factors. Some research explored the potential of volunteered geographic information (e.g., OpenStreetMap) to derive environmental correlates (e.g., land use), (Bakillah et al., 2014), but the accuracy and completeness of volunteered geographic information is still questionable (Aghaabbasi et al., 2018; Yamashita et al., 2019; Hanibuchi et al., 2011). Other studies used remote sensing data to capture environmental characteristics (e.g., green space). Although this type of data varies in spatial resolution, the influence of the sensor spatial resolution on identifying the associations with environments seems to be minor (Su et al., 2019).

The effects of natural and built environments on walking also differ by walking purpose, which can be broadly classified into: recreational and transportation walking (Yun, 2019; Saelens and Handy, 2008; Gao et al., 2020). Despite certain inconsistencies, studies showed that transportation walking is mainly facilitated by crossing density, land-use mix, and access to public transportation, while recreational walking is associated with neighborhood employment, neighborhood sidewalks, and access to parks and open spaces (Ussery et al., 2018; Yun, 2019). Another factor underlying the associations is the temporal aspect of walking. Although a few studies found no significant difference in walking time between weekdays and weekends (Carlson et al., 2015), other research reported that people's walking behaviors differed between weekdays and weekends (Brooke et al., 2014; Bürgi and De Bruin, 2016). This implies that the environmental influences on walking also differ between weekdays and weekends. However, to our knowledge, few efforts have been made to examine the differences between weekends and weekdays in the associations between environments and recreational and transportation walking.

To address these research gaps, the present study investigated how natural and built environmental exposures are associated with recreational walking and transportation walking in the Netherlands. Our research questions were:

- What are the differences in the associations of objectively measured natural and built environments with different types of walking?
- Do the natural and built environments correlate with walking differently between weekdays and weekends?
- To what extent are potential walking-environment associations sensitive to the buffer size used for delimiting the residential context?

2. Data and methods

2.1. Study design and study population

The study was based on the cross-sectional Dutch National Travel Survey (CBS, 2015). Each year a random sample of respondents report their travel behaviors over one 24-h period by means of a travel diary. We considered those people aged 18 years and above. Respondents are assigned to a specific day in order to include seasonal effects. The survey contains a wide range of questions related to socio-demographic characteristics (e.g., income, age, education, and household composition) and travel information (e.g., transportation mode, travel purpose, trip duration, and the postcodes of trip origin and destination). To maximize the sample size, we pooled data from three consecutive years, namely 2015, 2016, and 2017. In total, our nationally representative sample comprised 65,785 respondents, after excluding those with incomplete data records. Ethical approval was not required because only secondary data were analyzed.

2.2. Walking behavior

Walking trips were classified as either recreational walking (e.g., for leisure) or transportation walking (e.g., for commuting to and from work), depending on the reported trip purpose. For both types of walking, the dependent variable was defined as the total duration of daily walking trips in minutes per person (within a 1000 m buffer). Trips outside the residential environments (>1000 m) were excluded, based on their origins and destinations.

2.3. Natural and built environmental exposures

Following previous studies (Sarkar et al., 2015; Gao et al., 2020), we included five measures of the residential natural and built environment. Based on their residential addresses, respondents were allocated to their 6-digit postal codes (PC6) rather than larger administrative areas as done previously by Gao et al. (2020). On average, a PC6 area comprised only 20 (standard deviation (SD) = 243) address locations–significantly fewer than the 2228 addresses (SD = 3368) in the case of the 4-digit postal code level.

To approximate people's walking environment, we applied circular buffers centered on respondents' PC6 residential location. To incorporate the immediate and extended walking environments, we used buffers with 300 m, 600 m, and 1000 m radii, following earlier studies (Villanueva et al., 2014; Mavoa et al., 2019).

1. The normalized difference vegetation index (NDVI) (Tucker, 1979) was used to capture the amount of outdoor greenery. The NDVI, which represents the chlorophyll content in the vegetation canopy (Helbich, 2019), was obtained from the Landsat 8 Operational Land Imager with a spatial resolution of 30 m for 2015. NDVI values range from −1 to 1. A higher NDVI value indicates more greenness, and negative values correspond to water bodies. To prevent negative values influencing mean NDVI scores per buffer, negative NDVI values were excluded from the calculation.
2. Blue space represented water bodies (e.g., canals), data on which were obtained from the Dutch land cover database (Landelijk Grondgebruiksbestand Nederland; LGN) for the year 2018. The dataset has a 5 m spatial resolution per raster cell. We calculated the proportion of blue space as the proportion of cells classified as fresh water or saltwater within the total number of cells within a buffer.
3. Land-use mix was operationalized through the Shannon entropy index, which measures the heterogeneity in the distribution of land-

use types within the residential environment (Sarkar et al., 2013). We obtained the Dutch land-use dataset (Bestand Bodemgebruik) for 2015 from Statistics Netherlands (CBS, 2019). Following previous studies (Bentley et al., 2018; Turrell et al., 2013), we grouped a total of 37 land-use types into five categories, namely residential, recreational, commercial, industrial, and others. The entropy index was computed based on the proportion of the area of each land-use category. Index values range between 0 and 1. A higher value means greater diversity.

4. Street connectivity is related to the design of the street layout and indicates the access to other places (Villanueva et al., 2014). We considered two aspects of street connectivity: ≥4-way crossings and cul-de-sacs. More ≥ 4-way crossings are indicative of a higher street connectivity, which promotes walking (Yun, 2019), while the opposite applies to cul-de-sacs. Crossing data were derived from the digital topographical base map of the Netherlands (TOP10NL) for 2016 (www.kadaster.nl/brt).
5. Residential building density refers to the ratio of the footprint area of residential buildings relative to the area per buffer. Building data were obtained from the Addresses and Buildings Registry (Basisregistratie Adressen en Gebouwen (BAG)) (Coetzee et al., 2020). We extracted residential buildings and computed their building footprints per buffer.

2.4. Meteorological conditions

In keeping with earlier work (Gao et al., 2020; Fishman et al., 2015), we considered meteorological variables. These variables were obtained from 33 weather stations distributed across the country and maintained by the Royal Dutch Meteorological Institute (www.knmi.nl). We attached each respondent's PC6 location to the geographically closest weather station and included hourly averages of measurements recorded 24 h a day to capture daily average precipitation (in mm), daily average wind speed (in m/s), and daily average temperature (in °C).

2.5. Control variables

We adjusted for a number of demographic and socioeconomic characteristics of the respondents. Age was divided into three categories: $18-44$, $45-64$, $>=65$. Level of education was classified as low (lower than secondary education), medium (secondary education), or high (college and university). Household income was grouped into three categories: low ($< 2,000$ euros/month, medium ($2,000- 4,000$ euros/month), and high ($> 4,000$ euros/month). The other control variables included were: gender (male, female), ethnicity (Dutch, non-Dutch), possession of driving license (yes, no), household composition (single person, couple without children, couple with children, single parent with children), number of cars per household, number of e-bikes per household, and number of mopeds per household.

2.6. Statistical analysis

Descriptive statistics summarized the data. We examined multicollinearity among neighborhood environmental variables using Spearman's correlation test. Correlations above 0.8 were critical.

For our regression analyses, the walking duration for recreation and transportation served as the dependent variable. Because a substantial share of the respondents did not report any walking, we faced many zero counts (87% in recreation walking and 89% in transportation walking). To cope with the excess of zeros, we employed Tobit regression models, which can censor zero values (i.e., no walking). The hierarchical data structure was disregarded, because nearly every respondent (90%) was nested in their own PC6 area (mean = 1.2, SD = 0.49).

In total, 12 fully-adjusted models were fitted. We separated models for transportation walking and recreational walking. Moreover, because some studies (e.g., Brooke et al. (2014); Bürgi and De Bruin (2016)) found that walking behavior differed between weekdays and weekends, models were also stratified in this respect. For sensitivity testing, we assessed the associations between walking and the environmental variables across the three buffer widths (i.e., 300 m, 600 m, and 1000 m). The significance of each variable was assessed based on the 95% confidence intervals (CI). The analyses were carried out in Stata 16.

3. Results

3.1. Descriptive statistics

After excluding records with missing covariates or with trips outside residential environments (>1000 m), a total of 65,785 respondents were included in the final sample. 52% were female, 84% were Dutch, 23% were retired (aged >65 years), and 60% had a household income of 20.000–40.000 euros (Table 1). The majority (88%) held a driving license, 52% owned a car, 13% had an e-bike, and 7% had a moped.

Fig. 1 shows the differences in respondents' daily walking duration stratified into weekdays and weekends. On average, the duration of recreational walking (6.99 min/day, SD = 25.4) was longer than the time spent on transportation walking (2.58 min/day, SD = 13.37). For both weekdays and weekends, people engaged more in recreational walking than in transportation walking. People walked longer for recreation at weekends (9.49 min/day, SD = 31.39) than on weekdays (6.09 min/day, SD = 22.78). The opposite appeared for transportation-related walking: Longer walking trips were undertaken on weekdays (2.78 min/day, SD = 14.27) than at weekends (2.02 min/day, SD = 10.46).

As the buffer sizes for the environmental variables increased, the mean NDVI scores, the proportions of blue space, and the land-use mix increased. In contrast, the mean values of residential building density and crossing density (cul-de-sacs and >= 4-way crossings) decreased with increasing buffer sizes. No major differences were observed between weekends and weekdays in the three meteorological conditions (i.e., daily precipitation sum, daily average wind speed, and daily average temperature).

3.2. Regression analyses

Tables 2 and 3 summarize the results of the Tobit regression for recreation and transportation walking stratified by weekdays and weekends. The built and the natural environmental characteristics were differently associated with recreational and transportation walking, and the associations differed between weekends and weekdays. On weekdays (Table 2), respondents living in residential areas with lower levels of NDVI, a pronounced land-use mix, less blue space, and a higher crossing density were more likely to engage in transportation walking. Recreational walking was inversely associated with NDVI, cul-de-sac, precipitation, and daily average temperature. At weekends (Table 3), while ≥ 4 way crossing density and land-use mix were positively correlated with transportation walking, NDVI had a negative association with transportation walking. For recreational walking at weekends, a positive association was found for land-use mix. Conversely, negative correlations were observed for precipitation and daily average temperature.

We also observed that varying the buffer sizes affected the association between the residential environment and walking. For example, negative associations between blue space and transportation and recreational walking at weekends were found for the buffer size of 300 m, but not for the 600 m and 1000 m buffers. There was also evidence that land-use mix based on 600 m buffer was positively associated with recreational walking at weekends ($p < 0.001$), but the association was less significant for buffers with 300 m ($p < 0.01$) and 1000 m ($p < 0.05$) radii. Similarly, the significance levels of the association of land use mix with transportation walking at weekends varied across different buffer sizes.

Table 1
Descriptive statistics of demographic and socio-demographic characteristics of the study population and the natural and built environmental characteristics of their residential environment.

Descriptive statistics for walking during weekdays and weekends						
	Total		Weekdays		Weekends	
	% per category	mean (std.dev.)	% per category	mean (std.dev.)	% per category	mean (std.dev.)
Indicators	100 (n = 65785)		73.5		26.5	
Gender						
Male	48.17		47.34		47.95	
Female	51.83		52.66		52.05	
Nationality						
Non-Dutch	15.78		15.78		15.78	
Dutch	84.22		84.22		84.22	
Age						
18–44	38.00		38.16		38.04	
45–64	39.03		38.64		38.93	
65+	22.97		23.20		23.03	
Education						
Low	25.96		25.11		25.73	
Medium	38.51		38.74		38.57	
High	35.53		36.15		35.70	
Driving licensee						
No	11.9		11.62		11.83	
Yes	88.1		88.38		88.17	
Household income						
<20,000	23.63		23.55		23.61	
20,000–40,000	59.60		59.21		59.50	
>40,000	16.77		17.24		16.89	
Household composition						
Single person	19.50		18.90		19.34	
Couple without children	35.94		36.35		36.05	
Couple with children	39.20		39.38		39.25	
Single parent with children	5.36		5.37		5.36	
Number of cars						
No cars	12.36		11.81		12.22	
1 car	51.86		52.05		51.91	
2 or more cars	35.78		36.13		35.87	
Number of E-bikes						
No E-bikes	79.09		78.69		78.98	
1 E-bike	12.50		12.32		12.45	
2 or more E-bikes	8.41		8.99		8.56	
Number of moeds						
No mopeds	91.60		92.04		91.71	
1 moped	7.06		6.78		6.99	
2 or more mopeds	1.34		1.18		1.30	
Built and natural characteristics						
NDVI 300 m		0.42(0.11)		0.43(0.11)		0.42(0.11)
Land-use mix 300 m		0.47(0.19)		0.47(0.19)		0.47(0.19)
Proportion of blue space 300 m		0.04(0.07)		0.04(0.07)		0.04(0.07)
Residential building density 300 m		0.3(0.27)		0.3(0.28)		0.3(0.28)
Cul-de-sac 300 m (100 crossings/km^2)		0.25(0.2)		0.25(0.2)		0.25(0.2)
≥4-way crossing density 300 m (100 crossings/km^2)		0.37(0.32)		0.37(0.32)		0.37(0.32)
NDVI 600 m		0.44(0.1)		0.44(0.1)		0.44(0.1)
Land-use mix 600 m		0.59(0.17)		0.59(0.17)		0.59(0.17)
Proportion of blue space 600 m		0.05(0.07)		0.05(0.07)		0.05(0.07)
Residential building density 600 m		0.27(0.28)		0.27(0.28)		0.27(0.28)
Cul-de-sac 600 m (100 crossings/km^2)		0.22(0.14)		0.22(0.13)		0.22(0.14)
≥4-way crossing density 600 m (100 crossings/km^2)		0.33(0.24)		0.33(0.24)		0.33(0.24)
NDVI 1000 m		0.46(0.1)		0.46(0.1)		0.46(0.1)
Land-use mix 1000 m		0.64(0.18)		0.64(0.18)		0.64(0.18)
Proportion of blue space 1000 m		0.06(0.07)		0.06(0.08)		0.06(0.07)
Residential building density 1000 m		0.25(0.29)		0.25(0.29)		0.25(0.29)
Cul-de-sac 1,000 m (100 crossings/km^2)		0.19(0.1)		0.18(0.1)		0.19(0.1)
≥4-way crossing density 1000 m (100 crossings/km^2)		0.29(0.21)		0.29(0.21)		0.29(0.21)
Weather conditions						
Daily precipitation sum (mm)		2.34(0.26)		2.34(0.26)		2.34(0.26)
Daily average wind speed (m/s)		4.33(0.91)		4.34(0.92)		4.33(0.91)
Daily average temperature (°C)		10.68(0.66)		10.68(0.68)		10.68(0.67)

4. Discussion

4.1. Main findings

This study examined the differences in the correlations between environmental exposures and different types of walking. Consistent with earlier studies (Bentley et al., 2018; De Bourdeaudhuij et al., 2005; Thornton et al., 2017), land-use mix was positively associated with transportation walking. For recreational walking, however, the relation differed between weekdays and weekends. At weekends, residential environments with a high mix of land use encouraged more recreational walking, but on weekdays no association was found. This may be

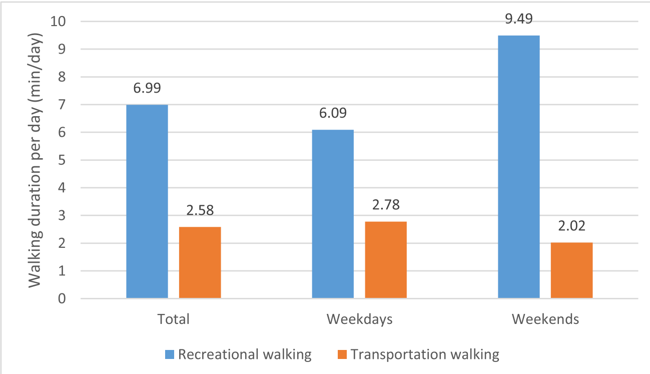

Fig. 1. Average walking behavior in the study population.

because environments with a high land-use diversity attract fewer recreational walkers on weekdays than at weekends. Although some research showed that the blue space encourages physical activities such as walking (Jansen et al., 2018; Perchoux et al., 2015), negative associations between the proportion of blue space and walking on weekdays were observed. This indicates that water bodies seem to be barriers to walking. NDVI was negatively associated with both recreational and transportation walking, which is inconsistent with previous studies (Su et al., 2019; Sarkar et al., 2015; James et al., 2017). A possible explanation is that less utilitarian destinations (e.g., shopping centers, stores, supermarkets) are located in areas with high levels of vegetation, which results in less transportation walking. Another reason may be that pronounced vegetation (e.g., parks) could reduce perceived safety. Especially at night, green spaces can be used for criminal activities (Baycan-Levent et al., 2009; Mensah et al., 2016), and people prefer not to walk in insecure areas (Ratnayake, 2013; Oyeyemi et al., 2019). Congruent with earlier work (Thornton et al., 2017), we found that street connectivity supported transportation walking. With regard to cul-de-sacs, they seem to be barriers to recreational walking on weekdays. This might be because most cul-de-sacs are located in suburbs where there are fewer opportunities for recreational walkers, who seek different scenic environments. However, there was a positive association between cul-de-sacs and transportation walking on weekdays. An explanation could be that on weekdays, more people in suburbs walk to transit points and commute via public transportation.

Although the built and natural environments were largely and consistently associated with walking across different buffer sizes, we observed that for some environmental factors, the associations varied with different geographical scales. This aligns with work conducted by Etman et al. (2014). For example, regarding residential building density, while a positive relationship was found with transportation walking within a 300 m buffer, no associations were observed at larger scales (i.e., 600 m and 1000 m). Conversely, a negative association with recreational walking on weekdays was found at a large scale (1000 m), but no associations were found at smaller scales (300 m and 600 m). A possible explanation for this inconsistency is that on weekdays, people prefer to walk for recreation in environments with less residential density, but for various reasons (e.g., time constraints), do not walk far for transportation. Moreover, we also found, confirming previous studies (Lee and Kwan, 2019), that the difference in buffer sizes influences the strength of the associations (e.g., that between land-use mix and transportation and recreational walking at weekends). This may be at least partly attributed to the difference in the walking environments of people in different age groups: Compared to younger adults, older adults have more spare time to walk and also prefer to walk more. A larger buffer size seems to be more appropriate for investigating the walking behavior of older adults (Villanueva et al., 2014).

Regarding meteorological variables, less precipitation was negatively associated with recreational walking duration, which echoes Gao et al. (2018) and Edwards et al. (2015). We also found that higher temperature was negatively related with recreational walking. This finding contradicts studies that found that people living places with higher temperatures spend more time engaging in physical activities (Mullahy and Robert, 2010). Nevertheless, a similar negative association between temperature and walking was reported by Fishman et al. (2015). A possible explanation is that in countries with a mild climate, like the Netherlands, increased temperatures might make people less active. Wind speed played no role in explaining recreational walking on weekdays or at weekends. For transportation walking on weekdays, no association was found. This lack of significance seems rational, as most transportation walking trips are undertaken for specific purposes (e.g., to go shopping or to work), which are less likely to be influenced by weather conditions. However, at weekends, the wind speed had a negative influence on transportation walking, possibly because a higher wind speed leads people to choose a travel mode (e.g., car or public transport) other than walking (Böcker et al., 2017).

4.2. *Strengths and limitations*

This study had a number of strengths. First, we used a large and nationally representative sample georeferenced at a micro-level, which resulted in pronounced statistical power. Second, compared to previous studies that relied on perceived measurements of environments (Oyeyemi et al., 2019; Cerin et al., 2014), we applied objective GIS-based measures of the natural and built environments, which were free of self-reporting bias. Moreover, instead of using crude PC4 location information as previously done (Gao et al., 2020), we used more detailed information at the PC6 level, which is likely to have reduced the risk of inaccurate environmental assessments. Third, we distinguished between recreational and transportation walking and time of the week (weekdays vs. weekends), and explored multiple buffer sizes to examine walking-environment associations across multiple geographical scales, which was rarely done in earlier studies.

A few limitations must be mentioned. First, our analyses were based on cross-sectional data, which precludes the drawing of conclusions regarding causality. We also lacked data to address peopleâ€™s residential self-selection. Second, as we focused on walking trips in the Netherlands (a country with a high population density), some of the findings may not be transferable to other countries. Third, our study relied on self-reported data. We did not know whether respondents reported their walking duration accurately (particularly short trips), and we lacked data to address people's residential self-selection bias. Fourth, due to a lack of GPS data on walking trips, we could not divide the trips based on the buffer size. 62% of all walking trips that had tracks beyond the residential environment were included, which resulted in an overestimation of the walking duration. Fifth, our green space measure (i.e., NDVI) included private gardens which are not accessible for walking. Moreover, such satellite-based measures are limited in representing how people perceive actual green space at the street level. Street view images rather than remotely sensed images seem promising to address this shortcoming. Finally, data on other urban form variables (e.g., sidewalks) and regional accessibility (Barr et al., 2019) were not available. However, in the Dutch context, most streets are walkable and we think the implications for our model estimates are minor.

5. Conclusions

In this study we examined differences in associations of people's residential environments with recreation and transportation walking on weekdays and at weekends, using a large sample with national coverage. We provided robust evidence that the associations between environmental correlates and walking differ by weekdays and weekends. Sensitivity assessments across buffer sizes confirmed that our results are reasonably robust. If future studies confirm our findings in a longitudinal setting, our results suggest that it may be more efficient for urban

Table 2
Statistical results of Tobit model for recreational walking (RW) and transportation walking (TW) on weekdays.

Results from Tobit model for recreational walking (RW) and transportation walking (TW) during weekdays												
	300 m buffer				600 m buffer				1000 m buffer			
	RW		TW		RW		TW		RW		TW	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Gender												
Male (ref.)												
Female	12.26***	(1.517)	13.79***	(0.878)	12.19***	(1.517)	13.73***	(0.877)	12.19***	(1.517)	13.63***	(0.876)
Nationality												
Non-Dutch (ref.)												
Dutch	6.394**	(2.184)	−3.455**	(1.133)	6.395**	(2.188)	−3.054**	(1.134)	6.388**	(2.191)	−2.832*	(1.136)
Age												
18-44 (ref.)												
45–64	23.91***	(1.858)	0.0232	(1.045)	23.84***	(1.857)	−0.220	(1.043)	23.76***	(1.857)	−0.583	(1.043)
65+	34.45***	(2.399)	15.34***	(1.326)	34.33***	(2.398)	14.92***	(1.323)	34.23***	(2.399)	14.47***	(1.322)
Education												
Low (ref.)												
Medium	3.900*	(1.975)	1.218	(1.128)	3.793	(1.974)	0.896	(1.126)	3.764	(1.975)	0.522	(1.125)
High	2.695	(2.119)	2.750*	(1.208)	2.506	(2.122)	2.090	(1.207)	2.411	(2.125)	1.561	(1.207)
Driving licensee												
No (ref.)												
Yes	7.560**	(2.699)	−6.411***	(1.339)	7.481**	(2.699)	−6.247***	(1.336)	7.384**	(2.699)	−6.051***	(1.336)
Household income												
<20,000 (ref.)												
20,000–40,000	−6.167**	(1.937)	−5.483***	(1.054)	−6.215**	(1.937)	−5.585***	(1.053)	−6.217**	(1.937)	−5.603***	(1.052)
>40,000	−8.507**	(2.720)	−5.377***	(1.549)	−8.748**	(2.718)	−6.016***	(1.546)	−8.881**	(2.716)	−6.403***	(1.544)
Household composition												
Single person (ref.)												
Couple without children	14.69***	(2.333)	2.082	(1.271)	14.68***	(2.333)	2.097	(1.269)	14.68***	(2.333)	1.987	(1.268)
Couple with children	10.32***	(2.576)	6.692***	(1.407)	10.28***	(2.576)	6.496***	(1.404)	10.27***	(2.577)	6.198***	(1.403)
Single parent with children	−3.935	(3.956)	−0.946	(2.044)	−4.038	(3.955)	−1.274	(2.040)	−4.022	(3.955)	−1.544	(2.040)
Number of cars												
No cars (ref.)												
1 car	−12.72***	(2.846)	−13.85***	(1.424)	−12.68***	(2.850)	−13.64***	(1.424)	−12.74***	(2.853)	−13.78***	(1.425)
2 or more cars	−20.57***	(3.347)	−24.87***	(1.780)	−20.58***	(3.357)	−24.31***	(1.782)	−20.80***	(3.362)	−24.62***	(1.785)
Number of E-bikes												
No E-bikes (ref.)												
1 E-bike	2.300	(2.246)	−6.674***	(1.388)	2.353	(2.247)	−6.409***	(1.387)	2.381	(2.248)	−6.290***	(1.385)
2 or more E-bikes	−1.996	(2.747)	−3.773*	(1.703)	−1.964	(2.748)	−3.307	(1.701)	−2.021	(2.749)	−3.025	(1.699)
Number of moeds												
No mopeds (ref.)												
1 moped	5.103	(2.951)	−2.677	(1.865)	5.100	(2.952)	−2.327	(1.863)	5.069	(2.951)	−2.283	(1.861)
2 or more mopeds	−2.499	(6.738)	−0.911	(4.180)	−2.609	(6.740)	−1.093	(4.185)	−2.603	(6.738)	−1.363	(4.189)
Built and natural characteristics												
NDVI	−47.42***	(9.292)	−95.18***	(5.439)	−44.12***	(11.69)	−83.91***	(6.545)	−43.87**	(14.43)	−53.74***	(8.016)
Land-use mix	2.999	(4.177)	12.95***	(2.424)	4.852	(5.284)	13.73***	(3.145)	4.633	(6.195)	18.00***	(3.743)
Proportion of blue space	−29.74*	(11.94)	−40.23***	(7.102)	−23.96*	(11.76)	−32.28***	(6.890)	−15.84	(11.51)	−9.134	(6.608)
Residential building density	−3.170	(2.881)	5.027**	(1.655)	−4.384	(2.818)	2.149	(1.645)	−5.369*	(2.683)	−0.755	(1.586)
Cul-de-sac (100 crossings/km^2)	−8.007*	(3.737)	4.123*	(2.083)	−11.29*	(5.764)	9.483**	(3.142)	−20.56*	(8.339)	9.369*	(4.447)
≥4-way crossing density (100 crossings/km^2)	−7.258*	(2.859)	7.114***	(1.469)	−7.299	(4.413)	14.39***	(2.320)	−8.361	(5.893)	20.65***	(3.145)
Weather conditions												
Daily precipitation sum (mm)	−17.98***	(3.867)	3.082	(2.201)	−17.96***	(3.910)	1.502	(2.222)	−18.24***	(3.957)	0.895	(2.247)
Daily average wind speed (m/s)	−0.208	(0.886)	0.0760	(0.505)	−0.229	(0.887)	0.0646	(0.504)	−0.253	(0.891)	0.140	(0.507)
Daily average temperature (°C)	−5.279***	(1.439)	0.560	(0.816)	−5.214***	(1.457)	−0.0467	(0.825)	−5.214***	(1.472)	−0.0264	(0.836)
Intercept	−26.25	(23.21)	−40.61**	(13.05)	−28.21	(24.29)	−37.89**	(13.59)	−25.28	(25.82)	−53.16***	(14.47)
Model fit												
Log likelihood	−45937.13		−41102.82		−45947.76		−41111.61		−45948.43		−41174.11	
McFadden's pseudo R2	0.0065		0.0288		0.0065		0.0286		0.0064		0.0271	

*p < 0.05, **p < 0.01, ***p < 0.001.

Table 3
Statistical results of Tobit model for recreational walking (RW) and transportation walking (TW) at weekends.

Results from Tobit model for recreational walking (RW) and transportation walking (TW) during weekends

	300 m buffer				600 m buffer				1000 m buffer			
	RW		TW		RW		TW		RW		TW	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Gender												
Male (ref.)												
Female	10.47***	(2.559)	5.171***	(1.438)	10.50***	(2.560)	5.296***	(1.436)	10.49***	(2.560)	5.497***	(1.435)
Nationality												
Non-Dutch (ref.)												
Dutch	12.54***	(3.700)	−0.704	(1.885)	12.21***	(3.705)	−0.397	(1.882)	12.14**	(3.714)	0.201	(1.886)
Age												
18-44 (ref.)												
45–64	24.41***	(3.102)	−0.548	(1.742)	24.18***	(3.100)	−0.620	(1.740)	23.81***	(3.099)	−0.827	(1.739)
65+	26.72***	(4.093)	4.567*	(2.186)	26.42***	(4.091)	4.616*	(2.181)	25.89***	(4.089)	4.308*	(2.178)
Education												
Low (ref.)												
Medium	3.725	(3.465)	−0.625	(1.921)	3.703	(3.464)	−0.663	(1.915)	3.538	(3.463)	−1.019	(1.913)
High	20.51***	(3.630)	4.633*	(2.022)	20.42***	(3.637)	3.862	(2.021)	20.35***	(3.643)	3.270	(2.021)
Driving licensee												
No (ref.)												
Yes	−1.270	(4.550)	−9.992***	(2.182)	−1.279	(4.552)	−9.861***	(2.175)	−1.324	(4.554)	−10.02***	(2.174)
Household income												
<20,000 (ref.)												
20,000–40,000	−2.292	(3.326)	−4.131*	(1.767)	−2.341	(3.328)	−4.013*	(1.764)	−2.392	(3.328)	−3.875*	(1.763)
>40,000	−7.009	(4.588)	−0.542	(2.543)	−7.366	(4.586)	−0.813	(2.538)	−7.802	(4.582)	−1.276	(2.535)
Household composition												
Single person (ref.)												
Couple without children	9.591*	(3.984)	0.00849	(2.041)	9.538*	(3.985)	−0.206	(2.035)	9.462*	(3.985)	−0.334	(2.033)
Couple with children	11.16*	(4.395)	−4.669*	(2.328)	10.90*	(4.397)	−4.953*	(2.323)	10.58*	(4.395)	−5.264*	(2.320)
Single parent with children	2.821	(6.474)	−0.481	(3.227)	2.745	(6.472)	−0.700	(3.219)	2.489	(6.471)	−1.297	(3.221)
Number of cars												
No cars (ref.)												
1 car	−14.53**	(4.834)	−10.00***	(2.299)	−14.97**	(4.849)	−9.592***	(2.297)	−15.26**	(4.862)	−9.237***	(2.303)
2 or more cars	−23.58***	(5.662)	−22.47***	(2.952)	−23.99***	(5.686)	−21.26***	(2.951)	−24.73***	(5.705)	−20.94***	(2.961)
Number of E-bikes												
No E-bikes (ref.)												
1 E-bike	0.944	(3.884)	−1.824	(2.309)	1.013	(3.886)	−1.318	(2.303)	0.945	(3.886)	−1.243	(2.299)
2 or more E-bikes	2.527	(4.603)	0.275	(2.823)	2.643	(4.608)	1.073	(2.816)	2.354	(4.611)	1.381	(2.812)
Number of moeds												
No mopeds (ref.)												
1 moped	6.888	(5.049)	−5.759	(3.341)	7.191	(5.051)	−5.730	(3.343)	6.848	(5.052)	−5.833	(3.344)
2 or more mopeds	16.75	(11.25)	2.457	(7.380)	16.84	(11.26)	2.896	(7.389)	16.70	(11.25)	2.413	(7.404)
Built and natural characteristics												
NDVI	−23.06	(15.58)	−93.98***	(9.072)	−4.693	(19.78)	−84.29***	(10.75)	4.985	(24.34)	−73.79***	(13.25)
Land-use mix	18.85**	(7.107)	16.47***	(4.058)	32.82***	(9.138)	13.24*	(5.383)	24.14*	(10.68)	10.88	(6.492)
Proportion of blue space	−43.22*	(20.34)	−25.40*	(11.20)	−24.78	(19.71)	−16.41	(11.04)	1.607	(18.86)	−9.370	(10.82)
Residential building density	4.278	(4.799)	6.242*	(2.753)	5.096	(4.628)	2.428	(2.750)	2.027	(4.469)	0.112	(2.692)
Cul-de-sac (100 crossings/km^2)	1.853	(6.364)	6.133	(3.512)	−6.459	(9.871)	11.18*	(5.319)	−26.09	(14.32)	11.98	(7.476)
≥4-way crossing density (100 crossings/km^2)	−4.672	(4.823)	9.540***	(2.394)	−8.223	(7.507)	20.51***	(3.752)	−7.343	(10.00)	24.69***	(5.145)
Weather conditions												
Daily precipitation sum (mm)	−19.19**	(6.573)	7.164	(3.747)	−18.03**	(6.642)	4.126	(3.789)	−16.94*	(6.714)	3.255	(3.832)
Daily average wind speed (m/s)	0.117	(1.500)	−1.666	(0.858)	0.294	(1.500)	−1.758*	(0.855)	0.285	(1.507)	−1.792*	(0.859)
Daily average temperature (°C)	−6.748**	(2.407)	4.299**	(1.406)	−6.194*	(2.433)	3.310*	(1.424)	−5.746*	(2.459)	2.885*	(1.441)
Intercept	−24.92	(39.15)	−81.67***	(21.88)	−49.42	(40.93)	−70.03**	(22.72)	−53.46	(43.47)	−65.54**	(24.19)
Model fit												
Log likelihood	−22049.27		−11320.46		−22047.52		−11313.87		−22053.01		−11328.66	
McFadden's pseudo R2	0.0045		0.0382		0.0046		0.0388		0.0043		0.0375	

*p < 0.05, **p < 0.01, ***p < 0.001.

planners and policy makers to take into account walking type and time when developing strategies to promote walking.

Credit author statement

Dick Ettema developed the research idea. Zhiyong Wang prepared the data together with Marco Helbich. Zhiyong Wang carried out the analyses and drafted the manuscript. All authors read, edited, and approved the final manuscript.

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.

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