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Green space definition affects associations of green space with overweight and physical activity

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ABSTRACT

Introduction: In epidemiological studies, exposure to green space is inconsistently associated with being overweight and physical activity, possibly because studies differ widely in their definition of green space exposure, inclusion of important confounders, study population and data analysis.

Objectives: We evaluated whether the association of green space with being overweight and physical activity depended upon definition of greenspace.

Methods: We conducted a cross-sectional study using data from a Dutch national health survey of 387,195 adults. Distance to the nearest park entrance and surrounding green space, based on the Normalized Difference Vegetation Index (NDVI) or a detailed Dutch land-use database (TOP10NL), was calculated for each residential address. We used logistic regression analyses to study the association of green space exposure with being overweight and being moderately or vigorously physically active outdoors at least 150 min/week (self-reported). To study the shape of the association, we specified natural splines and quintiles.

Results: The distance to the nearest park entrance was not associated with being overweight or outdoor physical activity. Associations of surrounding green space with being overweight or outdoor physical activity were highly non-linear. For NDVI surrounding greenness, we observed significantly decreased odds of being overweight [300 m buffer, odds ratio (OR) = 0.88; 95% CI: 0.86, 0.91] and increased odds for outdoor physical activity [300 m buffer, OR = 1.14; 95% CI: 1.10, 1.17] in the highest quintile compared to the lowest quintile. For TOP10NL surrounding green space, associations were mostly non-significant. Associations were generally stronger for subjects living in less urban areas and for the smaller buffers.

Conclusion: Associations of green space with being overweight and outdoor physical activity differed considerably between different green space definitions. Associations were strongest for NDVI surrounding greenness.

1. Introduction

Exposure to green space has been suggested to reduce the risk of several adverse health outcomes by multiple pathways including physical activity (James et al., 2015). Green space could reduce the likelihood of being overweight by offering suitable spaces that encourage physical activity (Hartig et al., 2014; Lee and Maheswaran, 2011). Overweight and physical inactivity are important risk factors for cardiovascular disease, diabetes and mental illness (Lachowycz and Jones, 2011).

Green space is inconsistently associated with physical activity and being overweight, according to reviews of epidemiological studies (Hartig et al., 2014; James et al., 2015; Lachowycz and Jones, 2011; Bancroft et al., 2015; Nieuwenhuijsen et al., 2017; Durand et al., 2011; Hansen et al., 2015; Mayne et al., 2015; Hunter et al., 2015). Green space was negatively associated with being overweight in some studies (Liu et al., 2007; Pereira et al., 2013), however in other studies, green space was either not associated or positively associated with being overweight (Mowafi et al., 2012; Richardson et al., 2013; Picavet et al., 2016; Cummins and Fagg, 2012; Witten et al., 2008). These inconsistent associations across studies have been attributed to the use of different green space measures, the focus on quantity instead of quality and the use of green space, different populations and definitions of physical activity (e.g. self-reported vs. accelerometry, total versus vs. outdoor)

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and lack of control for important confounders (Lachowycz and Jones, 2011; James et al., 2015). Studies in large populations evaluating some of these sources of heterogeneity are needed.

The most commonly used way to objectively assess exposure to green space is to determine the greenness within a circular buffer of the residential address (James et al., 2015). The radius of the buffers used to define surrounding green space varied among studies and ranged from 30 (McMorris et al., 2015) to 3000 m (Maas et al., 2008). Green space within a buffer can be assessed by using the Normalized Difference Vegetation Index (NDVI) or by using national land-use databases (James et al., 2015). Another common measure to determine exposure to green space is the distance (Euclidian or network) of the residential address to the nearest park entrance (James et al., 2015).

So far, only a few epidemiological studies have investigated the effects of different types of green space (Hartig et al., 2014; Lee and Maheswaran, 2011). Green spaces can be subdivided into publically accessible and private green; or into natural, agricultural and urban green. Variance in greenness within the surrounding area can also be used as a measure (Pereira et al., 2013). In addition, most studies assumed a linear association of exposure to green spaces with the health outcome of interest (Shanahan et al., 2015) without providing information about the validity of this assumption. Non-linear associations between green space and overweight and physical activity are plausible. For instance, high levels of green space tend to be associated with higher distances to facilities (e.g. shops, work). Distance is probably the most important determinant for choosing an active or non-active mode of transportation (Heinen et al., 2010). Assessing exposure-response curves could provide information on how changes in quantity of green space could affect overweight and physical activity (Shanahan et al., 2015).

The goal of this cross-sectional study is to evaluate whether the association between exposure to green space and being overweight (body mass index (BMI) ≥ 25 kg/m^2) and outdoor physical activity depends on the definition of green space, adjustment for potential confounders, population characteristics and assumed shape of the association.

2. Methods

2.1. Study design and study population

This cross-sectional study was based on a national health survey (Public Health Monitor 2012, PHM *(Gezondheidsmonitor Volwassenen GGD-en, CBS en RIVM)*). The PHM covered issues related to personal characteristics, lifestyle, socio-economic status (SES) and physical and mental health status, and was conducted by 28 Public Health Services (GGD-en), Statistics Netherlands (CBS) and the National Institute for Public Health and the Environment (RIVM) in 2012. The response rate of the PHM was 45–50%. In total, the PHM includes information on 387,195 citizens aged ≥ 19 years. The address of each subject was geocoded; hence no individuals were excluded due to missing geocodes. The study was approved by the authorized review board. More information about the PHM can be found elsewhere (Statistics Netherlands, 2015).

Statistics Netherlands has enriched the PHM with information on standardized household income and country of origin. The PHM was also linked with information on the degree of urbanization and neighborhood SES (four-digit postal code). The degree of urbanization consists of five categories ranging from very strongly urban to non-urban. This indicator is based on the average address density within a radius of one kilometer (Den Dulk et al., 1992). Neighborhood SES represents the educational, occupational and economical status of the neighborhood and is derived by the Netherlands Institute for Social Research (SCP) (Knol, 1998). A high neighborhood SES score indicates a high SES of the neighborhood; a low score indicates a low SES of the neighborhood. We used the 2002 neighborhood SES score.

2.2. Outcome definition

Self-reported height and weight were used to calculate the body mass index (BMI (kg/m^2)) for each subject. In line with previous work, BMI was used as a binary outcome (BMI ≥ 25 kg/m^2) (Ellaway et al., 2005; Pereira et al., 2013; Richardson et al., 2013; Cummins and Fagg, 2012).

Questions related to physical activity, were divided into physical activity for commuting purposes, physical activity at work or school, household physical activity, leisure time physical activity and sport including the type of sports. For each of the aforementioned types of physical activity, subjects reported the number of days per week and the average number of minutes per day that they spent, in a regular week in recent months, on that type of physical activity.

The WHO recommends at least 150 min/week of moderate to vigorous physical activity. Hence, we defined activities of light and moderate-vigorous intensity based on WHO-guidelines (WHO, 2010). Because we hypothesized that green space only encourages physical activity that can be done outdoors, we used “outdoor physical activity” as our physical activity outcome measure. We defined outdoor physical activity as all moderate and vigorous physical activities that can be done outdoors (physical activity for commuting purposes, leisure time physical activity (walking, cycling, gardening), and outdoor sports). The remaining moderate to vigorous physical activities were defined as indoor physical activity. More information about the definition of outdoor and indoor physical activity can be found in the supplement (1. Description of physical activity definitions).

To estimate the association between green space and the probability of meeting the WHO activity recommendations with outdoor physical activity alone, we classified outdoor physical activity as a binary outcome (being moderately-vigorously physically active outdoors for at least 150 min/week or not). We also used outdoor physical activity as a continuous outcome (min/week).

2.3. Green space exposure assessment

Since there is no clear conceptual model from which relevant green space exposure measures can be defined, we used different green space exposure measures consistent with previous epidemiological studies. We used three different indicators of exposure to green space: 1) network distance (distance along roads) to the nearest entrance of a park, 2) NDVI surrounding greenness, i.e. average NDVI within a circular buffer of the participant's residential address and 3) a land-use database showing surrounding green spaces, i.e. the proportion of green space within a circular buffer of the participant's residential address. The NDVI and land-use databases were assessed in buffers of various sizes (a radius of 100, 300, 500, 1000 and 3000 m).

Analyses to determine green space exposures were performed in ArcGIS 10.2.2 (Esri, Redlands, CA, USA).

2.3.1. Network distance to park entrance

To determine the network distance between a residential address and the nearest park or public garden (in the remainder of the article referred as “park”) entrance, we used a land classification database of the Netherlands (‘Bestand Bodemgebruik’, CBS and Kadaster, 2010). This database contains fewer land-use categories than TOP10NL, used to define surrounding green space (Section 2.3.3), but it has a ‘Park and public garden’ terrain class. These parks can be smaller than 0.5 ha and are located within cities and villages. With a detailed map covering roads and paths of the Netherlands in 2013 (“OpenStreetMap”, OpenStreetMap Contributors, 2013), we identified all locations where roads and paths crossed the border of a park. These points represented entrances of parks and were used to perform (network) service area analyses in ArcGIS. A service area is an area that encloses all accessible streets within a specified network distance. We created service areas of the park entrances of 100, 200, 300, 400, 500 and 1000 m and labeled

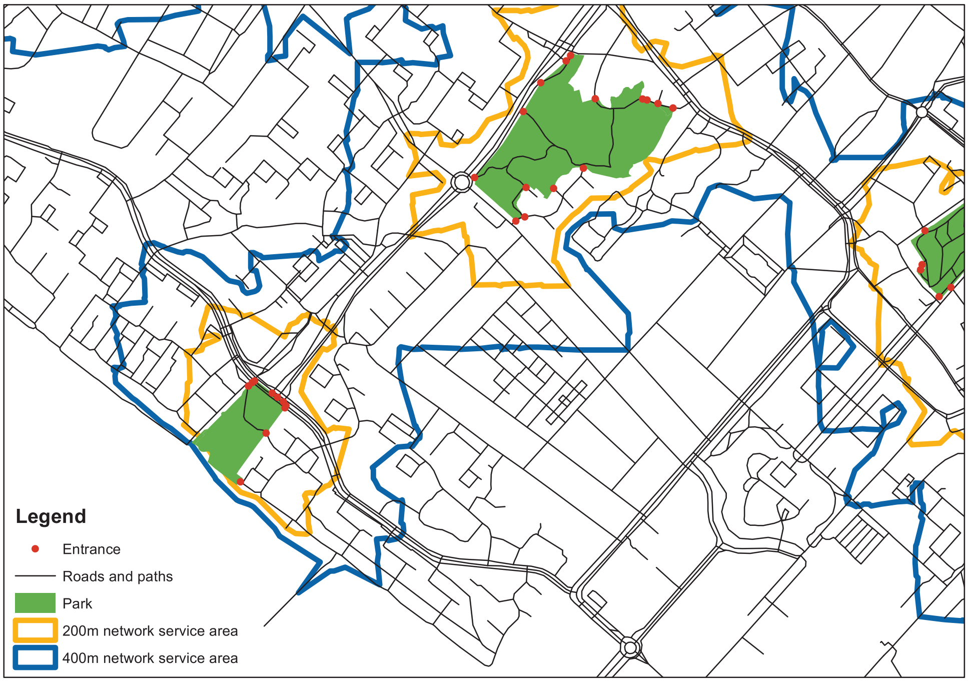

Fig. 1. Network service areas of 200 and 400 m in a neighborhood in the Netherlands.

all addresses located within these service areas. As an example, network service areas of 200 and 400 m are given in Fig. 1. Due to computational limitations we were not able to calculate the exact distance from each address to the nearest park entrance.

2.3.2. NDVI surrounding greenness

The NDVI captures the density of green vegetation at a spatial resolution of 30 m. Values for NDVI range between −1 and 1, with higher numbers indicating a higher density of green vegetation (NASA, 2015). No green vegetation gives a value close to zero. Negative values correspond to blue spaces (water) and may result in averaging out green spaces. Therefore, negative NDVI values were set to zero. The NDVI was derived from LANDSAT 5 Thematic Mapper (TM) satellite images, available from the Global Visualization Viewer from the United States Geological Service (USGS) (USGS, 2015). We combined cloud free images from the summer of 2010 to create a map covering nearly the entire country, with one image of every region. We resampled the 30 × 30 m NDVI raster to a 10 × 10 m raster to calculate mean NDVI values in the different buffer sizes with the neighborhood function (focal statistics tool) in ArcGIS (10.2.2). This tool calculated the mean NDVI value within the specified circular buffer around each 10 × 10 m grid cell. These mean NDVI values were linked to the addresses that were located inside the cell. NDVI surrounding greenness indicates the average density of green vegetation within a buffer.

2.3.3. TOP10NL surrounding green space

We used TOP10NL (CC-BY Kadaster, 2010), a highly detailed national land-use database of the Netherlands (produced in 2010), to assess the proportion of surrounding green space. TOP10NL divides the Netherlands into polygons with different classes of land-use (water, road and terrain). The terrain class is divided in 21 subclasses; eleven of which correspond to green areas (cropland, orchard, plant nursery, mixed forest, willow forest, deciduous forest, coniferous forest, fruit farm, grassland, heather and poplar). TOP10NL does not include private green property and street greenery. Moreover, we did not include sport facilities and dunes as green spaces. To distinguish between different types of green space, we defined all green areas within a population cluster (a city or village) as 'urban green'. Green areas outside a population cluster were defined as 'agricultural green' when these areas corresponded to cropland, orchards, plant nurseries, fruit farms or grassland and as 'natural green' when they corresponded to mixed forests, willow forests, deciduous forests, coniferous forests, heather or poplars. The vector polygons used byTOP10NL to divide the Netherlands were converted to four 10 × 10 m raster datasets (total, urban, agricultural and natural green) in ArcGIS based on the 'maximum combined area' cell assignment type (green = 1, not green = 0). By using the neighborhood function (as described above), for each 10 × 10 m grid cell surrounding green spaces of the different buffers was calculated and linked to the addresses. Thus, the TOP10NL surrounding green space indicates the proportion of green space within a buffer.

An illustration of surrounding green space in a 300 m buffer for the city of Utrecht (the Netherlands) and its surroundings is shown in Fig. 2A (TOP10NL) and C (NDVI). The surrounding green space in a 300 m buffer for a neighborhood in Utrecht is shown in Fig. 2B (TOP10NL) and D (NDVI).

2.4. Data analysis

Logistic regression models were used to estimate whether green space (distance to parks, NDVI surrounding greenness and TOP10NL surrounding green space) was associated with being overweight and with being physically active outdoors for at least 150 min/week. Linear regression models were used to estimate whether green space was associated with the number of minutes per week of physical activity outdoors.

We specified *a priori* several regression models with increasing degrees of confounder adjustment. As previous studies differed in the level of detail of adjustment for confounders, we aimed to compare the effect estimates of green space with different detail of covariate adjustment. Model 1 included age and sex (crude model); Model 2 was additionally adjusted for individual SES indicators (marital status, country of origin, work, household income and level of education). In Model 3 lifestyle factors (smoking status, alcohol use and indoor physical activity) were added. Model 4 expanded Model 3 with information about neighborhood SES, and Model 5 added degree of urbanization (main model). For overweight, we additionally added outdoor physical activity to Model 5. All continuous covariates were transformed into categories in order not force a linear relationship (Table 1). Categories of covariates in the regression analyses were similar to the categories presented in Table 1, except for age (12 categories: 19–24, 25–29, 30–34, 35–39, 40–44,

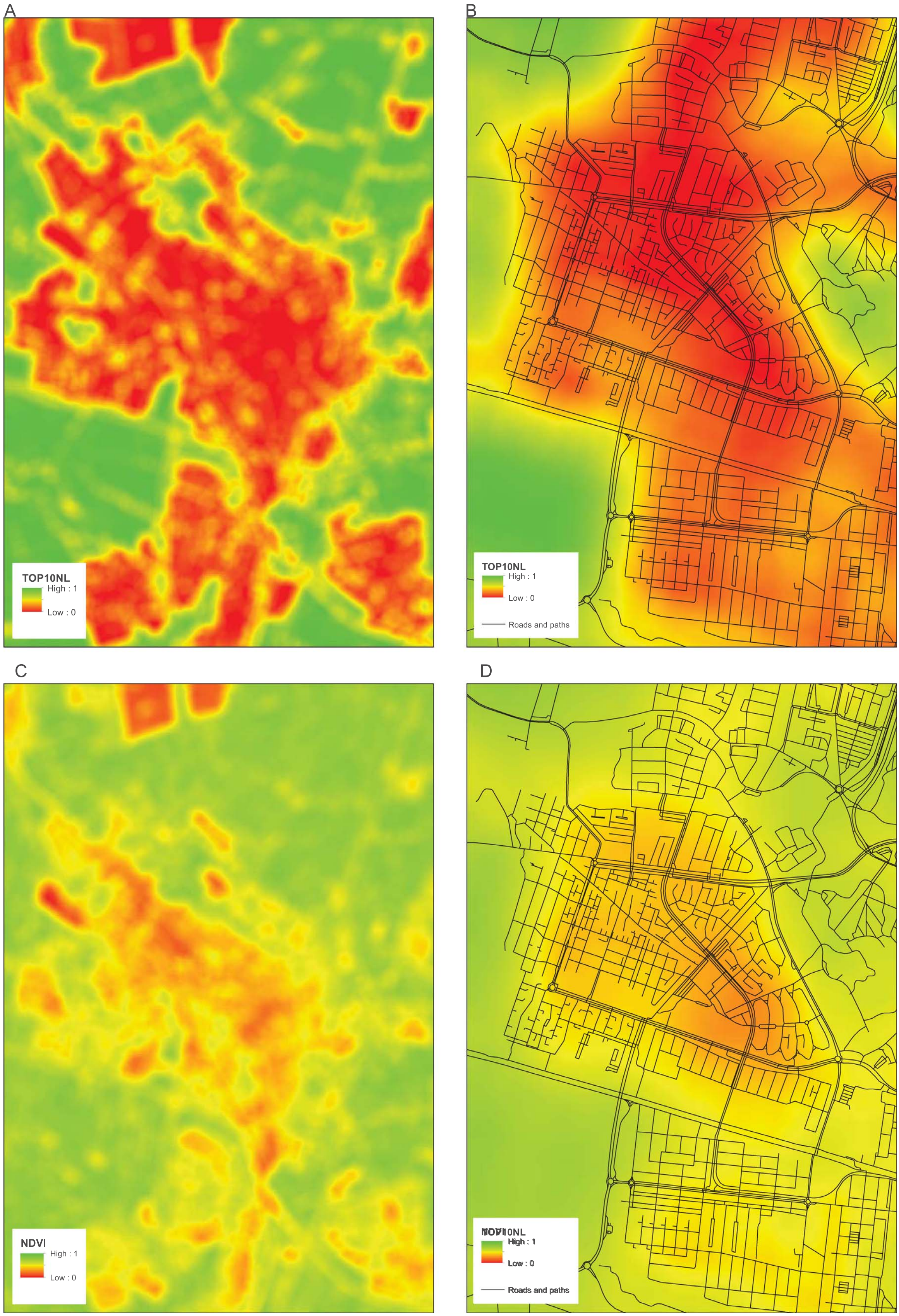

Fig. 2. Surrounding green in a 300 m buffer for the city of Utrecht and its surroundings (A: TOP10NL surrounding green space, C: NDVI surrounding greenness). Surrounding green in a 300 m buffer for a neighborhood in Utrecht (B: TOP10NL surrounding green space, D: NDVI surrounding greenness). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Table 1
Characteristics of the population (n = 354,827).

Characteristic	Category	n (%)
Gender	female	193,782 (55)
Age	19–39 years	68,940 (19)
	40–64 years	134,161 (38)
	≥ 65 years	151,726 (43)
Marital status	married, living together	246,775 (71)
	unmarried/never married	42,233 (12)
	divorced	22,509 (6)
	widowed	38,089 (11)
Country of origin	Dutch	308,167 (87)
	other western	29,215 (8)
	other non-western	17,445 (5)
Education	primary or less	33,679 (10)
	Lower-secondary	119,549 (35)
	Higher-secondary	97,005 (28)
	University	92,733 (27)
Work	yes	158,704 (48)
Income	< €15,200	35,539 (10)
	€15,200 − 19,399	67,391 (19)
	€19,400 − 24,199	74,677 (21)
	€24,200 − 30,999	83,916 (24)
	≥ €31,000	91,224 (256)
Smoking	current	65,702 (20)
	former	133,267 (40)
	never	134,794 (40)
Alcohol	current	280,311 (82)
	former	20,564 (6)
	never	40,007 (12)
Degree of urbanization	very highly urbanized (≥ 2500 addresses/km^2)	51,747 (15)
	highly urbanized (1500–2499 addresses/km^2)	88,513 (25)
	moderately urbanized (1000–1499 addresses/km2)	65,311 (18)
	low urbanized (500–999 addresses/km^2)	80,711 (23)
	not urbanized (< 500 addresses/km^2)	68,528 (19)
Neighborhood SES	≤ 30	75,223 (21)
	30–34	78,723 (22)
	35–38	73,947 (21)
	38–43	58,521 (17)
	> 43	67,342 (19)
Indoor physical activity	≤ 30 min/week	103,021 (34)
	31–180 min/week	57,347 (19)
	181–600 min/week	69,991 (23)
	> 600 min/week	70,652 (24)
Outdoor physical activity	150 min a week >	71,269 (24)
	150 min a week ≤	229,742 (76)
BMI	≤ 24.9 kg/m^2	159,223 (45)
	≥ 25.0 kg/m^2	190,045 (54)
Park distance	≤100 m	24,845 (7)
	101–200 m	44,142 (12)
	201–300 m	50,624 (14)
	301–400 m	34,192 (10)
	401–500 m	36,571 (10)
	501–1000 m	127,371 (36)
	> 1000 m	37,082 (11)
NDVI 100 m [mean (SD)]		0.49 (0.11)
NDVI 300 m [mean (SD)]		0.52 (0.10)
NDVI 500 m [mean (SD)]		0.54 (0.10)
NDVI 1000 m [mean (SD)]		0.56 (0.11)
NDVI 3000 m [mean (SD)]		0.59 (0.11)
TOP10NL 100 m [mean (SD)]		0.15 (0.18)
TOP10NL 300 m [mean (SD)]		0.24 (0.20)
TOP10NL 500 m [mean (SD)]		0.30 (0.20)
TOP10NL 1000 m [mean (SD)]		0.40 (0.21)
TOP10NL 3000 m [mean (SD)]		0.55 (0.20)

SD = standard deviation.

45–49, 50–54, 55–59, 60–64, 65–74, 75–84, ≥ 85 years) and country of origin (7 categories: Dutch native, Morocco, Turkey, Suriname, Netherlands Antilles, Other non-western, Other western).

The independent effects of the different types of surrounding green space were investigated by including natural, urban and agricultural surrounding green space of the same buffer size together into one regression model. For further interpretation of the impact of confounder adjustment, we additionally analyzed the association of individual SES indicators (household income, level of education and work) on surrounding green space in 300 m and 1000 m buffers. Associations between individual SES indicators and surrounding green space were adjusted for age, gender, marital status and country of origin.

For NDVI surrounding greenness and TOP10NL surrounding green space, we specified a linear term (1 degree of freedom), quintiles and natural splines. Because splines are sensitive to the number and location of the knots (Eisen et al., 2004), we specified natural splines with 2, 3 and 4 degrees of freedom. To test whether the goodness-of-fit of the models that contained splines was significantly better than the linear model, we used the likelihood ratio test (LRT). P-values lower than 0.05 indicate that the goodness-of-fit of the model that contains splines was significantly better than that of the linear model. To assess which model (df = 1, 2, 3 or 4) fitted the data best the Akaike Information Criterion (AIC), which penalizes for the additional degrees of freedom, was used. We used quintiles of surrounding green space (categorical variable) to further assess and quantify potential deviations from linearity. We a priori used quintiles instead of tertiles or quartiles to obtain a finer assessment, which was made possible by the large study population.

To study the shape of the association of NDVI and TOP10NL surrounding green with being overweight and outdoor physical activity, we plotted exposure-response curves. The plots were presented so that the odds ratio (OR) or regression coefficient (Beta) was zero at the mean green space exposure rather than at zero (Eisen et al., 2004). Surrounding green space distribution bars are shown on the x-axis of the plots.

Because we hypothesized that associations of green space with being overweight and outdoor physical activity could differ between elderly and non-elderly and between highly urban and moderate-low urban dwellers, we also performed stratified analyses by age (< 65 years, ≥ 65 years) and degree of urbanization (≥ 1500 addresses/km2, 1500 < addresses/km2).

Analyses with green space as a linear variable were performed with SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Spline models were analyzed with R 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria), package 'Splines' (R Core Team, 2016). All analyses were performed in a secured remote access environment of Statistics Netherlands.

3. Results

3.1. Study population statistics

As land-use data across the border of the Netherlands was unavailable, subjects with residential addresses within 3 km (largest buffer) of the border and those located outside the NDVI map were excluded from analyses (8.4% of total population). Hence, our dataset contained information on exposure to green space for 354,827 persons aged 19 years or older (Table 1). The elderly (≥ 65 years) were oversampled by design; almost 43% of the subjects of our study population were 65 years or older (Table 1), in contrast to 18% of the general Dutch population within the studied age range (CBS, 2016). Further, people of Dutch origin (86.9% compared with 78% in the general population) were overrepresented in our study population (Table 1).

Of the study population, 37.2% reported a BMI between 25.0 and 30.0 kg/m^2 and 17.2% reported a BMI higher than 30.0 kg/m^2. The distribution of outdoor physical activity was right skewed. Mean outdoor physical activity was 534 min/week with standard deviation of

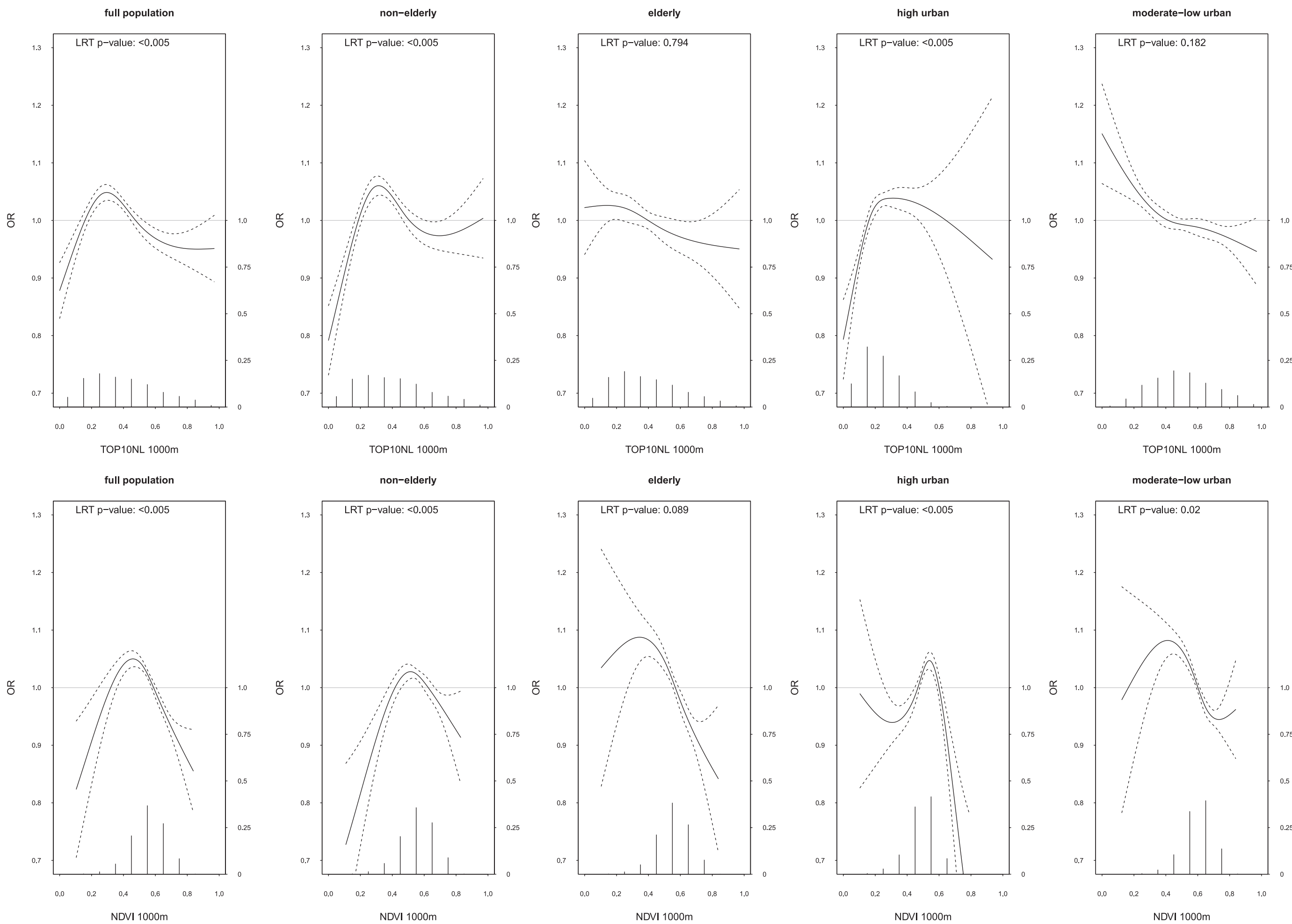

Fig. 3. Estimated exposure-response curves (M4B, solid lines) and 95% CIs (dashed lines) for the odds of being overweight for 1000 m TOP10NL and NDVI surrounding green (df = 3) for the full population and stratified by age or degree of urbanization. At the left x-axis the OR is shown, at the right x-axis the probability distribution of the exposure is shown. LRT p-values showed whether the goodness-of-fit of the model was significantly better than linear model.

586 min/week. Of all subjects, 8.6% reported 0 min/week of outdoor physical activity.

3.2. Green space exposure

Only 11% of all subjects lived more than 1000 m away from a park entrance (Table 1). Some of the parks included in the database were small, such as small playgrounds or public gardens. The mean and median proportion of surrounding green space increased with increasing buffer size, especially for TOP10NL surrounding green space. The variation in TOP10NL surrounding green space was larger compared to NDVI surrounding greenness (Table 1, Fig. 3). Exposure to surrounding green was lower for the highly urban population compared to the moderate-low urban population (Fig. 3).

Correlations between the NDVI and TOP10NL in the same buffer were moderate to strong (Table S1). The correlations ranged from 0.64 for the 100 m buffer to 0.82 for the 1000 m buffer. The correlations between the different buffer sizes of the same indicator ranged from 0.43 to 0.93 for the NDVI and from 0.19 to 0.90 for TOP10NL.

3.3. Associations green space with being overweight

3.3.1. Distance to park

We found no indication that living closer to a park is associated with decreased odds of being overweight (Table 2). Further, no associations were found when stratifying by degree of urbanization or age: the odds ratios for those living within 100 m of a park compared to the reference category (> 1000 m) were 1.04 (95% CI: 0.83, 1.25) and 1.02 (95% CI: 0.96, 1.07) for the highly urban and moderate-low urban population respectively. For elderly (≥ 65 years) and non-elderly these odds ratios were 1.01 (95% CI: 0.96, 1.07) and 1.02 (95% CI: 0.94, 1.08) respectively.

Table 2
Association between network distance to nearest park entrance and being overweight and being at least 150 min/week physically active outdoors. Statistically significant OR (P < 0.05) are given in bold.

Distance to nearest park entrance (m)	Being overweight (BMI ≥ 25.0 kg/m2) OR (95% CI)[a]	Being at least 150 min/week physically active outdoors OR (95% CI)[a]
< 100	1.00 (0.96, 1.05)	**1.08 (1.03, 1.14)**
101–200	1.02 (0.98, 1.06)	**1.06 (1.01, 1.11)**
201–300	1.03 (0.99, 1.07)	**1.11 (1.06, 1.16)**
301–400	0.99 (0.95, 1.03)	**1.11 (1.05, 1.16)**
401–500	1.01 (0.97, 1.05)	**1.08 (1.03, 1.13)**
501–1000	**0.95 (0.92, 0.98)**	**1.12 (1.08, 1.16)**
> 1000	ref	ref

[a] Adjusted for age, gender, marital status, country of origin, education, work, income, smoking, alcohol, indoor physical activity, neighborhood SES and degree of urbanization.

Table 3
Associations between quintiles of surrounding green within specified buffers and being overweight. Results are given as OR (95% CI) relative to the reference category (OR = 1.00). Statistically significant OR (P < 0.05) are given in bold.

Buffer (m)	Quintiles NDVI	Quintiles TOP10NL	Being overweight (BMI ≥ 25.0 kg/m2) OR (95% CI)[a]		Being at least 150 min/week physically active outdoors OR (95% CI)[a]	
			NDVI	TOP10NL	NDVI	TOP10NL
100	≤ 0.40	< 0.00	ref	ref	ref	ref
	0.41–0.47	0.00–0.05	0.98 (0.95, 1.01)	1.01 (0.98, 1.03)	**1.06 (1.03, 1.09)**	1.01 (0.98, 1.04)
	0.48–0.52	0.06–0.12	**0.97 (0.94, 0.99)**	1.01 (0.99, 1.04)	**1.08 (1.05, 1.11)**	0.99 (0.96, 1.02)
	0.53–0.59	0.13–0.26	**0.90 (0.88, 0.93)**	0.99 (0.96, 1.02)	**1.12 (1.09, 1.15)**	1.00 (0.97, 1.03)
	> 0.59	> 0.26	**0.84 (0.81, 0.87)**	**0.97 (0.94, 0.99)**	**1.18 (1.15, 1.21)**	**0.94 (0.91, 0.97)**
300	≤ 0.44	≤ 0.08	ref	ref	ref	ref
	0.45–0.50	0.09–0.15	1.00 (0.97, 1.02)	**1.03 (1.01, 1.06)**	1.02 (0.99, 1.05)	0.97 (0.94, 1.01)
	0.51–0.55	0.16–0.24	0.99 (0.96, 1.02)	**1.04 (1.01, 1.07)**	**1.04 (1.00, 1.07)**	0.97 (0.94, 1.00)
	0.56–0.61	0.24–0.37	**0.95 (0.92, 0.98)**	1.01 (0.98, 1.04)	**1.09 (1.06, 1.12)**	1.00 (0.97, 1.03)
	> 0.61	> 0.37	**0.88 (0.86, 0.91)**	**0.97 (0.94, 1.00)**	**1.14 (1.10, 1.17)**	0.99 (0.95, 1.02)
500	≤ 0.46	≤ 0.12	ref	ref	ref	ref
	0.47–0.51	0.13–0.21	1.02 (0.99, 1.04)	**1.07 (1.04, 1.09)**	1.02 (0.99, 1.05)	**0.96 (0.93, 0.99)**
	0.52–0.56	0.22–0.31	1.00 (0.97, 1.03)	**1.05 (1.02, 1.07)**	1.01 (0.98, 1.04)	**0.97 (0.94, 1.00)**
	0.57–0.62	0.32–0.46	**0.95 (0.92, 0.98)**	1.02 (0.99, 1.05)	**1.08 (1.05, 1.12)**	1.01 (0.98, 1.04)
	> 0.62	> 0.46	**0.91 (0.87, 0.94)**	0.98 (0.95, 1.01)	**1.12 (1.09, 1.16)**	0.97 (0.94, 1.01)
1000	≤ 0.48	≤ 0.20	ref	ref	ref	ref
	0.49–0.54	0.21–0.31	**1.06 (1.03, 1.08)**	**1.05 (1.02, 1.08)**	**0.96 (0.92, 0.99)**	**0.96 (0.93, 1.00)**
	0.55–0.59	0.32–0.44	1.02 (0.99, 1.04)	1.03 (1.00, 1.06)	0.97 (0.94, 1.00)	0.98 (0.95, 1.02)
	0.60–0.65	0.45–0.58	**0.96 (0.93, 0.99)**	1.00 (0.97, 1.03)	**1.04 (1.00, 1.07)**	1.01 (0.97, 1.04)
	> 0.65	> 0.58	**0.92 (0.89, 0.95)**	0.99 (0.95, 1.03)	**1.08 (1.04, 1.12)**	0.98 (0.93, 1.02)
3000	≤ 0.50	≤ 0.36	ref	ref	ref	ref
	0.51–0.57	0.37–0.50	1.00 (0.97, 1.02)	**1.04 (1.01, 1.07)**	0.97 (0.94, 1.00)	**0.95 (0.92, 0.98)**
	0.58–0.63	0.51–0.63	**0.96 (0.93, 0.99)**	1.02 (0.99, 1.06)	0.99 (0.96, 1.02)	1.01 (0.98, 1.05)
	0.64–0.69	0.64–0.74	**0.93 (0.91, 0.96)**	1.02 (0.98, 1.05)	**1.05 (1.02, 1.08)**	1.03 (0.98, 1.07)
	> 0.69	> 0.74	**0.92 (0.89, 0.95)**	1.01 (0.97, 1.05)	**1.06 (1.02, 1.09)**	0.98 (0.93, 1.02)

[a] Adjusted for age, gender, marital status, country of origin, education, work, income, smoking, alcohol, indoor physical activity, neighborhood SES and degree of urbanization.

3.3.2. Surrounding green full population

Associations of NDVI and TOP10NL surrounding green with being overweight were significantly different ($p < 0.05$) from linearity (Fig. 3 and S1) in our main model. Similar patterns of the association were found for models with two and four degrees of freedom. The non-linear models had the lowest AIC values, which indicate that these models fitted the data better than models assuming linearity.

For NDVI surrounding greenness, the odds of being overweight were significantly lower in the two highest quintiles compared to the lowest quintile for all buffers (Table 3). The strongest (decreased) ORs were found for the smallest buffer sizes. For the second and third quintiles no consistent difference with the lowest quintile was found, confirming the non-linearity detected in the spline analysis. In contrast, for TOP10NL surrounding green space no decreased odds of being overweight were found for the highest quintiles, except in the 100 m buffer. We found some statistically significant ORs in the unexpected direction (> 1, Table 3). For NDVI only one association in the unexpected direction was found, but for TOP10NL associations for the second and third quintile were consistently increased compared to the lowest quintile. When we compare the quintile results with the spline results, we observe that the plots show non-monotonic patterns with increases and decreases at different levels of the green space distribution for both NDVI and TOP10NL (Fig. 3 and S1). The difference is that for NDVI the counter-intuitive increase largely occurs within the first quintile and for TOP10NL within the first three quintiles.

We found that adjustments for covariates hardly affected the associations of surrounding green space with being overweight (Fully adjusted model (5) versus age-gender adjusted model (1) in Table S2). Adjustment for individual SES factors attenuated the ORs, which is consistent with the significantly higher levels of surrounding green found for subjects with higher household income (Table S3). Associations without adjustment for outdoor physical activity did not show large differences compared to associations with adjustment for outdoor physical activity (Table S2). This suggests that outdoor physical activity hardly affects the association of surrounding green space with being overweight.

3.3.3. Surrounding green stratified analyses and types of green space

Associations between almost all surrounding green indicators and being overweight did not deviate significantly from linearity for elderly and moderate-low urban area dwellers (Fig. 3). Stronger negative associations (i.e. lower odds of being overweight with increasing green space exposure) were found for NDVI surrounding greenness compared to TOP10NL surrounding green space (Table S4). For high urban dwellers and non-elderly (< 65 years), the associations of surrounding green space exposure were highly non-monotonic and deviated significantly from linearity (Fig. 3, Table S4)

Associations of natural, agricultural and urban surrounding green with being overweight also deviated significantly from linearity (Fig. S2). The direction for the types of green based upon TOP10NL differed; natural green predominantly showed a decrease in odds with increasing amount of green, while urban green showed an increase in odds of overweight with increasing amount of green.

3.4. Associations of green space with outdoor physical activity

3.4.1. Distance to park

The odds of being physically active outdoor for at least 150 min/week was significantly higher for subjects living within 1000 m of a park entrance compared to subjects living more than 1000 from a park entrance (Table 2). However, no difference in odds between the different distance categories below 1000 m was observed. When outdoor physical activity was analyzed as continuous outcome no consistent pattern was found (Table S5).

When we stratified by age or degree of urbanization, non-significant associations were found for elderly and high urban dwellers. For non-elderly and moderate-low urban dwellers we found significant, but inconsistent associations. For example, the moderate-low urban dwellers living within 100 m of a park as well as those living between 500 and 1000 m of a park entrance had an increased OR compared to the reference category (OR = 1.13; 95% CI: 1.07, 1.20 and OR = 1.13; 95% CI: 1.09, 1.17 respectively).

3.4.2. Surrounding green full population

The associations between surrounding green and being physically active outdoors for at least 150 min/week deviated significantly from linearity (Fig. S3). Exposure-response curves were highly non-monotonic, with increases and decreases in odds at different levels of surrounding green. The curves based on models with two and four degrees of freedom also showed non-linear patterns. Associations between surrounding green space and outdoor physical activity (continuous) also deviated significantly from linearity (Fig. S4). For both outcomes, the lowest AIC values were found for non-linear models, indicating that these models fitted the data better than models assuming linearity.

For NDVI surrounding greenness, the odds of being physically active outdoors for at least 150 min/week were significantly higher in the two highest quintiles compared to the lowest quintile for all buffers (Table 3). The increased ORs were strongest for the 100 and 300 m buffers. Similar patterns were found when we used outdoor physical activity as a continuous outcome (Table S6). In contrast, for TOP10NL surrounding green space no consistent increase or decrease of odds of outdoor physical activity was found for any of the quintiles (Table 3), while significant associations with min/week of outdoor physically active were found in the two highest deciles (Table S6). Some statistically significant ORs in the unexpected direction were found (< 1, Table 3). For NDVI only one OR in the unexpected direction was found, but for TOP10NL ORs for the second and third quintile were fairly consistently decreased compared to the lowest quintile.

Associations of surrounding green with outdoor physical activity were affected by the adjustment for degree of urbanization (Table S2). Without adjustment for neighborhood indicators (Model 3) significant decreased ORs were found. With adjustments for degree of urbanization (Model 5) non-significant or increased ORs were found. This influence might be caused by the negative relationship between surrounding green and degree of urbanization.

3.4.3. Surrounding green stratified analyses and types of green space

Associations between almost all surrounding green indicators and outdoor physical activity (Fig. S5) deviated significantly ($p < 0.05$) from linearity when stratified by age or degree of urbanization. Analysis by quintiles of NDVI surrounding greenness showed significant positive associations for both elderly and non-elderly (Table S7, S8). The same pattern was observed for moderate-low urban dwellers.

All associations of natural, agricultural and urban green with outdoor physical activity deviated significantly from linearity (Fig. S2). The direction of the association for the types of green differed; natural green showed a predominantly positive association with outdoor physical activity, while urban green showed negative association.

4. Discussion

In this study, we evaluated whether the association of green space with being overweight and outdoor physical activity depends on the definition of green space exposure and subgroups of the population. We found no indication that distance to the nearest park entrance is associated with being overweight or outdoor physical activity. Associations with being overweight and outdoor physical activity were stronger for NDVI surrounding greenness compared to land-use surrounding green space (TOP10NL). Associations also differed between subgroups of the population and types of green space. The size of the buffer and adjustments for confounders affect the strength of the association. Moreover, exposure-response curves showed that associations were highly non-linear.

4.1. Comparison with previous studies

We are not aware of other studies that tested the linearity assumption for the association of surrounding green with being overweight or physical activity. Some studies used surrounding green as a categorical variable. Pereira et al. (2013) reported decreased ORs for being overweight or obese in the highest green category compared to the lowest. Contrary to our findings, this decreased OR was only found for mid-age adults (25–64 years) and not for elderly (65+) (Pereira et al., 2013). Cummins and Fagg (2012) reported significant, counterintuitive, increased associations for being overweight and being obese in the highest green space category compared to the reference, in the period 2000–2003. In the period 2004–2007, they found decreased relative risks of being overweight and being obese in the second-highest green space category but not in the highest. Richardson et al. (2013) reported no significant ORs for being overweight or obese in any green space category compared to the lowest category. On the other hand, they found increased OR of being physically active for at least 150 min/week in the highest green category compared to the reference category. Coombes et al. (2010) found a, counterintuitive, lower odds of being overweight for people living further away from green space compared to people living nearby green space. They found no association between distance to green space and being physically active for at least 150 min/week in any category. Ord et al. (2013) reported no increased OR of meeting recommendations for physical activity in any surrounding green space category compared to the reference category.

Pereira et al. (2013) and Coombes et al. (2010) also used other exposure measures than 'total' green space. Pereira et al. (2013) used variation in greenness as an exposure variable. They found decreased ORs for being overweight and being obese in the second and third tertile compared to the lowest tertile of variation in greenness. Coombes et al. (2010) found higher odds of being overweight and lower odds of achieving physical activity guidelines for people living further away from well organized, maintained and structured green spaces compared to those living nearby.

In contrast to this study, Ord et al. (2013), Richardson et al. (2013) and Coombes et al. (2010) included all physical activities in their analyses, whereas we only included outdoor physical activities. Ord et al. (2013) also analyzed the association of green space with walking (≥ 150 min/week) as an outcome. However, they did not found an association. Pereira et al. (2013), Richardson et al. (2013), Ord et al. (2013) and Coombes et al. (2010) only included urban residents in their analyses and excluded children. The study population (aged 18+ years) of Cummins and Fagg (2012) included also rural residents, but consisted predominantly of urban residents.

4.2. Explanation for associations

We found stronger associations with being overweight and outdoor physical activity for NDVI compared to TOP10NL. We do not have a clear explanation for this finding, but note that NDVI and TOP10NL surrounding green differ. The NDVI corresponds to the density of green vegetation and gives each 10*10 m grid cell a value between 0 and 1, while TOP10NL indicates whether an area (grid cell) is green (1) or not (0). Furthermore, the NDVI included private green (gardens) and street greenery while TOP10NL does not. Consequently, TOP10NL surrounding green space in smaller buffers was much lower compared to NDVI surrounding greenness. TOP10NL surrounding green space is more associated with publicly accessible green space (e.g. parks) for urban dwellers than NDVI. Advantages of TOP10NL include better geographical accuracy and the possibility to distinguish between different types of green.

As previous studies have used either NDVI or land-use green (Ord et al., 2013; Picavet et al., 2016; McMorris et al., 2015; Maas et al., 2008; Coombes et al., 2010; Richardson et al., 2013; Pereira et al., 2013), differences in greenness metrics may have contributed to inconsistent findings. However, a lack of consistent associations with being overweight and physical activity does not imply that green space is not related to cardiovascular and other health outcomes, as green space may be related to health via other pathways (James et al., 2015).

We found significantly higher levels of surrounding green for subjects with higher household income. The link between income and surrounding green can be explained by the fact that a view on a green strip or open area or the presence of a park or forest adds value to parcels (Luttik, 2000; Mansfield et al., 2005). As a consequence, certain attractive, green settings are inhabited by the rich (Luttik, 2000). The stronger associations for NDVI are probably caused by the fact that the NDVI takes private green into account, whereas TOP10NL does not. The stronger association for the 300 m buffer is likely related to the larger relative proportion of private green in 300 m compared to 1000 m buffers.

Exposure to green space was non-monotonically associated with being overweight and outdoor physical activity. For green defined by TOP10NL, we found ORs in the unexpected direction for both outcomes (increased OR for being overweight and decreased OR for being physically active outdoors for at least 150 min/week). This unlikely reflects a causal pathway. More likely, it illustrates the potential for residual confounding and selection bias. We do not have a clear explanation for the findings in our study, but note that a large range of individual, social and environmental factors affect weight status and physical activity. The effect of individual and social determinants has been suggested to outweigh the effect of environmental determinants on levels of physical activity (Giles-Corti and Robert, 2002). Individual psychological factors, like the perceived importance of a healthy weight and weight-related beliefs, and self-efficacy of weight-related behaviors (diet and physical activity) are important factors influencing weight status (Friedman and Kelly, 1995; Kuchler and Lin, 2002; Baranowski et al., 1999; Trost et al., 2002; Ball and Crawford, 2006). According to a study performed in the UK, nature-relatedness was the strongest predictor for meeting physical activity guidelines (Flowers et al., 2016). Quantity of green space and perceived access to green were not predictors for meeting physical activity guidelines (Flowers et al., 2016). Like most previous epidemiological studies, we did not have information about these factors. Some of the impact of adjustment for SES and degree of urbanization may be related to the above mentioned factors.

Of the environmental factors (distance, shopping facilities, infrastructure, land use etc.), distance to a destination is probably the most important factor for choice of active or non-active mode of transportation (Heinen et al., 2010). Besides, the density of sport facilities is high in the Netherlands (Maas et al., 2008). Thus, the direct effect of green space on levels of physical activity might be limited. Nevertheless, green space can support physical activity by providing suitable places for physical activities. Green space might be necessary to achieve certain levels of physical activity, but a supportive, green environment alone may be insufficient to increase levels of physical activity and decrease overweight (Giles-Corti and Robert, 2002).

In this study, associations of TOP10NL and NDVI with being overweight and outdoor physical activity differed significantly from linearity. Forcing a linear relationship in epidemiological studies can misspecify the effect of green space on outcomes. If the non-linear associations of green space with being overweight and outdoor physical activity are also present in other study areas, the use of linear relations in previous epidemiological studies could be an explanation for the inconsistent findings between epidemiological studies.

The functional form of non-linear associations can be demonstrated by the use of categorical or spline variables (May and Bigelow, 2005). However, specifying a categorical or spline variable is not without disadvantages. Transforming a continuous exposure variable into categories can give rise to bias away from the null and is sensitive to the selection of cut-points to define categories that affect the shape (Wacholder et al., 1991; Flegal et al., 1991). Specifying natural splines is sensitive to the number and location of the knots (Eisen et al., 2004). The knots, breaking points that define the spline, are placed at quantiles of the green space variable. To overcome this problem, we specified splines with 2, 3 and 4 degrees of freedom.

4.3. Limitations

This study is cross-sectional and therefore we do not know whether exposure precedes the outcome. The associations found between green space and being overweight and physical activity can be explained by (1) the effect of green space on physical activity, (2) the effect of propensity for physical activity on residential choice, or (3) both (Boone-Heinonen et al., 2011). The second mechanism can bias the effect of green space on physical activity (first mechanism). We adjusted for SES and degree of urbanization which may partly have corrected for the second mechanism.

We used data of the PHM that included information of 387,195 subjects, with overrepresentation of the elderly and people of Dutch origin. Results may therefore not be generalizable to the general public. Moreover, height, weight and levels of physical activity to define the outcomes in this study were self-reported. Self-reported outcome data is prone to recall bias and underestimation of weight and overestimation of physical activity levels. This may not necessarily lead to bias because we do not expect that this under- or overestimation is associated with objectively determined surrounding green space or distance to the nearest park entrance.

Another limitation of our study is that we only had information about the quantity of green space and did not know if and how often people use green areas located within the specified buffers we used. Moreover, we had no information about perceived quality, safety and accessibility of green spaces.

We performed subgroup analyses only for the two groups we hypothesized to differ most in their impact of green space: age and degree of urbanization. There may be additional factors that we did not analyze that may affect the impact of green space, like sex and SES.

5. Conclusion

This study demonstrated that associations of green space with being overweight and outdoor physical activity differ considerably between different green space definitions. Associations were strongest for NDVI surrounding greenness and for the smallest buffers. We found no indications that distance to park is associated with being overweight or outdoor physical activity. Exposure-response relationships showed that the magnitude of the potential benefits of surrounding green depend on the level of surrounding green. Therefore, we recommend more research to evaluate optimum levels of green space. Moreover, our study suggests that the inconsistency of associations of green space with being overweight and physical activity in previous studies may partly be due to non-linearity of the associations, subgroups and adjustment for confounders.

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Competing financial interests

The authors declare that they have no actual or potential competing financial interests.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2017.10.027.

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