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 to increase people’s energy expenditure, but there is limited evidence whether the neighborhood environment correlates differently with recreational and transportation walking.

Aim: To 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 transport from the Dutch National Travel Survey 2015-2017 (N=66,880), and analyzed it as an outcome variable. Objective measures of the natural (i.e., Normalized Difference Vegetation Index (NDVI) 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 1,000 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.

Results: On weekdays, people living in areas with less NDVI, higher land use mix, higher residential building density, and higher crossing density, were more likely to engage in transportation walking. While recreational walking was negatively associated with NDVI, crossing density, precipitation and daily average temperature, it was positively associated with residential building density. 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.

Conclusions: Our findings suggest that the built and natural environments have different impacts on 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.

Keywords: Recreational walking; Transportation walking; Built and natural environments; Exposure; The
Introduction

Sedentary behavior and physical inactivity are well-known risk factors for developing chronic disease, threatening people’s physical and mental health alike [1]. 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) [2, 3]. In the Netherlands, the daily average distance walked by Dutch people is around 800 m [4], 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.) [5–7]. Previous research showed that the availability of green space and water bodies is positively associated with people’s walking behavior [8, 9]. Built environment factors include land use diversity and urban design features, such as street connectivity, building density, and accessibility. While a few studies found positive associations between walking and land-use diversity, design (street density and intersections), and access to recreational and commercial places [10–12], other environmental characteristics (e.g., traffic noise and risk) were reported to be inversely correlated with walking [13, 14].

However, these associations between environmental exposures and walking were not consistently found across studies. For example, while [15], [16], and [17] found that land use mix was positively associated with walking, [12] found a negative association. Results were also inconsistent for crossing density [17, 18]. These inconsistencies can to a certain extent be attributed to, first, the difference between using perceived and objective measures [5]. 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 administrative areas (e.g., census tracts) to delimit people’s neighborhood environments. This approach, however, has been conceptually and methodologically criticized [19]. Refined exposure assessments are achieved through GIS-based buffers centered on people’s residential locations [20, 21]. While circumventing 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 200m to 2,000m [22, 23]. Third, different kinds of data sources were used in previous studies to incorporate environmental factors. Some research explored the potential of volunteered geographic information (VGI) (such as OpenStreetMap) to derive environmental correlates (e.g., land use), [24], but the accuracy and completeness of VGI data are still questionable [20, 25, 26]. Other studies used remote sensing data to capture environmental characteristics (e.g., green space). Although this type of data varies in spatial resolution (ranging from 2 m to 30 m), there seems to be no significant impact of the sensor spatial resolution on identifying the associations with environments [21].

The effects of natural and built environments on walking also differ by walking purpose, which can be broadly classified into: recreational and transportation walking [5, 6]. 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 [5, 27]. 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 [28], other research reported that people’s walking behaviors differed between weekdays and weekends [29, 30]. 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. Our research questions were:

- What are the differences in the associations of objectively measured natural and built environments with different types of walking in the Netherlands?
- Do objectively measured 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?

Data and methods
Study design and study population
The study was based on the cross-sectional Dutch National Travel Survey [31]. Each year around 40,000 respondents report their travel behaviors over one 24-hour period by means of a travel diary. Respondents are assigned to a specific day in order to include seasonal effects. To maximize the sample size, we pooled data from three consecutive years, namely 2015, 2016, and 2017. In total, our nationally representative sample comprised 66,880 respondents. Ethical approval was not required because only secondary data were analyzed.

Walking behavior
Walking trips were classified as either recreational walking (e.g., for leisure) or transportation walking (e.g., 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 1000m buffer). Note that trips outside the residential environments (>1,000 m) were excluded.

Natural and built environmental exposures
We included four measures of the residential natural and built environment, following previous studies [8, 32]. Based on their residential addresses, respondents’ were allocated to their 6-digit postal code (PC6) rather than larger administrative areas as done previously by [32]. On average, a PC6 area comprised only 20 (standard deviation (SD)=243) address locations—significantly fewer than the 2,228 addresses (SD=3,368) 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 300m, 600m, and 1,000m radii, following earlier studies [23, 33].

1 The Normalized Difference Vegetation Index (NDVI) [34] was used to capture the amount of outdoor greenery. The NDVI, which represents the chlorophyll content in the vegetation canopy [35], was obtained from the Landsat 8
Operational Land Imager with a spatial resolution of 30m 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 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 [36]. We obtained the Dutch land-use dataset (Bestand Bodemgebruik) for 2015 from Statistics Netherlands [37]. Following previous studies [38, 39], 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.

3 Street connectivity is related to the design of the street layout and indicates the access to other places [33]. We considered two aspects of street connectivity: $\geq$4-way crossings and cul-de-sacs. More $\geq$4-way crossings are indicative of a higher street connectivity, which promotes walking [5], 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).

4 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)) [40]. We extracted residential buildings and computed their building footprints per buffer.

Meteorological conditions
In keeping with earlier work [32, 41], 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 hours a day to capture daily average precipitation (in mm), daily average wind speed (in m/s), and daily average temperature (in °C).

Control variables
We adjusted for a number of demographic and socioeconomic characteristics of the respondents. Age was divided into three categories: $\leq 44$, $45 - 64$, $\geq 65$. 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 moped per household.

Statistical analysis
Descriptive statistics summarized the data. We examined multi-collinearity 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 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., [29, 30]) 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., 300m, 600m, and 1,000 m). The significance of each variable was assessed based on the 95% confidence intervals (CI). The analyses were carried out in Stata 16.

**Results**

**Descriptive statistics**

Of the 66,880 respondents, 52% were female, 84% were Dutch, 23% were retired (aged > 65 years), and 59% had a household income of 20,000-40,000 euros (Table 1). The majority (87%) held a driving license, 52% owned a car, 21% had an e-bike, and 8% had a moped.

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

Figure 1 shows the differences in respondents’ daily walking duration stratified into weekdays and weekends. On average, the duration of recreational walking (6.93 min/day, SD=25.33) was longer than the time spent on transportation walking (2.57 min/day, SD=13.32). For both weekdays and weekends, people engaged more in recreational walking rather than transportation walking. People walked longer for recreation at weekends (9.4 min/day, SD=31.2) than on weekdays (6.04 min/day, SD=22.79). The opposite appeared for transportation-related walking: Longer walking trips were undertaken on weekdays (2.76 min/day, SD=14.19) than at weekends (2.03 min/day, SD=10.51).

As the buffer sizes for the environmental variables increased, the mean NDVI scores 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).

**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, a higher residential building density, 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, while it was positively associated with residential building density. 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, positive associations were found for land-use mix and residential building density. Conversely, negative correlations were observed for precipitation and daily average temperature.

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

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

We also observed that varying the buffer sizes affected the association between the residential environment and walking. For example, a positive association between cul-de-sacs and transportation walking during weekdays was found for the buffer size of 600m, but was absent in the 300m and 1,000m buffers. There was also evidence that land-use mix based on 300m buffers was positively associated with transportation walking at weekends (p < 0.001), but the association was less significant for buffers with 600m (p < 0.01) and 1,000m (p < 0.05) radii. Similarly, the significance levels of the association of land use mix with recreational walking at weekends varied across different buffer sizes.

Discussion
Main findings
This study examined the differences in the correlations between environmental exposures and different types of walking. Consistent with earlier research [16, 17, 38], 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 because environments with a high land-use diversity attract fewer recreational walkers on weekdays than at weekends. NDVI was negatively associated with recreational and transportation walking, which is inconsistent with previous studies [8, 9, 21]. 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 [42, 43], and people prefer not to walk in insecure areas [13, 44]. Residential building density, which is correlated with population density [24], was positively associated with recreational and transportation walking, as also found by [11, 45] and [46]. However, its association with transportation walking was insignificant at weekends, possibly because many business and commercial facilities are closed at weekends, and therefore fewer people walk for transportation. Congruent with earlier work [17], we found that street connectivity supported transportation walking. However, cul-de-sacs seem to be barriers to recreational walking on weekdays. An explanation could be that most cul-de-sacs are located in suburbs where there are fewer opportunities for recreational walkers, who seek different scenic environments.

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 [47]. For example, while a negative relationship was found between cul-de-sac and recreational walking at weekends within a 1,000m buffer, no associations were observed at smaller scales (i.e., 300 m and 600 m). This confirms the results reported by [23], namely that for certain neighborhood measures like street connectivity, the associations with physical activity were dependent on the analytical scales. Conversely, for NDVI, a negative association with recreational walking on weekdays was found at small scales (300 m and 600 m buffers), but no associations were noticeable at a larger scale (1,000 m). A possible explanation for this inconsistency is that for various reasons (e.g., time constraints), people do not walk far for recreation on weekdays. Moreover, we also found, confirming previous research [48], 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 among people of different age groups. Compared to younger adults, older adults have more spare time to walk and prefer to walk more. A larger buffer size seems to be more appropriate for investigating the walking behavior of older adults [33].

Regarding meteorological variables, less precipitation was negatively associated with recreational walking duration, which echoes [32] and [49]. We also found that higher temperature was negatively related with recreational walking. This finding contradicts studies that found that people living in a place with higher temperatures spend more time engaging in physical activities [50]. Nevertheless, a similar negative association between temperature and walking was reported by [41]. A possible explanation could be that in countries with a mild climate, like the Netherlands, an increasing temperature might make people less active. Wind speed played no role in explaining recreational walking during weekdays and 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) rather than walking [51].

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 [13, 52], 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 [32], we used more detailed information at the PC6 level, which is likely to have reduced the risk of exposure misclassification. Third, we distinguished between recreational and transportation 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 are susceptible to reverse causality. 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 regarding 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 filter out those trips that went beyond the residential environment (62% of all trips), which resulted in an overestimation of the walking duration. Fifth, NDVI was used to capture the exposure to greenery in walking environments. However, 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 [53] were not available. However, in the Dutch context, most streets are walkable and we think the implications for our model estimates are minor.

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

Ethics approval and consent to participate
Not applicable

Consent for publication
Statistics Netherlands (CBS) provided consent for publication of the results presented in this paper.

Availability of data and material
Supplementary data and material to this article can be found online at https://github.com/vitality-data-center

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Competing interests
The authors declare that they have no competing interests.

Author’s contributions
DE developed the research idea. ZW prepared the data together with MH. ZW carried out the analyses and drafted the manuscript. All authors read, edited, and approved the final manuscript.

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