WHAT MATTERS MOST?

A CROSS-SECTIONAL STUDY ON THE CONTRIBUTION OF THE OBJECTIVE AND PERCEIVED ENVIRONMENT ON ADULTS' PHYSICAL ACTIVITY BEHAVIOR WITHIN THEIR HOME NEIGHBORHOOD

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What matters most? A cross-sectional study on the contribution of the objective and perceived environment on adults' physical activity behavior within their home neighborhood

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Abstract

This study examined associations between objective and perceived environmental characteristics and adult's physical activity (PA) behavior within their home neighborhood. Data was collected in 2016-2017 from 617 Dutch adults living in the South-Limburg region. PA in the home neighborhood was measured using an accelerometer and GPS-logger. The perceived environment was assessed using the NEWS questionnaire, the objective environment using Geographic Information Systems. Multiple linear regression analyses showed that four environmental characteristics (the perceived presence of greenspace and many destinations and the objective presence of pedestrian infrastructure and green strip sidewalk buffers) were associated with MVPA, while none were associated with LPA after controlling for socio-demographic characteristics. The results suggest that both the objective and perceived environment uniquely contribute to adult's PA behavior within the home neighborhood, but only to a small extent. Future studies should combine objective and perceived measures to further disentangle the environment-PA relationship in this specific context.

Keywords: Built environment, objective environment, perceived environment, physical activity, home neighborhood

Introduction

Physical activity (PA) can decrease the risk of cardiovascular diseases, diabetes, and cancer, thereby reducing morbidity and mortality rates (Lear et al., 2017). Increased levels of PA can also enhance physical and mental health, thereby improving overall wellbeing (Sallis et al., 2020; World Health Organization [WHO], 2020). Yet, around a quarter of the worldwide population (WHO, 2020) and nearly half of the Dutch population (Sporten en bewegen in cijfers, 2020) do not meet physical activity recommendations. Moreover, there has not been an improvement in global PA levels since 2001 (WHO, 2020), making physical inactivity one of the major global health challenges (Sallis et al., 2020), also identified as 'the pandemic of physical inactivity' (Kohl et al., 2012).

Traditionally, research into PA behavior focused on individual determinants such as self-efficacy, attitudes, and skills (Bauman et al., 2012; Van Holle et al., 2012). However, over the years the development of theories that include non-personal determinants, such as Bandura's Social Cognitive Theory (Kelder et al., 2015) and socio-ecological models, led to a wider approach for explaining health and PA behavior. Nowadays, it is increasingly recognized that PA is largely influenced by the (built) environment as well (Bauman et al., 2012; Peters et al., 2020; Van Holle et al., 2012). According to socio-ecological models, behavior is influenced by individual, social, and physical environmental characteristics at multiple levels (e.g., interpersonal, community) that interact. It also presumes that the environmental context is a significant determinant of behavior (Bauman et al., 2012; Sallis & Owen, 2015). These multi-level interacting factors indicate that exploration of the environment-behavior relationship calls for collaboration between different fields (Sallis & Owen, 2015) and that counteracting the physical inactivity pandemic requires a systems approach (Kohl et al., 2012). Especially the spatial planning field plays a major role here, as this is the field responsible for designing and shaping the living environment (Jackson, 2003; Tran, 2016).

The Importance of the Environment

A variety of physical and social environmental characteristics that are associated with PA behavior can be derived from public health or spatial planning literature. These can be characterized in terms of their objective (i.e., actual) or subjective (i.e., perceived) qualities (Peters et al., 2020). Objective environmental characteristics include land-use mix (such as the presence of and proximity to recreational facilities, stores, greenspace, and other locations), infrastructure (such as street connectivity, sidewalks, bicycle paths, street lighting, and public transport), traffic safety, and safety from crime (Bauman et al., 2012; Hunter et al., 2015; McCormack & Shiell, 2011; Orstad et al., 2017; Peters et al., 2020; Remme et al., 2021). Next to the actual presence of these environmental characteristics in an area, perceptions about these characteristics (such as the perceived distance to facilities or the perceived safety) are also related to PA behavior (Hoehner et al., 2005; Sallis & Owen, 2015). Other perceived environmental characteristics include aesthetics (such as cleanliness, diversity, and maintenance of the environment), accessibility, affordability, and quality of facilities (Bauman et al., 2012; Hoehner et al., 2005; McCormack & Shiell, 2011; Orstad et al., 2017; Peters et al., 2020).

Yet, evidence regarding the exact role of objective and perceived environmental characteristics in PA behavior is still inconclusive. Different associations between the same environmental characteristics are found across studies (Bauman et al., 2012; McCormack & Shiell, 2011). In addition, the environmental context in which PA behavior takes place (e.g., work, school, neighborhood, or home environment) is found to influence PA behavior, but few studies take this specific context into account when studying the environment-PA behavior relationship (Brownson et al., 2009; Giles-Corti et al., 2005; Sallis & Owen, 2015). Furthermore, only a few studies have assessed the objective and perceived environment simultaneously, while both are considered important in explaining PA behavior (Ma et al., 2014; Orstad et al., 2017). Studies that did assess both types showed mixed evidence. Some studies suggest that perceptions are more important than objective environmental characteristics (Bauman et al., 2012; Ma et al., 2014), some authors show that objective and perceived environmental characteristics are related but distinct constructs (Orstad et al., 2017), and other studies indicate that the objective environment indirectly affects PA behavior by influencing perceptions (Ma et al., 2014).

Research aim

These inconsistencies in evidence regarding the importance and contribution of objective and perceived environmental characteristics on PA behavior may be due to two highly independently operating research fields, that both use their own methods and measurements. Whereas public health research often relies on self-reported surveys to assess perceptions of the environment and PA behavior, spatial planning studies often use objective environmental measures (Hoehner et al., 2005; Orstad et al., 2017).

Based on these current inconsistencies, this study focused on the association between environmental characteristics and PA behavior in one specific context. Specifically, this study aimed to examine the extent to which objective and perceived environmental characteristics contribute to adult's PA behavior within their home neighborhood. This specific environment is chosen because this is where the majority of PA is undertaken (McCormack & Shiell, 2011). This study revolved around the following three questions:

1. What is the relation between objective environmental characteristics and adults' PA behavior within their home neighborhood?
2. What is the relation between perceived environmental characteristics and adults' PA behavior within their home neighborhood?
3. What is the joined effect of objective and perceived environmental characteristics on adults' PA behavior within their home neighborhood?

Method

Study Design and Sample

This cross-sectional study used data that has been collected as part of *the A2 Health Study*[1]. The protocol of that study was submitted to the Medical Ethics Committee (METC) of Maastricht University Medical Center+/University Maastricht, who granted ethical approval (METC 16-4-109) (Stappers et al., 2018; 2020). All participants received written information and provided signed informed consent. The Research Ethics Committee of the Faculty of Health, Medicine and Life Sciences of Maastricht University reviewed and approved the research proposal of the current study (FHML/HEP_2021.936).

Participants of the *A2 Health Study* were adults (>18 years, able to walk without medical devices and able to fill in a Dutch questionnaire) living in the cities of Maastricht and Heerlen (South-Limburg region, The Netherlands). Individuals were recruited randomly via flyers, posters, social media, advertisements in local/regional newspapers, and personalized mailing. Study materials were distributed from the participants' local community centers and were collected from participants' homes after completion of the measurements. The current study used the data that was collected between September 2016 and July 2017 (the baseline measurement of the *A2 Health Study*). This comprises GPS data, objectively measured PA behavior, and a questionnaire on the perceived environment and socio-demographic characteristics. The objective environment was assessed using Geographic Information Systems (GIS).

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[1] Briefly, the *A2 Health Study* aims to evaluate the effect of a major infrastructural change ('Green Carpet' in the city of Maastricht) on the PA behavior and health of individuals living in the near surroundings (Maastricht-East), compared to individuals living further away (Maastricht-West and Heerlen).

Neighborhood Environment Measures

A common issue in research on neighborhood effects is misspecification, i.e., that the boundaries of a neighborhood are defined or described differently by researchers and research participants in the same study (Coulton et al., 2013). To avoid this issue, participants in the *A2 Health Study* were asked to think of their neighborhood as to be within a 10 to 15 minutes walking distance from their home address. In the current study, home neighborhood refers to a 1-kilometer street network buffer around each participant's home address. Based on the average walking speed, this distance corresponds to the neighborhood definition used in the *A2 Health Study* (10-15 min. walk), thereby limiting the risk of misspecification (Giles-Corti et al., 2005; Frank et al., 2017).

In line with the aim of the current study, and based on other studies that assessed the environment-PA behavior relationship (either the objective or perceived environment or both), corresponding objective and perceived environmental characteristics were selected and categorized into land-use, infrastructure, aesthetics, traffic safety, and safety from crime based on literature (Bauman et al., 2012; Hoehner et al., 2005; McCormack & Shiell, 2011; Orstad et al., 2017; Peters et al., 2020; Sallis & Owen, 2015). A similar approach has been used in comparable studies (Gebel et al., 2009; Wu et al., 2016). This provides a way to examine whether the objective or perceived measure of a particular environmental characteristic has a stronger association with PA. Table 1 provides an overview of the corresponding objective and perceived environmental characteristics as used in this study, including their definitions, and the sources upon which this was based.

Perceived Environment

The perceived environment reflects individuals' perceptions about their environment, which was assessed using a questionnaire based on the abbreviated version of the Neighborhood Environment Walkability Scale (NEWS-A). This is a validated and reliable tool to assess perceptions of the environment that are believed to influence PA, and it has been validated against matched objective GIS measures (Adams et al., 2009). The questionnaire assessed a variety of items using a 4-point Likert scale (ranging from disagree [1.0] to agree [4.0]). All items were coded in a way that a higher score denotes a higher perceived activity-friendly environment (Scoring for the Neighborhood Environment Walkability Scale, 2007). This study used items from the categories land-use mix – access, infrastructure and safety for walking, aesthetics, traffic hazards, and crime. Items that were not objectively measurable were excluded (this included, amongst others, items that assessed perceptions about maintenance or attractiveness of environmental characteristics; see table 1).

Objective Environment

The objective environment reflects the objects that are present in the environment, such as the number of stores or the amount of green. A spatial analysis using ArcGIS software (Desktop version 10.5.1. and Pro version 2.8.) was performed to calculate the objective environmental variables. This is a commonly used and feasible method to assess the objective environment (Brownson et al., 2009; McCormack & Shiell, 2011; Orstad et al., 2017). The validity and reliability of GIS-based measures depend on the accuracy and completeness of data sources (Brownson et al., 2009). Commonly used measures of objective environmental characteristics are intensity measures, such as the number, percentage, or density of a certain characteristic (Brownson et al., 2009; Campoli, 2012; Forsyth et al., 2012). Therefore, either one of these measures was calculated for every selected environmental characteristic for each home neighborhood. By calculating every characteristic relative to the size of the area (‘x’ per m^2, km^2) or the length of the road (‘x’ per km) of each home neighborhood, this also allowed for comparison between home neighborhoods. These calculations were largely based upon GIS protocols specifically designed for PA research, namely the International Physical Activity and Environment Network (IPEN) template by Adams et al. (2012) and the Neighborhood Environment for Active Transport (NEAT) template by Forsyth et al. (2012).

This study used publicly accessible data. To reflect the situation as it was during the baseline measurement (t0, 2016-2017), only datasets up to the year 2017 were used. When this was not possible, all features in a dataset that were added after July 1, 2017 (end of data collection t0) were deleted from the dataset. The variables sidewalks, bicycle & pedestrian trails, sidewalk buffers (parking spots and green strips), pedestrian infrastructure, and greenspace were derived from the BGT[2], which contains nearly all aspects of the physical environment with an accuracy of 20 meters. The variable access to stores was derived from the BAG[3], which contains all buildings and their function. Land-use mix and greenspace were derived from the BBG2015[4]. Infrastructure-related variables (e.g., roads, sidewalks) were derived from the TOP10NL 2017. Data on traffic safety was derived from BRON2016[5]. All these data sources are managed by the Dutch Government or governmental organizations. Public transportation access and pedestrian infrastructure was based on the Open Street Map. Safety from crime was based on annual crime records per neighborhood provided by the Dutch police. During the spatial analysis, the variables streetlights and trees were excluded because neither the BGT nor the TOP10NL contained complete data (e.g., only a few streets with streetlights and very few trees compared with the aerial photo). Additional file I provides the data sources used and a summary of the steps taken in ArcGIS to calculate each objective environmental variable.

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[2] Basisregistratie Grootschalige Topografie – Dutch Government

[3] Basisregistratie Adressen en Gebouwen – Dutch Government

[4] Bestand Bodemgebruik – Statistics Netherlands

[5] Bestand geRegistreerde Ongevallen in Nederland – Rijkswaterstaat (Ministry of Infrastructure and Water Management)

Table 1

Overview of the corresponding objective and perceived measures of selected environmental characteristics.

Theme & environmental characteristic	Perceived environment – Item questionnaire	Objective environment – GIS item[a]	Relationship with PA	Based upon[b]
Land-use				
Access to stores	Stores are within easy walking distance of my home.	Store density[c] = average number of stores per square kilometer *Includes buildings characterized as a store and buildings with a mixed function where 'store' is one of them.*	Stores within the neighborhood increase the available destinations, which may contribute to PA (see also land-use mix).	Adams et al. (2012); Campoli (2012); Hoehner et al. (2005)
Land-use mix	There are many places to go within easy walking distance of my home.	Entropy score = measure of variation or diversity of land-uses across an area. A value of 0 indicates homogeneity, a value of 1 indicates heterogeneity *Includes the land-uses residences, retail & restaurant, civic & institutional, recreation, sports terrain, and greenspace.*	A mixture of land-uses creates many destinations and improves attractiveness (visual variety), interests, and greater safety (informal policing), which all may contribute to PA.	Adams et al. (2012); Brownson et al. (2009); Campoli (2012); Christian et al. (2011); Forsyth et al. (2008; 2012); Gebel et al. (2009); Jansen et al. (2018); Sallis et al. (2020); Smith et al. (2017); Song et al. (2013)
Public transportation access	It is easy to walk to a transit stop (bus, train) from my home.	Public transportation density = average number of public transportation stops per square kilometer *Includes bus stops and train stations.*	Public transportation density may increase PA.	Adams et al. (2012); Campoli (2012); Forsyth et al. (2012); Smith et al. (2017); Stewart et al. (2016)
Infrastructure				

Theme & environmental characteristic	Perceived environment – Item questionnaire	Objective environment – GIS item[a]	Relationship with PA	Based upon[b]
Sidewalks	There are sidewalks on most of the streets in my neighborhood.	Density of sidewalks = average length of sidewalks per kilometer of road *Sidewalks are defined as any footpath that runs along a road or street.*	Sidewalks support walking and thus may contribute to PA.	Forsyth et al. (2008; 2012); Sallis et al. (2015); Smith et al. (2017); Wu et al. (2016)
	The sidewalks in my neighborhood are well maintained (paved, even, and not a lot of cracks).	*n/a*		
Bicycle & pedestrian trails	There are bicycle or pedestrian trails in or near my neighborhood that are easy to get to.	Density of bicycle & pedestrian trails = average length of bicycle & pedestrian trails per kilometer of road *Pedestrian trails are all footpaths excluding sidewalks.*	Bicycle trails support cycling and thus may contribute to PA.	Forsyth et al. (2012); Smith et al. (2017)
Sidewalk buffer – parked cars	Sidewalks are separated from the road/traffic in my neighborhood by parked cars.	Parking spot density = average length of parking spots that act as a sidewalk buffer per kilometer of road *Parking spots act as sidewalk buffer when they are located between a sidewalk and a road or street.*	On-street parking provides a sidewalk buffer and may slow down traffic, which improves safety, which is important for PA (see also pedestrian infrastructure).	Forsyth et al. (2012); Sallis et al. (2015); Safe Routes to School Guide (SRTS, n.d.)
Sidewalk buffer – green strip	There is a grass/dirt strip that separates the streets from the sidewalks in my neighborhood.	Green strip density = the average length of green strips that act as sidewalk buffer per kilometer of road	A green strip can function as a sidewalk buffer, which improves attractiveness and safety, which is important for PA	Sallis et al. (2015); SRTS Guide (n.d.)

Theme & environmental characteristic	Perceived environment – Item questionnaire	Objective environment – GIS item[a]	Relationship with PA	Based upon[b]
		Green strips act as sidewalk buffer when they are located between a sidewalk and a road or street.	(see also pedestrian infrastructure).	
Streetlights	*My neighborhood is well lit at night.*	*Density of street lights = average number of street lights per kilometer of road*	*Street lighting improves both safety from accidents and safety from crime, which is important for PA (see also pedestrian infrastructure).*	*Adams et al. (2009); Forsyth et al. (2008; 2012); Sallis et al. (2015); Wu et al. (2016)*
	Walkers and bikers on the streets in my neighborhood can be easily seen by people in their homes.	*n/a*		
Pedestrian infrastructure	There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood.	Density of pedestrian infrastructure (other than sidewalks) = average number of pedestrian infrastructure per kilometer of road *Includes areas characterized as pedestrian zone and 'woonerf' and crossings, speedbumps, roundabouts, traffic signs, and traffic signals.*	Design features, such as crossings and traffic calming features, influence safety. Safety from accidents is an important issue for walking, cycling, and other forms of PA (i.e., greater safety may contribute to PA).	Forsyth et al. (2008; 2012); Smith et al. (2017); Wu et al. (2016)
Aesthetics				
Trees	*There are trees along the streets in my neighborhood.*	*Tree density = average number of trees per kilometer of road*	*Trees improve users' comfort (e.g., shading, wind protection) and attractiveness of the street, which positively affects PA.*	*Adams et al. (2009); Forsyth et al. (2012)*

Theme & environmental characteristic	Perceived environment – Item questionnaire	Objective environment – GIS item[a]	Relationship with PA	Based upon[b]
	Trees give shade for the sidewalks in my neighborhood.	*n/a*		
	There are many interesting things to look at while walking in my neighborhood.	*n/a*		
	My neighborhood is generally free from litter.	*n/a*		
	There are many attractive natural sights in my neighborhood (such as landscaping, views).	*n/a*		
	There are attractive buildings/homes in my neighborhood.	*n/a*		
Greenspace	There are parks or green areas in my neighborhood where I can easily walk or bike to.	Greenspace (% area) = percentage of the total home neighborhood area that consists of greenspace *Includes public parks, urban greening (Dutch: 'gemeentelijk groen'), road verges, allotments, forests, meadows, farmland, fruit cultivation, and arboriculture.*	Greenspace may improve PA.	Adams et al. (2012); Hunter et al. (2015); Remme et al. (2021); Taylor & Hochuli (2017); Wu et al. (2016)
Traffic safety				
	These three questions were combined into one score for traffic safety[d] ▪ There is so much traffic along nearby streets that it makes it difficult or	No. of road accidents = average number of road accidents annually per kilometer of road	Safety from traffic is an important issue for PA (i.e., greater safety [fewer accidents] may contribute to PA).	Wu et al. (2016)

Theme & environmental characteristic	Perceived environment – Item questionnaire	Objective environment – GIS item[a]	Relationship with PA	Based upon[b]
	unpleasant to walk in my neighborhood. · The speed of traffic on most nearby streets is usually slow (max. 50 km per hour). · Most drivers exceed the posted speed limits while driving in my neighborhood.			
Safety from crime				
	These three questions were combined into one score for safety from crime[d] · There is a high crime rate in my neighborhood. · The crime rate in my neighborhood makes it unsafe to go on walks during the day. · The crime rate in my neighborhood makes it unsafe to go on walks at night.	No. of crime records = number of crimes annually relative to the size of the area (in m^2) of the home neighborhood *Includes all registered crimes that are punishable by the Criminal Law of the Netherlands and other special laws such as the Opium Act, Weapons and Ammunition Act, and Road Traffic Act.*	Safety from crime is an important issue for PA (i.e., greater safety [low crime rate] may contribute to PA).	Wu et al. (2016)

Note. N/a = not applicable. All objective measures were calculated within each participant's home neighborhood buffer. Grey italic items were included in the questionnaire but were not objectively measurable (Adams et al., 2009). Therefore, they were excluded from the analysis. Regarding the coding of the variables: for all variables, a higher score denotes a higher conduciveness to PA.

[a] See additional file I for an overview of the calculations that were performed in ArcGIS for the assessment of the objective environment.

[b] This column contains the sources upon which the definition of the objective environmental GIS items (third column) and/or the relationship of the environmental characteristics with PA behavior (fourth column) was based.

[c] Density refers to the quantity of a feature per unit of area to allow for comparison between objects of a different size (i.e., the home neighborhoods) and indicates the intensity of a feature (Campoli, 2012; Forsyth et al., 2012; Tran, 2016).

[d] Scoring corresponds to the scoring procedures for these two subscales (‘traffic hazards’ and ‘crime’) of the NEWS-A (Scoring for the Neighborhood Environment Walkability Scale, 2007).

Physical Activity Behavior in the Home Neighborhood

PA was measured objectively, rather than subjectively (i.e., self-report) to avoid common measurement errors such as overestimation of own behavior (Ainsworth et al., 2015; Dyrstad et al., 2014) and mistakenly recalling own behavior (Adams et al., 2009). Participants wore an accelerometer (Actigraph GT3X+) and GPS-logger (Qstarz BT-Q1000XT) to assess context-specific PA, which is in this study defined as PA behavior within the home neighborhood. The participants were instructed to wear both devices for seven consecutive days at their right hip, during daytime only. This device and wearing instructions are considered a valid and reliable tool for measuring PA in adults (Aadland & Ylvisåker, 2015).

After the data collection was finished, a distinction was made between sedentary behavior (0-99 counts per minute [cpm]), light PA (LPA; 100-1951 cpm), and moderate-to-vigorous PA (MVPA; >1951 cpm) based on the Freedson cut-off points (Freedson et al., 1998; see Stappers et al., 2020, for a detailed description). Because LPA and MVPA are both associated with health benefits, but encompass different activities that may be influenced by the environment differently (Füzéki et al., 2017; WHO, 2020), this study used both LPA and MVPA. The two main outcomes are defined as the average time spent on LPA or MVPA in minutes per day spent in the home neighborhood, as commonly used elsewhere (Ainsworth et al., 2015; Dowd et al., 2018).

Based on the combined accelerometer and GPS data, home neighborhoods of 1 kilometer (street network buffer) around the home address were created for each participant (see Stappers et al., 2020, for a detailed description). The advantage of a street network buffer over a circular buffer is that it better represents the area accessible to an individual (Frank et al., 2017). Both the type and the size of these buffers are commonly used in studies on PA and the neighborhood (Frank et al., 2017; Sallis et al., 2020; Troped et al., 2010) and considered an appropriate measure to assess LPA and MVPA within the home neighborhood environment (Giles-Corti et al., 2005; Sallis et al., 2020).

Socio-demographic Characteristics

Participants also reported socio-demographic characteristics in the questionnaire. This included age, gender (0 = male, 1 = female), and educational level. Educational level was based on the Dutch educational system and included the categories primary education, secondary education VMBO, secondary education HAVO/VWO, secondary vocational education (MBO), higher professional education (HBO), and university education (WO), which was recoded into 0 = lower educated and 1 = higher educated (for HBO and higher).

Statistical Analysis

The statistical analysis was performed using IBM SPSS software (version 26.0). Descriptive statistics were used to describe mean values and standard deviations of participants' socio-demographic characteristics, LPA and MVPA levels, and scores on the objective and perceived environmental variables.

Multiple linear regression analyses were used to assess the association between objective and perceived environmental characteristics and PA outcomes. Because of the aforementioned inconsistencies in research regarding the importance of environmental characteristics for PA behavior, the variables were added to the model according to the enter method (Field, 2013) after they were checked for multi-collinearity (for which no issues were found). Since the socio-demographic characteristics age, gender, and educational level are found to influence both PA behavior and perceptions of the environment (Ma et al., 2014; Hoehner et al., 2005; Peters et al., 2020), these three variables were treated as covariates and were controlled for in the statistical analysis. For sub-question 1, the first block in the regression model contained the covariates and the second block contained the objective environmental variables. For sub-question 2, the second block contained the perceived environmental variables. For sub-question 3, all objective and perceived environmental variables were entered together in block 2. For each sub-question, the analysis was run twice: once with LPA within the home neighborhood as the dependent variable and once with MVPA within the home neighborhood as the dependent variable. *P*-values of less than 0.05 were regarded as statistically significant.

Results

Participant Characteristics

In this study, 736 participants were included. Out of this sample, 51 participants had invalid home neighborhoods, 45 participants were missing data on PA behavior, 18 participants were missing socio-demographic data and 5 participants were missing data on the perceived environment. These participants were therefore excluded from the analysis, leaving valid data for 617 participants in the final sample. Table 2 shows the characteristics of the participants, their PA levels, and the mean scores on the objective and perceived environmental variables. The average age of participants was 56.2 (*SD* = 16.05) years old. A majority of participants were female (53%), higher educated (53%), and employed (55%). The mean Body Mass Index was 25.03 (*SD* = 4.29) kg/m^2.

Participants wore the accelerometers on average 5.83 (*SD* = 1.30) days, with an average wear time of around 14 (*SD* = 1.45) hours a day of which over half of this wear time was spent in the home neighborhood. Table 2 shows the average time (in minutes) a day spent on LPA and MVPA both in total and within the home neighborhood. On average, nearly 60% of total LPA and 41% of total MVPA was spent in the home neighborhood. Based on the average minutes in MVPA a day, 69% of the participants met the Dutch physical activity guidelines of 150 minutes of MVPA a week (Sporten en bewegen in cijfers, 2020).

Objective Environment and Neighborhood-Based PA

Table 3 shows the associations between the objective environmental variables and LPA and MVPA within the home neighborhood. Older participants and women showed more LPA within the home neighborhood compared to men and younger participants. The socio-demographic characteristics were not associated with MVPA within the home neighborhood. After controlling for the covariates (i.e., age, gender, educational level), no objective environmental variables were associated with LPA within the home neighborhood. A sidewalk buffer of green strips and density of pedestrian infrastructure were respectively negatively and positively associated with MVPA within the home neighborhood.

Perceived Environment and Neighborhood-Based PA

Table 4 shows the associations between the perceived environmental variables and LPA and MVPA within the home neighborhood. After controlling for the covariates, no perceived environmental variables were associated with LPA within the home neighborhood. Many places to go within the neighborhood (land-use mix) and the presence of parks and greenspace (greenspace) were positively associated with MVPA within the home neighborhood.

Joined Effect of the Objective and Perceived Environment on Neighborhood-Based PA

Table 5 shows the associations between the objective and perceived environmental variables and LPA and MVPA within the home neighborhood when they were all entered into the same model. Older participants and women showed more LPA within the home neighborhood compared to men and younger participants. Socio-demographic characteristics were not associated with MVPA within the home neighborhood. After controlling for the covariates, none of the objective and perceived environmental variables was associated with LPA within the home neighborhood. The density of pedestrian infrastructure (objective environment), many places to go within the neighborhood, and the presence of parks and greenspace (both perceived environment) were positively associated with MVPA within the home neighborhood. A sidewalk buffer of green strips (objective environment) was negatively associated with MVPA within the home neighborhood.

Table 2

Means and standard deviations of socio-demographic characteristics, physical activity levels, and the objective and perceived environmental variables of the study sample.

	% / Mean (SD)
Socio-demographic characteristics (*n* = 617)	
Gender (% females)	53.00%
Age (years)	56.19 (16.05)
Educational level (% higher educated)	52.84%
Work status (% employed)	54.94%
Body Mass Index (kg/m^2)	25.03 (4.29)
Physical activity levels (*n* = 617)	
Wearing days	5.83 (1.30)
Average wear time (minutes per day)	840.02 (86.70)
Average time in LPA (minutes per day)	265.44 (75.64)
Average time in MVPA (minutes per day)	36.20 (24.93)
Average wear time that was spent in the home neighborhood (minutes per day)	481.69 (180.02)
Average time in LPA that was spent in the home neighborhood (minutes per day)	158.42 (71.44)
Average time in MVPA that was spent in the home neighborhood (minutes per day)	14.07 (13.26)
Percentage of total LPA that was spent in the home neighborhood	59.82%
Percentage of total MVPA that was spent in the home neighborhood	41.35%
Percentage that met the physical activity guideline (based on the average time in MVPA per day)	68.88%
Home neighborhood in km^2 (*n* = 617)	1.52 (0.32)
Objective environmental variables (*n* = 617)	
Land-use	
Access to stores *(Store density)*	45.43 (51.96)

	% / Mean (SD)
Land-use mix *(Entropy score)*	0.41 (0.15)
Public transportation access *(Public transportation density)*	10.65 (3.12)
Infrastructure	
Sidewalks *(Sidewalk density)*	1.17 (0.27)
Bicycle & pedestrian trails *(Bicycle & pedestrian trail density)*	0.27 (0.12)
Sidewalk buffer – parked cars *(Parking spot density)*	0.24 (0.08)
Sidewalk buffer – green strip *(Green strip density)*	0.26 (0.12)
Pedestrian infrastructure *(Pedestrian infrastructure density)*	4.42 (1.74)
Aesthetics	
Greenspace *(% Greenspace)*	23.34%
Traffic safety	
Traffic safety subscale *(No. of road accidents per km of road)*	0.87 (0.49)
Safety from crime	
Safety from crime subscale *(No. of crime records relative to the size of the area in m^2)*	424.45 (349.40)
Perceived environmental variables (n = 617)	
Land-use	
Access to stores *(Stores are within easy walking distance of my home)*	3.5 (0.6)
Land-use mix *(There are many places to go within easy walking distance of my home)*	3.3 (0.7)
Public transportation access *(It is easy to walk to a transit stop (bus, train) from my home)*	3.4 (0.7)
Infrastructure	
Sidewalks *(There are sidewalks on most of the streets in my neighborhood)*	3.4 (0.6)
Bicycle & pedestrian trails *(There are bicycle or pedestrian trails in or near my neighborhood that are easy to get to)*	3.3 (0.5)
Sidewalk buffer – parked cars *(Sidewalks are separated from the road/traffic in my neighborhood by parked cars)*	2.9 (0.6)
Sidewalk buffer – green strip *(There is a grass/dirt strip that separates the streets from the sidewalks in my neighborhood)*	2.0 (0.7)

	% / Mean (SD)
Pedestrian infrastructure *(There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood)*	2.6 (0.8)
Aesthetics	
Greenspace *(There are parks or green areas in my neighborhood where I can easily walk or bike to)*	3.2 (0.7)
Traffic safety	
Traffic safety subscale	2.8 (0.5)
Safety from crime	
Safety from crime subscale	3.1 (0.6)

Note. LPA = light physical activity; MVPA = moderate-to-vigorous physical activity.

Table 3

Associations between objective environmental variables and LPA and MVPA within the home neighborhood.

Variable	LPA		MVPA	
	Model 1	Model 2	Model 1	Model 2
	β	β	β	β
Socio-demographics (*n* = 617)				
Age	.339***	.336***	.027	.049
Gender *(REF = male)*	.212***	.207***	-.034	-.026
Educational level *(REF = low educated)*	.001	-.007	-.041	-.036
Explained variance (R^2)	***.134****		***.004***	
Objective environmental variables (*n* = 617)				
Land-use				
Access to stores *(Store density)*		.003		-.068
Land-use mix *(Entropy score)*		-.034		-.001
Public transportation access *(Public transportation density)*		.027		-.076
Infrastructure				
Sidewalks *(Sidewalk density)*		.017		-.058
Bicycle & pedestrian trails *(Bicycle & pedestrian trail density)*		.033		-.074
Sidewalk buffer – parked cars *(Parking spot density)*		.025		.038
Sidewalk buffer – green strip *(Green strip density)*		-.018		-.125*
Pedestrian infrastructure *(Pedestrian infrastructure density)*		.026		.172*
Aesthetics				
Greenspace *(% Greenspace)*		-.030		.038
Traffic safety				

Variable	LPA		MVPA	
	Model 1	**Model 2**	**Model 1**	**Model 2**
	β	**β**	**β**	**β**
Traffic safety subscale *(No. of road accidents per km of road)*		.035		-.040
Safety from crime				
Safety from crime subscale *(No. of crime records relative to the size of the area in m^2)*		-.137		.108
Explained variance (R^2)		***.145***		***.062****

Note. LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; REF = reference category.
$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 4

Associations between perceived environmental variables and LPA and MVPA within the home neighborhood.

Variable	LPA		MVPA	
	Model 1	Model 2	Model 1	Model 2
	β	β	β	β
Socio-demographics (*n* = 617)				
Age	.339***	.330***	.027	.001
Gender *(REF = male)*	.212***	.207***	-.034	-.037
Educational level *(REF = low educated)*	.001	.011	-.041	-.027
Explained variance (R^2)	***.134****		***.004***	
Perceived environmental variables (*n* = 617)				
Land-use				
Access to stores *(Stores are within easy walking distance of my home)*		.037		.041
Land-use mix *(There are many places to go within easy walking distance of my home)*		.068		.147**
Public transportation access *(It is easy to walk to a transit stop (bus, train) from my home)*		-.068		-.061
Infrastructure				
Sidewalks *(There are sidewalks on most of the streets in my neighborhood)*		-.050		-.016
Bicycle & pedestrian trails *(There are bicycle or pedestrian trails in or near my neighborhood that are easy to get to)*		.044		.014
Sidewalk buffer – parked cars *(Sidewalks are separated from the road/traffic in my neighborhood by parked cars)*		.047		-.009
Sidewalk buffer – green strip *(There is a grass/dirt strip that separates the streets from the sidewalks in my neighborhood)*		-.037		-.027
Pedestrian infrastructure *(There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood)*		-.016		.005

Variable	LPA		MVPA	
	Model 1	**Model 2**	**Model 1**	**Model 2**
	β	**β**	**β**	**β**
Aesthetics				
Greenspace *(There are parks or green areas in my neighborhood where I can easily walk or bike to)*		.014		.088*
Traffic safety				
Traffic safety subscale		-.056		-.056
Safety from crime				
Safety from crime subscale		.017		-.004
Explained variance (R^2)		***.150***		***.040****

Note. LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; REF = reference category.
*$p < .05$, **$p < .01$, ***$p < .001$.

Table 5

Associations between both objective and perceived environmental variables and LPA and MVPA within the home neighborhood.

Variable	LPA		MVPA	
	Model 1	Model 2	Model 1	Model 2
	β	β	β	β
Socio-demographics (*n* = 617)				
Age	.339***	.323***	.027	.023
Gender *(REF = male)*	.212***	.200***	-.034	-.029
Educational level *(REF = low educated)*	.001	.003	-.041	-.039
Explained variance (R^2)	***.134****		***.004***	
Objective environmental variables (*n* = 617)				
Land-use				
Access to stores *(Store density)*		.004		-.099
Land-use mix *(Entropy score)*		-.043		-.005
Public transportation access *(Public transportation density)*		.040		-.074
Infrastructure				
Sidewalks *(Sidewalk density)*		.012		-.061
Bicycle & pedestrian trails *(Bicycle & pedestrian trail density)*		.048		-.065
Sidewalk buffer – parked cars *(Parking spot density)*		.028		.031
Sidewalk buffer – green strip *(Green strip density)*		-.021		-.122*
Pedestrian infrastructure *(Pedestrian infrastructure density)*		.019		.174*
Aesthetics				
Greenspace *(% Greenspace)*		-.017		.010
Traffic safety				

Variable	LPA		MVPA	
	Model 1	Model 2	Model 1	Model 2
	β	β	β	β
Traffic safety subscale *(No. of road accidents per km of road)*		.040		-.028
Safety from crime				
Safety from crime subscale *(No. of crime records relative to the size of the area in m^2)*		-.153		.105
Perceived environmental variables (*n* = 617)				
Land-use				
Access to stores *(Stores are within easy walking distance of my home)*		.037		.044
Land-use mix *(There are many places to go within easy walking distance of my home)*		.078		.100*
Public transportation access *(It is easy to walk to a transit stop (bus, train) from my home)*		-.063		-.068
Infrastructure				
Sidewalks *(There are sidewalks on most of the streets in my neighborhood)*		-.058		-.038
Bicycle & pedestrian trails *(There are bicycle or pedestrian trails in or near my neighborhood that are easy to get to)*		.053		.034
Sidewalk buffer – parked cars *(Sidewalks are separated from the road/traffic in my neighborhood by parked cars)*		.047		-.022
Sidewalk buffer – green strip *(There is a grass/dirt strip that separates the streets from the sidewalks in my neighborhood)*		-.041		.005
Pedestrian infrastructure *(There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood)*		-.023		-.007
Aesthetics				
Greenspace *(There are parks or green areas in my neighborhood where I can easily walk or bike to)*		.027		.090*
Traffic safety				
Traffic safety subscale		-.059		-.031

Variable	LPA		MVPA	
	Model 1	Model 2	Model 1	Model 2
	β	β	β	β
Safety from crime				
Safety from crime subscale		.013		.031
Explained variance (R^2)		***.164***		***.087******

Note. LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; REF = reference category.
**p* < .05, ***p* < .01, ****p* < .001.

Discussion

This study aimed to determine the extent to which objective and perceived environmental characteristics contribute to adult's PA behavior within their home neighborhood. No associations were found between either objective or perceived environmental characteristics and LPA within the home neighborhood. The perceived presence of parks and greenspace and many places to go and the actual (i.e., objective) presence of pedestrian infrastructure and sidewalk buffers of green strips were associated with MVPA within the home neighborhood.

Socio-demographic characteristics (i.e., age and gender) were associated with LPA, but not with MVPA within the home neighborhood. This may be explained by the relatively old study sample, with a considerable number of retired participants, and a majority of female participants. Accumulating evidence shows that older adults spend much of their time on sedentary behavior or LPA and that women tend to engage in more LPA than MVPA compared to men (Amagasa et al., 2017; Hall & McAuley, 2010). In addition, LPA within the home neighborhood was not associated with objective or perceived environmental characteristics. Few studies have assessed LPA (Chastin et al., 2019) and specifically the relationship between the environment and LPA, despite the increasingly emphasized importance of LPA for health outcomes (Füzéki et al., 2017; Howard et al., 2015). Jansen et al. (2018) are among the very few studies that did assess this relation and that found associations between several objectively measured environmental characteristics (proportions of roads, recreational areas, and greenspace) and LPA. Despite the limited evidence, the lack of an association between LPA and environmental characteristics in the current study might be explained by the fact that LPA often consists of everyday activities, such as household chores (e.g., cooking, ironing) and maintenance tasks (e.g., gardening) at one's house (Chastin et al., 2019; Howard et al., 2015; Jansen et al., 2018). This implies that these activities are more likely to occur without the influence of the environment, in contrast to MVPA which may require more motivation, planning, and (environmental) facilities (Jansen et al., 2018).

Out of the eleven included objective environmental characteristics, only two (theme infrastructure) were associated with MVPA within the home neighborhood. In line with other studies (Barnett et al., 2017; Forsyth et al., 2008 & 2012; Smith et al., 2017; Wu et al., 2016), this study found that a higher density of pedestrian infrastructure (including traffic calming features, e.g., crossings and speedbumps; see table 1) is associated with more MVPA within the home neighborhood. However, the density of green strips that separates the sidewalks from the street (sidewalk buffer) was negatively associated with MVPA within the home neighborhood, despite the often-considered importance of sidewalk buffers for active transportation (which is a form of MVPA) because they can increase safety and pedestrian comfort (Forsyth et al., 2012; Sallis et al., 2015). An explanation for this may be that this consideration is mostly based on evidence from U.S.-based studies (McCormack & Shiell, 2011; Sallis et al., 2015; SRTS Guide, n.d.). However, this country has a very different urban design and other environmental characteristics than The Netherlands (Jansen et al., 2018), hence this U.S.-based evidence might not be generalizable to the Dutch context.

Regarding the perceived environment, only two out of eleven characteristics were associated with MVPA within the home neighborhood as well. Both a higher perceived presence of parks and green areas (theme aesthetics) and many different destinations (theme land-use) within one's home neighborhood were associated with more MVPA within the home neighborhood. These findings were also reported by Barnett et al. (2017) and Wu et al. (2016), although comparability with these studies is limited because both focused specifically on older adults and used different outcome measures (i.e., total PA and outdoor recreational activity, respectively).

When all objective and perceived environmental characteristics were entered together into the same regression model, no additional environmental characteristics were associated with LPA or MVPA within the home neighborhood. This final model shows various notable findings. First, it accounted for slightly more variance (8.7%) in MVPA within the home neighborhood than the models with only the objective environmental characteristics (6.2%) and only the perceived environmental characteristics (4.0%) did. In other words, there was a very small joined effect of all environmental characteristics together. Second, when looking at the respective contributions of the objective and perceived environmental characteristics, they all predicted MVPA within the home neighborhood at similar rates (β around 0.1). This implies that both the objective and perceived environment should be considered when designing interventions to improve MVPA within the home neighborhood. However, the low explained variance also indicates that the built environment only contributes to a small extent to PA behavior within the home neighborhood of the study sample and that there should be other factors that are not included in this study that play a role as well, such as the social environment (McNeill et al., 2006; Kepper et al., 2019) or attitudes towards PA (Bauman et al., 2012; Ma & Dill, 2015). Third, the four significant environmental characteristics represent three different themes (aesthetics, land-use, and infrastructure). Furthermore, the two significant objective environmental characteristics (both theme infrastructure) do not correspond to the two significant perceived environmental characteristics (themes aesthetics and land-use), which corroborates the findings by Ma & Dill (2015) who also found different perceived and objective measures associated with PA behavior (specifically bicycling propensity). All of these findings together suggest that objective and perceived measures of environmental characteristics might capture distinct constructs and that they may have their unique influences on MVPA behavior, a finding previously reported elsewhere. A systematic review by Orstad et al. (2017), for example, showed low agreement between perceived and objective environmental characteristics and concluded that objective and perceived measures of environmental characteristics account for unique variance in PA behaviors. This may explain the aforementioned findings of the final model.

The final major finding of this study is that most objective and perceived environmental characteristics were not associated with LPA or MVPA within the home neighborhood after controlling for socio-demographic characteristics, even though these characteristics have been associated with PA before in a variety of studies (e.g., McCormack & Shiell, 2011; see table 1; i.e., this is also the reason why these characteristics were included in the current study). One reason for this may be that these studies used other research methods, measures, and measurements (Adams et al., 2014; McCormack & Shiell, 2011; Peters et al., 2020). However, Troped and colleagues (2010) and Jansen and colleagues (2017) for example, who both conducted a methodologically similar study as the current one (accelerometer, GPS, neighborhood buffers around participants' home addresses, objective environment assessed using GIS), both showed an association between land-use mix and MVPA and various land-use types and MVPA, respectively. Other possible explanations for these results may be that LPA often consists of everyday activities (Jansen et al., 2018), that the current study does not consider the specific PA domain (such as active transport or recreational PA) (Peters et al., 2020; Van Holle et al., 2012), or that much of the current evidence is derived from non-(Western-) European countries (Adams et al., 2014; Van Holle et al., 2012).

Strengths and Limitations

This study has several strengths and weaknesses. First, a major limitation of this study is its cross-sectional design, because this does not allow to detect causal relationships. Second, the relatively old age of the study sample may have influenced the outcomes of this study. With a substantial proportion of retired people, the time spent in the home neighborhood is possibly higher compared to the total population. This implies that the results might be better generalizable to an older population than to a general adult population. Third, this study used publicly accessible data using ArcGIS to assess the objective environment. This has important implications for the study outcomes. These data sources may not always reflect the actual environment one-to-one, thereby influencing the validity of these measures Also, it might be that changes in the environment are not directly processed into the GIS database, or that different definitions are applied and different data sources are used for similar variables across studies, which influences the reliability of GIS-based measures (Brownson et al., 2009). However, by using national datasets managed by governmental organizations and by carefully selecting variables, examining datasets, and deleting variables with incomplete data (i.e., trees, streetlights), validity is warranted as best as possible. The current study also tried to contribute to the replicability of this study by basing the calculation of objective environmental measures on protocols (Adams et al., 2012; Forsyth et al.,2012), and by providing an extensive overview of used data and the steps taken in ArcGIS to calculate each objective variable (additional file I). This can be considered a strength of this study, as it provides a guide for future research. Other strengths of this study are that PA was measured objectively, thereby limiting the risk of biases commonly found by self-reported measures (Adams et al., 2009; Ainsworth et al., 2015; Dyrstad et al., 2014). In addition, this is one of the first studies that combines the measures that are often used in either the public health (i.e., self-reported perceptions of the environment) or spatial planning fields (i.e., GIS-based measures). Furthermore, this study adds to the limited number of studies that simultaneously assess both objective and perceived environmental characteristics, and that focuses on context-specific PA behavior (i.e., the home neighborhood). Lastly, as the focus of this study was on both LPA and MVPA, it also contributes to the little evidence on the environment-LPA behavior relationship (Chastin et al., 2019).

Directions for Future Research

First, future studies on the environment-PA behavior relationship should include both perceived and objectively measured environmental characteristics, objectively measured PA behavior, and should work on a more consistent conceptualization of these measures. This study corroborated earlier findings that objective and perceived environmental measures may have their unique influence on PA. Moreover, the current inconsistencies in the evidence-base on the environment-PA behavior relationship are due to the wide variety of definitions, measures, and measurements used across studies (Adams et al., 2014). Further investigation of this relationship, therefore, calls for more uniformity and comparability between studies to achieve a more complete picture of the role of the environment in PA behavior.

Second, the relation between the environment and LPA should be more extensively studied. LPA makes a large share of total PA, has important health benefits, and might especially yield benefits for inactive individuals (Chastin et al., 2018; Füzéki et al., 2017). Yet, studies that examine the relationship between the environment and PA behavior often only focus on MVPA. It is, therefore, suggested to conduct additional cross-sectional research that focuses specifically on the relationship between the environment and LPA behavior. Preferably this research will also take into account possible subgroup differences because the shown associations between socio-demographic characteristics and LPA in the current study indicate that differences may exist between age (groups) and gender.

Third, because of the cross-sectional design of the current study, future research should also apply longitudinal designs to investigate causal relationships between objective and perceived environmental characteristics and MVPA within the home neighborhood.

Fourth, because the results of this study show that the built environment only partly explains adult's PA behavior within their home neighborhood, more research is needed that includes other factors that possibly play a role in PA behavior in this specific context. This could include individual factors (e.g., attitudes), social (environmental) factors (e.g., social cohesion, sense of place, participation), and policy-related factors (Bauman et al., 2012; Kepper et al., 2019).

Fifth, this study only made a distinction between the intensity of PA (i.e., LPA and MVPA). However, evidence shows that associations between the environment and PA behavior may also differ per PA domain (e.g., transportation, recreation) (Peters et al., 2020; Van Holle et al., 2012). It is therefore suggested to repeat the current study, only with different PA domains as outcome variables.

Conclusion

Both the objective and perceived environment contribute to adult's PA behavior within their home neighborhood, but only to a small extent. Perceptions about aesthetics and land-use, and the actual presence of infrastructure related to safety (e.g., traffic calming features) are associated with MVPA levels of adults within their home neighborhood. The findings of this study indicate that objective and perceived environmental characteristics may have their unique influence on MVPA within the home neighborhood, which suggests that both the objective and perceived environment should be considered when designing interventions to promote MVPA behavior. Nevertheless, the outcomes of this study also show that there should be other factors that play a role in adult's PA behavior within their home neighborhood. Therefore, additional research that focuses on the relation between different PA intensities (e.g., LPA, MVPA) and PA domains (e.g., active transport, recreation) and objective and perceived environmental characteristics and other (environmental) factors is needed to increase knowledge on adult's PA behavior within their home neighborhood. Only with a more thorough understanding of the relationship between the environment and PA behavior within the home neighborhood, public health professionals, policymakers, city planners, and community workers can design effective activity-friendly environments that can potentially combat the physical inactivity pandemic.

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Additional files

Additional File I

Overview of the spatial analysis in ArcGIS to assess the objective environment.

Theme & environmental characteristic	Objective environment measure & definition	Source	Summary of actions in ArcGIS[a]
General			
Home neighborhoods	Home neighborhoods of 1000m around each participant's home address (street network buffer)	GPS data (Qstarz BT-Q1000XT GPS logger)	See Stappers et al. (2020)
Land-use			
Access to stores	Store density = average number of stores per square kilometer *Includes buildings characterized as a store and buildings with a mixed function where 'store' is one of them.*	Basisregistratie Adressen en Gebouwen (BAG) https://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/1c0dcc64-91aa-4d44-a9e3-54355556f5e7?tab=general	1. [Select] → Select year of construction equal to or below 2017 2. [Select] → Select buildings characterized as a store and buildings with a mixed function where 'store' is one of them 3. [Spatial Join] → Join the buildings with a store function with the home neighborhoods (match option = intersect) 4. [Summary Statistics] → Count the number of stores per home neighborhood 5. [Join Field] → Join the count with the home neighborhood feature class 6. [Calculate Field] → Calculate the store density as the count of stores per home neighborhood divided by the area of the home neighborhood (in km^2)
Land-use mix	Entropy score = measure of variation or diversity of land uses across an area. A value of 0 indicates homogeneity, a value of 1 indicates heterogeneity	Bestand Bodemgebruik (BBG) 2015 https://data.overheid.nl/dataset/7265-bestand-bodemgebruik-2015	1. [Select] → Select 'hoofdweg' to reflect roads 2. [Select] → Select 'woongebied' to reflect residences 3. [Select] → Select 'detailhandel en horeca' to reflect retail & restaurant 4. [Select] → Select 'sociaal-culturele voorziening' OR 'openbare voorziening' to reflect civic & institutional 5. [Select] → Select 'dagrecreatief terrein' OR 'verblijfsrecreatie' to reflect recreation

Theme & environmental characteristic	Objective environment measure & definition	Source	Summary of actions in ArcGIS[a]
	Includes the land-uses residences, retail & restaurant, civic & institutional, recreation, sports terrain, and greenspace.		6. [Select] → Select 'sportterrein' to reflect sports terrain 7. [Select] → Select 'Park en plantsoen' OR 'Volkstuin' OR 'Bos' OR 'Droog natuurlijk terrein' OR 'Nat natuurlijk terrein' to reflect greenspace 8. [Summarize Within] → Summarize the area (in km^2) of each of the six land-uses above per home neighborhood 9. [Join Field] → Join the area of each of the six land-uses with the home neighborhoods 10. The entropy score per home neighborhood was calculated in Excel based on the following formula (Christian et al., 2011): $H = -1(\sum_{i=1}^{n} pi * \ln(pi))/\ln(n)$ *Where H = entropy (land use mix) score, pi = the proportion of the area covered by land use i against the summed area for land use classes of interest (including i), and n is the number of land use classes of interest.*
Public transportation access	Public transportation density = average number of public transportation stops per square kilometer *Includes bus stops and train stations.*	Open Street Map ('points' included bus stops; train stations were a separate layer)	1. [Select] → Select 'highway = bus_stop' 2. [Merge] → 'Busstops' & 'Stations_NS' 3. [Summarize Within] → Summarize the point features that reflect a bus stop or train station per home neighborhood (count) 4. [Calculate Field] → Calculate the public transport density as the count of public transport stops per home neighborhood divided by the area of the home neighborhood (in km^2)
Infrastructure			
Sidewalks	Density of sidewalks = average length of sidewalks per kilometer of road	Basisregistratie Grootschalige Topografie (BGT) (polygon feature 'wegdeel'; function 'rijbaan', 'voetpad') TOP10NL 2017	*TOP10NL (roads)* 1. [Select] → Select 'hoofdverkeersgebruik = gemengd verkeer' 2. [Summarize Within] → Summarize the length of the roads (km) per home neighborhood (sum) *'Wegdeel' BGT (Sidewalks)*

Theme & environmental characteristic	Objective environment measure & definition	Source	Summary of actions in ArcGIS[a]
	Sidewalks are defined as any footpath that runs along a road or street.	(line feature 'wegdeel hartlijn'; function 'gemengd verkeer')	3. [Select] → Select 'objectbegintijd' equal to or before 2017-06-30 4. [Select] → Select functie = 'voetpad' OR functie = 'voetpad op trap' to reflect footpaths 5. [Select layer by location] → Select all footpath features whose boundaries touches the roads, then export the selected features to reflect sidewalks 6. [Polygon to Centerline] → transforms the sidewalk polygons to centerlines 7. [Spatial Join] → Join the sidewalks with the home neighborhoods (match option = intersect) 8. [Summary Statistics] → Sum the lengths of sidewalks (km) per home neighborhood 9. [Join Field] → Join the length of sidewalks per home neighborhood with the length of roads per home neighborhood feature class 10. [Calculate Field] → Calculate the sidewalk density as the length of sidewalks per home neighborhood divided by the length of roads per home neighborhood (in km)
Bicycle & pedestrian trails	Density of bicycle & pedestrian trails = average length of bicycle & pedestrian trails per kilometer of road	TOP10NL 2017 (line feature 'wegdeel hartlijn'; function 'fietsers/bromfietsers', 'voetgangers')	1. [Select] → hoofdverkeersgebruik = 'fietsers, bromfietsers' OR hoofdverkeersgebruik = 'voetgangers' to reflect bicycle & pedestrian trails 2. [Summarize Within] → Summarize the length of the bicycle & pedestrian trails (km) per home neighborhood (sum)
	Pedestrian trails are all footpaths excluding sidewalks.	TOP10NL 2017 (the created 'roads' feature; see sidewalks)	3. [Join Field] → Join the length of bicycle & pedestrian trails per home neighborhood with the length of roads per home neighborhood feature class 4. [Calculate Field] → Calculate the bicycle & pedestrian trail density as the length of those trails per home neighborhood divided by the length of roads per home neighborhood (in km)
Sidewalk buffer – parked cars	Parking spot density = average length of parking spots that act as a	Basisregistratie Grootschalige Topografie (BGT)	1. [Select] → Select 'objectbegintijd' equal to or before 2017-06-30

Theme & environmental characteristic	Objective environment measure & definition	Source	Summary of actions in ArcGIS[a]
	sidewalk buffer per kilometer of road *Parking spots act as sidewalk buffer when they are located between a sidewalk and a road or street.*	(polygon feature ’wegdeel’; function ’parkeervlak’) TOP10NL 2017 (the created ‘roads’ feature; see sidewalks)	2. [Select] → Select functie = 'parkeervlak' to reflect parking spots 3. [Select layer by location] → Select all parking spot features whose boundaries touches the footpaths, then export the selected features to reflect parking spots that are next to a footpath 4. [Select layer by location] → Of the parking spots that are next to a footpath, select all parking spot features whose boundaries touches the roads, then export the selected features to reflect parked cars that act as a sidewalk buffer 5. [Polygon to Centerline] → transforms the parking spots to centerlines 6. [Spatial Join] → Join the parking spots with the home neighborhoods (match option = intersect) 7. [Summary Statistics] → Sum the lengths of parking spots (km) per home neighborhood 8. [Join Field] → Join the length of parking spots per home neighborhood with the length of roads per home neighborhood feature class 9. [Calculate Field] → Calculate the parking spot density as the length of parking spots per home neighborhood divided by the length of roads per home neighborhood (in km)
Sidewalk buffer – green strip	Green strip density = the average length of green strips that act as sidewalk buffer per kilometer of road *Green strips act as sidewalk buffer when they are located between a sidewalk and a road or street.*	Basisregistratie Grootschalige Topografie (BGT) & Basisregistratie Bodemgebruik (BBG) 2015 (the created ‘greenspace’ feature; see below) TOP10NL 2017 (the created ‘roads’ feature; see sidewalks)	1. [Select layer by location] → Select all greenspace features whose boundaries touches the footpaths, then export the selected features to reflect greenspaces that are next to a footpath 2. [Select layer by location] → Of the greenspaces that are next to a footpath, select all greenspace features whose boundaries touches the roads, then export the selected features to reflect green strips that act as a sidewalk buffer 3. [Polygon to Centerline] → transforms the green strips to centerlines 4. [Spatial Join] → Join the green strips with the home neighborhoods (match option = intersect)

Theme & environmental characteristic	Objective environment measure & definition	Source	Summary of actions in ArcGIS[a]
			5. [Summary Statistics] → Sum the lengths of green strips (km) per home neighborhood 6. [Join Field] → Join the length of green strips per home neighborhood with the length of roads per home neighborhood feature class 7. [Calculate Field] → Calculate the green strip density as the length of green strips per home neighborhood divided by the length of roads per home neighborhood (in km)
Streetlights	*Density of street lights = average number of street lights per kilometer of road*	*Not available*	
Pedestrian infrastructure	Density of pedestrian infrastructure (other than sidewalks) = average number of pedestrian infrastructure per kilometer of road *Includes areas characterized as pedestrian zone and 'woonerf' and crossings, speedbumps, roundabouts, traffic signs, and traffic signals.*	Basisregistratie Grootschalige Topografie (BGT) (polygon feature 'wegdeel'; function 'rijbaan lokale weg: verkeersdrempel', 'rijbaan regionale weg: verkeersdrempel', 'voetgangersgebied', 'woonerf') Open Street Map (OSM) (point features: traffic signs, traffic signals, crossing, speedbump, roundabout) TOP10NL 2017 (the created 'roads' feature; see sidewalks)	*'Wegdeel' BGT* 1. [Select] → Select 'rijbaan lokale weg:verkeersdrempel' OR 'rijbaan regionale weg:verkeersdrempel' OR 'voetgangersgebied' OR 'woonerf' to reflect pedestrian infrastructure from the BGT 2. [Spatial Join] → Join the pedestrian infrastructure with the home neighborhoods (match option = intersect) 3. [Summary Statistics] → Count the number of pedestrian infrastructure attributes per home neighborhood *Open Street Map* 4. [Select] → Select 'crossing' OR 'mini_roundabout' OR 'traffic_sign' OR 'traffic_signals' OR 'speedbump' to reflect pedestrian infrastructure from the OSM 5. [Summarize Within] → Summarize the point features that reflect pedestrian infrastructure from the OSM per home neighborhood (count) 6. [Join Field] → Join both tables from pedestrian infrastructure BGT & OSM 7. [Calculate Field] → Calculate total pedestrian infrastructure by adding both counts of the BGT and OSM

Theme & environmental characteristic	Objective environment measure & definition	Source	Summary of actions in ArcGIS[a]
			8. [Join Field] → Join the count of pedestrian infrastructure per home neighborhood with the length of roads per home neighborhood feature class 9. [Calculate Field] → Calculate the pedestrian infrastructure density as the count of pedestrian infrastructure per home neighborhood divided by the length of roads per home neighborhood (in km)
Aesthetics			
Trees	*Tree density = average number of trees per kilometer of road*	*Not available*	
Greenspace	Greenspace (% area) = percentage of the total home neighborhood area that consists of greenspace *Includes public parks, urban greening (Dutch: 'gemeentelijk groen'), road verges, allotments, forests, meadows, farmland, fruit cultivation, and arboriculture.*	Basisregistratie Grootschalige Topografie (BGT) (polygon features 'begroeid terreindeel' and 'ondersteunend wegdeel'; function 'berm' Basisregistratie Bodemgebruik (BBG) 2015 (the created 'greenspace' feature; see land-use mix)	*'Begroeid terreindeel' BGT* 1. [Select] → Select 'objectbegintijd' equal to or before 2017-06-30 2. [Erase] → Erase the 'greenspace' feature (see land-use mix) from the 'begroeid terreindeel' feature class (because this sometimes overlaps) *'Ondersteunend wegdeel' BGT* 3. [Select] → Select 'objectbegintijd' equal to or before 2017-06-30 4. [Select] → 'berm' 5. [Erase] → Erase the 'greenspace' feature (see land-use mix) from the 'ondersteunend wegdeel' feature class (because this sometimes overlaps) 6. [Merge] → Merge both feature classes to reflect greenspace 7. [Summarize Within] → Summarize the area (in km^2) of the greenspace per home neighborhood 8. [Calculate Field] → Calculate the percentage of greenspace per home neighborhood as the total area of greenspace per home neighborhood divided by the area of the home neighborhood (in km^2) * 100

Theme & environmental characteristic	Objective environment measure & definition	Source	Summary of actions in ArcGIS[a]
Traffic safety			
	No. of road accidents = average number of road accidents annually per kilometer of road	Bestand geRegistreerde Ongevallen Nederland (BRON) 2016 https://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search?node=geonetwork#/metadata/4gqrs90k-vobr-5t59-x726-4x2unrs1vawz	1. [Table to Table] → 'puntlocaties.txt.', display XY data to make a feature class → 'Puntlocaties_BRON2016 Events' 2. [Table to Table] → 'ongevallen.txt.' to make an ArcGIS compatible table of the road accidents 3. [Join Field] → Join the 'puntlocaties' feature class with the road accidents table 4. [Select] → Select 'VKL_NUMMER IS NOT NULL' to create a feature class that contains the point features (location) of each road accident 5. [Spatial Join] → Join the road accidents with the home neighborhoods (match option = contains). This provides the number of road accidents per home neighborhood
		TOP10NL 2017 (the created 'roads' feature; see sidewalks)	6. [Join Field] → Join the count of accidents per home neighborhood with the length of roads per home neighborhood feature class 7. [Calculate Field] → Calculate traffic safety as the number of road accidents per home neighborhood divided by the length of roads per home neighborhood (in km)
Safety from crime			
	No. of crime records = average number of crimes annually relative to the size of the area (in m^2) of the home neighborhood *Includes all registered crimes that are punishable by the Criminal Law of the Netherlands and other special laws such as the*	Registered crime per neighborhood 2016 https://data.politie.nl/#/Politie/nl/dataset/47018NED/table?ts=1620132224811 CBS neighborhoods 2016 'Buurten 2016 – CBS Wijk- en buurtkaart' version 3	*This variable required a different approach than the other variables, because the dataset used for this variable contained the number of crimes annually per neighborhood (CBS neighborhoods). Because a home neighborhood as used in this study can overlap different CBS neighborhoods, this variable was calculated pro-rata (based on m^2).* *CBS neighborhoods* 1. Select neighborhoods within the municipalities of Heerlen and Maastricht. Used to add the crime records to the neighborhood codes.

Theme & environmental characteristic	Objective environment measure & definition	Source	Summary of actions in ArcGIS[a]
	Opium Act, Weapons and Ammunition Act, and Road Traffic Act.	(Esri Nederland, Centraal Bureau voor de Statistiek)	*Registered crime* 2. [Table to Table] → 'Geregistreerde_misdrijven_buurt_jaarcijfers_2016.csv' to make an ArcGIS compatible table of the registered crime 3. [Join Field] → Join the table of registered crime with the CBS neighborhoods feature class based on *Bu_Code* 4. [Calculate Field] → Calculate the number of crimes per m^2 as the number of crimes annually divided by the area of the CBS neighborhood 5. [Intersect] → Shows the area of each CBS neighborhood that overlaps with each of the home neighborhoods 6. [Calculate Field] → Calculate the number of crimes per area of each CBS neighborhood that overlaps a home neighborhood as the area of the certain piece of the overlapping CBS neighborhood multiplied by the number of crimes per m^2 for that CBS neighborhood (see step 4) 7. [Summary Statistics] → Sum the number of crimes of each piece of CBS neighborhood that overlaps a certain home neighborhood. This gives the number of crimes annually (2016) relatively to the size of the area (in m^2) of the home neighborhood

Note. Grey italic items were included at first but were not available in the datasets. Therefore, they were excluded from the analysis. After the calculations were performed in ArcGIS, the feature's attribute tables were exported to Excel for the subsequent analysis in SPSS.

[a] This provides only a summary and broad overview of the main steps taken in the calculation. For further details, contact can be sought with the author.