Full length article

Exploring mechanisms underlying the relationship between the natural outdoor environment and health and well-being – Results from the PHENOTYPE project

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ABSTRACT

Background: Despite the large number of studies on beneficial effects of the natural outdoor environment (NOE) on health, the underlying mechanisms are not fully understood.
Objective: This study explored the relations between amount, quality, use and experience of the NOE; and physical activity, social contacts and mental well-being.
Methods: In this cross-sectional study, data on GIS-derived measures of residential surrounding greenness (NDVI), NOE within 300 m, and audit data on quality of the streetscape were combined with questionnaire data from 3947 adults in four European cities. These included time spent in NOE (use); and perceived greenness, and satisfaction with and importance given to the NOE (experience). Physical activity, social contacts and mental health were selected as key outcome indicators. Descriptive and multilevel analyses were conducted both on pooled data and for individual cities.
Results: More minutes spent in the NOE were associated with more minutes of physical activity, a higher frequency of social contacts with neighbors, and better mental well-being. Perceived greenness, satisfaction with and importance of the NOE, were other strong predictors of the outcomes, while GIS measures of NOE and streetscape quality were not. We found clear differences between the four cities.
Conclusions: Use and experience of the natural outdoor environment are important predictors for beneficial effects of the natural outdoor environment and health. Future research should focus more on these aspects to further increase our understanding of these mechanisms, and needs to take the local context into account.

1. Introduction

The potential health benefits of natural outdoor environment (NOE) exposure have been extensively studied in recent decades. While some researchers warn against overestimating the value of nature on health (e.g. Kang and Zhang, 2010), many studies are indicative of a positive association between nature and health (Hartig et al., 2014; Lee and Maheswaran, 2011; Maas et al., 2006; WHO, 2016). However, the mechanisms underlying these associations are not fully understood (Hartig et al., 2014; Nieuwenhuijsen et al., 2014; van den Berg et al.,

2015). Suggested mechanisms of the positive association between NOE and health are (1) reduction of mental stress – defined as the degree in which an environment can aid recovery from mental fatigue and attentional capacities – (2) facilitating physical activity, (3) facilitating social contact, (4) stimulation of development in children, (5) stimulation of personal development and a sense of purpose (Hartig et al., 2014; Health Council of the Netherlands and Dutch Advisory Council for Research on Spatial Planning, Nature and the Environment, 2004), (6) mitigation against potentially harmful environmental exposures, such as air pollution, noise pollution and reduction of excessive UV from sunlight (Hartig et al., 2014; Nieuwenhuijsen et al., 2014, WHO, 2016) and (7) improved functioning of the immune system (Kuo, 2015; WHO, 2016).

It is clear that the mechanisms underlying the beneficial effects of the NOE on health are multiple and potentially synergistic (Hartig et al., 2014). For example, people who are socially well imbedded may more often be stimulated to engage in physical activity and even more so when green and blue space is easily accessible. In addition, physical activity may affect stress levels and via that pathway favorably affect both physical and mental health (e.g. Sugiyama et al., 2008a,b). It remains unclear if the possible mechanisms act in isolation or together, since they have been predominantly studied in isolation (Nieuwenhuijsen et al., 2014). The association between the NOE and health also seems to vary across a whole range of dimensions (type of contacts, environments, life course, age, gender, social groups, level of physical activity) (e.g. Annerstedt et al., 2012; Astell-Burt et al., 2013, 2014; Hartig et al., 2014; Mitchell and Popham, 2008; van den Berg et al., 2015). Hartig et al. (2014) emphasize the importance of research into the mechanisms because understanding the association would enable to develop better tailored interventions.

Many studies have focused on quantitative measures of NOE (amount, distance, Normalized Difference Vegetation Index (NDVI)), and do not take into account quality (van den Berg et al., 2015). However, there are indications that quality aspects of neighborhood NOE such as pleasantness, lack of nuisance and good paths are associated with more walking time and other forms of physical activity (Björk et al., 2008; Sugiyama and Ward Thompson, 2008). Van Dillen et al. (2012) found that both quantity and quality of the NOE, especially from streetscape greenery, may be important with respect to health benefits. De Vries et al. (2013) found an association between streetscape greenery and perceived social cohesion at the neighborhood level, both for the quantity and, even more strongly, for the quality of greenery.

Another shortcoming of most studies is failure to consider use of the NOE (Nieuwenhuijsen et al., 2014), with few exceptions (Grahn and Stigsdotter, 2003; Nielsen and Hansen, 2007; Stigsdotter et al., 2010; van den Berg et al., 2016). Grahn and Stigsdotter (2003) and Stigsdotter et al. (2010) showed that a larger number of visits and more time spent per week in the NOE were significantly associated with lower levels of perceived stress. Nielsen and Hansen (2007) found that the number of visits mediated the association between living closer to greenspace and lower levels of reported stress. Van den Berg et al. (2015) showed significant positive associations between time spent visiting the NOE and mental health and vitality. Other studies, analyzing the determinants of use of the NOE indicated that it is not only important to have greenspace nearby, but that it also needs to be accessible, well-maintained, and suitable for the activities people want to undertake; that it offers opportunities for socialization; and that it feels safe and secure (Lee et al., 2015; Leslie et al., 2010; Mowen et al., 2007; Ou et al., 2016; Seaman et al., 2010).

Furthermore, people's experience of the NOE also determines levels of use (Hartig et al., 2014; Lee et al., 2015; Lin et al., 2014; Seaman et al., 2010). Perception of greenness, satisfaction with the NOE, and importance of the NOE for activities people want to undertake there - also called 'environmental supportiveness' (Sugiyama and Ward Thompson, 2007) - are all important for this experience.

In summary, there is a growing body of evidence indicating positive effects of the NOE on health, but the mechanisms remain largely hypothetical. There are still important knowledge and research gaps, as discussed in detail elsewhere (Nieuwenhuijsen et al., 2014). Most studies on NOE and health focus on GIS based indicators for NOE. Only a few studies focus on quality, use and experience of the NOE, while these may be important to better understand the mechanisms underlying the relationship between NOE and health.

The current paper explores determinants of mechanisms underlying the positive effects of the NOE on health. It studies the association of a wide set of indicators for quantity and quality of the NOE, use of and experience of the NOE with the three most commonly mentioned mechanisms physical activity, social contacts, and reduction of mental stress through visiting green areas. Since the process of reduction of mental stress can only be studied in experimental settings, but not in a cross sectional study such as ours, a proxy needed to be found that can be assessed in such a study. Mental well-being was selected for this purpose. The rationale for this is explained in the Methods section.

For the analyses a rich set of data was used, collected as a part of the PHENOTYPE study that aimed to investigate the interconnections between natural outdoor environments and better human health and well-being (Nieuwenhuijsen et al., 2014). It was collected in a large sample of adults in four European cities using a largely comparable approach. Our main research question was:

What relationships exist between amount, quality, use of and experience of the NOE; and physical activity, social contacts and mental well-being?

2. Methods

2.1. Study design

To explore the mechanisms underlying the relationship between the NOE and health and well-being across Europe, we used a cross-sectional design. An extensive description of the study design can be found in the paper of Nieuwenhuijsen et al. (2014).

2.2. Study area

From May-December 2013, data were collected in four European cities: Barcelona (Spain), Stoke-on-Trent (United Kingdom), Doetinchem (the Netherlands), and Kaunas (Lithuania). To collect comparable data, a common protocol was used.

In each city, approximately 30 neighborhoods were selected that varied in their distance to the NOE and in socio-economic status (SES).

Urban Atlas was used to define the NOE because it was available in a standardized form for a large number of European cities. It is a Europe-wide database that provides reliable, comparable, high-resolution land use maps for large urban zones and their surroundings with more than 100,000 inhabitants (European Union, 2012). The following land use categories (and codes) were used to extract NOEs: Green Urban Areas (14100), Agricultural & Semi Natural Areas (20000), Forests (30000), and Water bodies (50000). Since Urban Atlas was not available for Doetinchem, an alternative database ('Top10 nl') was used, based on which similar categories were defined. These have shown high comparability (82%) with Urban Atlas categories in another Dutch city (Utrecht) for which Urban Atlas was available. Using GIS, straight line distance to natural spaces of more than 1 ha was calculated for all residential addresses (households) within spatial units that were approximately comparable between cities. The average distance to natural environments was then used to rank each area and classify them into quintiles for each city.

For SESno comparable data were available, so each city used their own local data - a local deprivation index in Barcelona and Stoke-on-Trent, household income in Doetinchem and education levels in Kaunas to define SES tertiles.

The selection of the neighborhoods was conducted in the following way:

1. A ranking of neighborhoods by socio-economic status (SES) and distance to the NOE.
2. Creation of a matrix of SES (3 categories) by distance to the NOE (5 categories),
3. The selection of two neighborhoods from each combination of top, middle and bottom tertiles of SES and quintiles of the NOE,
4. A final check of the selected neighborhoods using local knowledge.

For more details we refer to Smith et al. (2017).

2.3. Study population

In these selected neighborhoods, we approached adults aged 18–75 years to participate in our study. We aimed for 1000 participants per city, with approximately 30 people in each of the selected 30 neighborhoods per city. However, response rates differed between the cities, a likely result of variations in recruitment method that were necessary to accommodate cultural differences and research traditions (see Table S1 and Discussion).

2.4. Collection of population data

Population data were collected through a questionnaire survey. Most questions were derived from existing and validated indices. Some were tailored to the specific objectives of the PHENOTYPE study. The survey was developed in English, was piloted in all participating cities and was translated and back translated into Dutch, Spanish and Lithuanian. The questionnaire was developed as an oral interview of 30–60 min at maximum. In the questionnaire survey, NOEs were defined as all public and private outdoor spaces that contain "green" and/ or "blue" natural elements such as street trees, forests, city parks and natural parks/reserves including all types of waterbodies. Ethical approval was obtained for all study populations, and all participants signed an informed consent.

2.5. NOE characterization using GIS and audit data

For each participant a set of GIS-derived measures of residential surrounding greenness was produced. To do so, residential addresses of the participants were geocoded. These geocodes were used to assign GIS-derived measures of residential surrounding greenness for each participant's residence. For NDVI, the source data used was Landsat 8 satellite images provided at 30 m × 30 m spatial resolution. We used cloud-free images within the greenest season (May to September) in 2011–2013, the period for this study in which also the largest part of the personal data were collected among study participants. Furthermore, for indicators on the amount of NOE, we used Urban Atlas data for the reference year 2006 and "Top 10 nl" for Doetinchem, the Netherlands as described before (see 'Study area').

Furthermore, a streetscape audit was used to collect more information on the quality of NOEs in a sample of streets in the participants' neighborhoods. To conduct the streetscape audit, each neighborhood was divided into approximately homogeneous sub-areas using a combination of data/maps on land use or function, and local knowledge. In each sub-area, several streets were selected and combined into a route that was representative of the sub-area, which was then audited. This involved 1–2 assessors completing a checklist of items that covered: general characteristics of the neighborhood, characteristics of the natural and non-natural elements, facilities, traffic safety, infrastructure, sidewalk amenities, incivilities, and a subjective pooled score for the neighborhood. In the Netherlands, additional criteria were applied: age of buildings, the way buildings were situated towards each other and the roads. A total of 408 audits were performed

in 225 subareas nested in 125 neighborhoods across the four cities.

2.6. Explanatory variables: amount, quality, use and experience

As explained in the introduction, a broad set of indicators related to amount, quality, use and experience of the NOE was selected to explore the mechanisms underlying relationship between the NOE and health that were addressed in the research questions (see Introduction).

For amount of NOE, we selected the GIS based measures "mean NDVI score within 300 m (straight-line distance)" (range 0–1) and "having a NOE of more than 1 ha within 300 m (straight-line distance) of the home" (yes/no). Three hundred meters was selected as distance measure, since it is often used in international studies to provide an indication of the surrounding greenness of the environment in the proximity of the participant's home (e.g. Annerstedt van den Bosch et al., 2016). The exact derivation of these indicators is described in more detail elsewhere (see Smith et al., 2017 for more details).

In addition, we considered the overall score for quality of natural features, assessed with the streetscape audit to characterize exposure to the NOE.

For use of the NOE we used data on visit frequency and visit duration for NOEs close to home; in the city; and close to the city. Visit frequency was based on the question in the questionnaire survey "how often in the last 4 weeks did you visit on purpose the following green spaces: (i) close to your home (less than 15 min by foot or bike); (ii) in your city or town (more than 15 min by foot or bike); and (iii) close to your city or town?" All items were scored on a 5-point scale with the categories: never; 1 time or less in past month; 2–3 times in past month; 1–4 times weekly; (almost) daily. Visit duration was assessed by asking "how much time did you spend in each of the following green spaces in the last four weeks (per visit)?: (i) close to your home (less than 15 min by foot or bike); ii) in your city or town (more than 15 min by foot or bike); and iii) close to your city or town". This was scored on a 4-point scale (< 1 h, 1–2 h, 3–5 h, 6–10 h). Visit frequency and visit duration for each of the three NOE categories (close to home; in the city; close to the city) were multiplied and summed to calculate the total duration of visits to green spaces (range 0–480). To obtain a variable with the dimension of hours, the middle values of the four categories from the visit frequency items were used and multiplied with the middle values of the four categories of the visit duration items ("never" and "not applicable" answers for visit frequency were both set on null hours in the past month) (van den Berg et al., 2015).

For experience of the NOE, we selected three indicators:

i. *perceived greenness:* a sum score (range 0–12) based on questions in the questionnaire survey adapted from van Dillen et al. (2011): "how would you describe your living environment in terms of green and blue?" scored on a 5- points scale ("not at all, little, neutral, fairly, very") for view from the home; the street; and the neighborhood. A higher score means perceiving the NOE to be greener.

ii. *satisfaction with the NOE:* a sum score (range 4–20) based on questions in the PHENOTYPE questionnaire survey: "overall, in your neighborhood, how satisfied are you with the following aspects?", with the aspects being quality, amount, maintenance and safety of the green/blue environment (NOE), and with the answer categories "very dissatisfied, dissatisfied, neutral, satisfied, very satisfied". A higher score means being more satisfied,

iii. *importance of the NOE*: a sum score (range 4–20) based on the questions in the questionnaire survey: "How important is it for you that near your home there is green/blue space for a) physical activity; b) social activities (picnic, BBQ, meet people, play with children); c) relaxation; d) there are green walking and biking paths to go to work, school and other destinations, with the answer categories very important; important; somewhat important; not important; not important at all. A higher score means valuing the NOE to be more important for the mentioned activities.

2.7. Outcome variables- physical activity, social contacts and mental well-being

In this paper we focus on three mechanisms by which the NOE can be beneficial to health: physical activity, social contacts and mental stress reduction - using mental well-being as a proxy. These were the basis for the selection of the outcome variables. We operationalized these outcome variables as follows:

For *physical activity*, we used the total number of minutes walking, cycling, gardening and sporting within a week (range 0–3780 min/week). These questions are part of the short questionnaire to assess health enhancing physical activity (SQUASH), a physical activity questionnaire (Wendel-Vos et al., 2002).

For *social contacts* the frequency of contacts with neighbors was selected as key indicator using a 5-point scale ((almost) daily; once a week or less; 1–3 times a month; less than once a month; seldom or never).

As explained in the Introduction, we used *mental well-being* as a proxy for the mental stress reduction in this study, since the process of recovery and stress reduction can only be studied in experimental settings, but not in a cross-sectional study such as ours. As described by van den Berg et al. (2015, p.8), mental well-being is affected if people are exposed to urban stressors such as noise, fear of crime and crowding, without possibilities for restoration from stress (Marin et al., 2011; Tafet and Bernardini, 2003; in: van den Berg et al., 2015). Mental well-being is thus directly related with stress-reduction, and can be measured in a reliable and valid way with MHI-5 (Ware, 2000) that can be used in questionnaire surveys in cross-sectional studies. The MHI-5 is a subscale of the SF-36 that includes questions related to feelings of nervousness and calmness, and somber versus happy mood in the past 4 weeks (Ware and Sherbourne, 1992). It is a so-called state instrument and therefore sensitive for changes in circumstances. This measure is a reliable and valid measure of mental well-being (Ware, 2000). All items were scored on a 6-point scale and summed scores were transformed into a scale from 0 to100. People scoring low on the scale felt nervous and depressed while people scoring high felt tranquil, calm and happy in the past 4 weeks.

2.8. Statistical analysis

The GIS-derived measures of residential surrounding greenness were linked with the questionnaire data at the individual level. Streetscape audit data were linked with the questionnaire survey data at the neighborhood level. Basic descriptive analyses were used to describe the populations in the four cities and to characterize the NOE, for a broad set of variables. Both NOE indicators and outcome variables were treated as continuous variables. Linear multilevel analyses were used to address the key questions of the study, thus assuming linear relations between the NOE indicators and the outcome variables. We included two levels in the analyses: the neighborhood level and the individual level because characteristics of both levels may influence the relations under study

For each outcome variable we conducted separate analyses to explore whether amount and quality of the NOE, use of and experience of the NOE are associated with physical activity, social contacts and mental well-being. These analyses were performed on the pooled data (all cities) and for individual cities. In the pooled analyses we adjusted for city specific characteristics not covered by the other included potential confounding variables, by including the city as a separate variable. In this way we adjusted for unforeseen city effects on the results. We ran analyses both with the explanatory variables included in the model individually and all together in one model. For the latter, we checked the correlation between the independent variables, using individual data. Only the quality of natural features and the NDVI score were strongly correlated ($r = 0.77$). For the other variables all correlation coefficients were smaller than 0.5. We also checked the

correlation between NOE variables and SES (highest educational level) for the pooled data and for individual cities. The correlation coefficients were smaller than 0.15, indicating only very weak correlations. Analyses were performed in SAS 9.4 (GLIMMIX).

Age, gender, and educational level were included as basic confounders in all multilevel analyses.

3. Results

3.1. General characteristics of the study population

Number of participants was 1045 in Barcelona, 1044 in Stoke-on-Trent, 861 in Doetinchem, and 997 in Kaunas (N = 3947 in total). Overall response rate was 19.8% and varied considerably between the four cities (see Supplemental Material, Table S1). In Doetinchem, the people selected for this study received a postcard in which they not only could indicate if they wanted to participate in this study, but could also respond to some general questions regarding their perception of and attitude towards the NOE. Based on analyses of these general questions, it appeared that responders in Doetinchem gave more importance to activities in the NOE than non-responders (data not shown). In addition, with the exception of Stoke-on-Trent, study participants were higher educated than the general population in each of the four cities. In addition, in Doetinchem the study population was relatively older and more often male compared to the general population (data not shown).

Table 1 and Supplemental Material, Tables S2 and S3 provide a general overview of the participant and environmental characteristics of the study population. Slightly fewer men participated than women. There were clear differences for a number of participant characteristics between the cities. In Kaunas and Doetinchem, the average age was statistically significantly higher than in the other two cities ($p < 0.0001$). The educational level was also statistically significant between the cities ($p < 0.0001$), being relatively high in Doetinchem (51.4% high educational level) and Kaunas (71.9% high educational level) (Table 1). General health was best in Doetinchem, with 81.5% of the participants reporting excellent or very good health, compared to only 7.5% of the participants from Kaunas. 57.2% of the Kaunas participants and 47.2% of the Doetinchem participants reported to have one or more chronic diseases, versus 18.2 and 24.5% in the other two cities (see Supplemental Material, Table S2).

There were clear differences in private facilities to spend time outdoors (see Supplemental Material, Table S3). While in Stoke-on-Trent and Doetinchem almost 90% of participants had their own garden, in Barcelona this was only true for 10.4%. However, in Barcelona, many people had a balcony or patio (69.4%), and/or a weekend or leisure house elsewhere (28.1%) (see Supplemental Material, Table S3). In Kaunas, there were also many people with a balcony or patio (62.1%), and/or a communal garden (42.4%). These percentages were higher than for the other cities.

In Kaunas, more than half of the people owned a dog- a far higher proportion than in the other cities (see Supplemental Material, Table S3) which may stimulate people to visit a NOE.

3.2. Amount and quality of NOE

Barcelona had the lowest amount of residential surrounding greenness (Table 1) and the largest average straight distance to NOE of 364 m, compared to 64 m in Doetinchem (see Smith et al., 2017). Only 49.3% of the participants from Barcelona had a natural outdoor environment within 300 m from their home, compared to e.g. 99.9% of the participants from Doetinchem (Table 1). Further details on GIS-measure NOE characteristics, including the distribution of the indicators, are reported elsewhere (Smith et al., 2017).

Doetinchem scored highest for overall quality of natural features, while Barcelona scored the lowest (Table 1 and Supplemental Material,

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Table 1
General characteristics of the study population.

	Pooled	Barcelona	Stoke-on-Trent	Doetinchem	Kaunas
N	3947	1045	1044	861	997
Male, (%)	44.6	47.3	48.1	43.3	39.4
Missing, n	*0*	*0*	*0*	*0*	*0*
Age (18–75 years) (mean (SD)) *Missing, n*	51.4 (16.0)	45.0 (15.6)	45.8 (16.1)	56.4 (12.2)	59.5 (14.0)
	54	*9*	*44*	*0*	*1*
Educational level (%)					
Low	7.0	14.4	9.5	1.2	1.7
Medium	44.2	38.8	64.3	47.4	26.4
High	48.8	46.8	26.2	51.4	71.9
Missing, n	*26*	*3*	*22*	*1*	*0*
Minutes walking/cycling/gardening/sporting p/w (mean (SD))	477.8	367.9	230.6	665.2	690.1
	(457.9)	(357.3)	(276.1)	(435.1)	(549.0)
Missing, n	*0*	*0*	*0*	*0*	*0*
Frequency of contact with neighbors (%)					
(Almost) daily	38.8	43.0	44.7	45.3	22.6
Seldom or never	9.3	10.0	7.8	1.7	16.8
Missing, n	*10*	*3*	*7*	*0*	*0*
Mental health score (mean (SD))	73.5 (16.2)	70.9 (15.8)	73.4 (16.4)	80.2 (13.5)	70.7 (16.9)
Missing, n	*24*	*4*	*8*	*12*	*0*
NDVI within 300 m	0.4 (0.2)	0.2 (0.1)	0.5 (0.1)	0.6 (0.1)	0.5 (0.1)
Missing, n	*1*	*1*	*0*	*0*	*0*
NOE within 300 m (%)	82.2	49.3	98.0	99.9	84.8
Missing, n	*1*	*1*	*0*	*0*	*0*
Quality of natural features (mean (SD))	13.6 (5.1)	7.3 (3.8)	14.6 (2.9)	17.0 (2.8)	16.4 (3.8)
Missing, n	*0*	*0*	*0*	*0*	*0*
Time spent in the NOE (hours; sum score (mean (SD))	29.2 (53.4)	24.8 (40.6)	23.2 (57.8)	27.2 (32.1)	43.1 (71.5)
Missing, n	*185*	*29*	*14*	*30*	*112*
Perceived greenness (sum score (mean (SD))	6.9 (3.3)	5.2 (3.4)	6.3 (3.2)	9.0 (2.6)	7.3 (2.6)
Missing, n	*6*	*2*	*4*	*0*	*0*
Satisfaction with the NOE (sum score (mean (SD))	14.2 (3.1)	13.2 (3.4)	14.9 (3.2)	15.4 (2.5)	13.6 (2.7)
Missing, n	*12*	*7*	*5*	*0*	*0*
Importance of NOE for health-related activities (sum score (mean (SD)))	16.4 (2.9)	16.9 (2.6)	16.3 (3.4)	16.5 (2.4)	15.7 (2.9)
Missing, n	*6*	*3*	*2*	*1*	*0*

Table S4). However, for the specific dimensions of infrastructure, amenities and facilities, based on a score of the auditors for presence of several related characteristics, Barcelona scored considerably higher (see Supplemental Material, Table S4). Objective quality of natural features appeared to correlate strongly with the mean NDVI within 300 m (r = 0.78).

3.3. Use of NOE

In general, looking at the combination of frequency and duration of all visits of the NOE (sum scores), participants from Kaunas spent most time in the NOE, and participants from Barcelona the least (Table 1).

The study participants visited green and blue spaces close to their homes most frequently, with the lowest percentage in Stoke-on-Trent (with 14.6% (almost) daily visits) and the highest perentage in Kaunas and Doetinchem (both 37.8% (almost) daily visits). Visits to green and blue spaces further away in the city and outside the city were highest in Kaunas and lowest in the Stoke-on-Trent (see Supplemental Material, Table S5).

Most visits to green and blue spaces near the home lasted less than 2 h. Visits to green and blue spaces further away, close to the town or city, lasted longer on average, but were less frequent (see Supplemental Material, Table S5 and S6).

3.4. Experience of NOE

Based on NDVI and GIS indicators, participants in Doetinchem had not only the most natural environment around their house, but the average sum score of perceived greenness was also the highest, meaning that it was also perceived as 'more green' (Table 1).

The sum score for satisfaction with the NOE showed that participants from Barcelona and Kaunas were least satisfied with the NOE, and the participants from Doetinchem were most satisfied (Table 1).

Focusing on the various elements of satisfaction (quality, amount, maintenance, safety) there were again clear differences between the four cities. Participants living in Stoke-on-Trent and in Doetinchem were generally most satisfied with the NOE. In Barcelona, satisfaction with the quality and amount of the NOE was lower, while in Kaunas this was the case for the maintenance and safety (see Supplemental Material, Table S7).

Presence of a NOE near their homes for health-related activities was considered (very) important by participants in all cities (see Supplemental Material, Table S8). Only a small percentage of participants indicated that the presence of the NOE was not important to them (at all) – less than 7% reported this in relation to physical activity, relaxing and walking and biking paths; and 11% reported this in relation to social contacts (data not shown). Based on the sum score, participants from Barcelona found it most important and participants from Kaunas the least (Table 1). People found the NOE particularly important for physical activity nearby (including for cycling and walking), and to a lesser extent for relaxation. Having a NOE for social contacts was considered least important, although (still) 72.8% of all study participants found it important or very important (see Supplemental Material, Table S8).

3.5. Description of the outcome and outcome-related variables

On average, participants spent about 480 min (~8 h) per week on walking, cycling, gardening and sport, but the large standard deviation indicates a large variation (Table 1). In Doetinchem and Kaunas, the average minutes of physical activity were much higher than in Barcelona and Stoke-on-Trent (665.1, 690.1, 367.9 and 230.6 min per week of physical activity, respectively). However, the differences between study participants within cities were also large, as indicated by the large standard deviations (Table 1). In addition, Stoke-on-Trent physical activity levels were lowest compared to the other three cities.

Only 22.7% of the study participants there adhered to one or two of the guidelines for physical activity (3 days a week 20 min vigorous activity and/or 5 days a week 20 min moderate activities), and only 22.2% participated in sports at least once a week (see Supplemental Material, Table S9).

With regard to social contacts, 38.8% of all participants reported (almost) daily contact with the neighbors. In Kaunas this was less common (22.6%) (Table 1). Most participants (90.7%) indicated contact with friends and family at least once per week; (almost) daily contacts were most frequently reported in Stoke-on-Trent (66.7%) and least often in Doetinchem (49.5%).

Doetinchem scored best on mental well-being (mean MHI-5 of 80.2), and Kaunas worst (mean MHI-5 of 70.7) (Table 1). There the social cohesion index was also highest, reflecting low perceived social cohesion (see Supplemental Material, Table S10). The social cohesion index is based on the question "how strongly do you agree or disagree with the following statements about your neighbourhood: (i) people are willing to help their neighbours; (ii) this is a close-knit neighbourhood; (c) people in this neighbourhood can be trusted; (d) People in this neighbourhood generally don't get along with each other; (e) people in this neighbourhood do not share the same values". All items were scored on a 5-point scale with the categories: "strongly agree, agree, neutral, disagree, strongly disagree".

3.6. Multilevel regression analyses

Tables 2–4 show the associations of amount and quality, use and experience of the NOE with the outcome variables physical activity, social contacts with neighbors, and mental well-being.

(i) Physical activity

In the pooled analyses, greater perceived greenness, spending more time in it and finding the NOE to be important for health-related activities was statistically significantly associated with more minutes of physical activity ($p < 0.05$) (Table 2). Every point increase in sum score of perceived greenness (range 0–12) was related with about 10 min increase in physical activity each week ($\beta_{pooled} = 9.6$). For every point increase in sum score of importance of NOE for health-related activities (range 4–20), this was about 19 min increase in physical activity each week ($\beta_{pooled} = 18.6$). For time spent in the NOE the effect

was small - for every additional hour spent in NOE, physical activity increased by only 1.3 min per week. For each of the individual cities, the time spent in the NOE was statistically significant and positively associated with more minutes of physical activity. However, the strength of the association was weak, and varied considerably between the four cities (e.g. $\beta_{Stoke-on-Trent} = 0.8$ vs. $\beta_{Doetinchem} = 3.2$). The importance of the NOE for health-related activities was associated with more minutes of physical activity in all cities except for Doetinchem. For this indicator the strength of the association also differed between the cities (e.g. $\beta_{Stoke-on-Trent} = 11.3$ vs. $\beta_{Kaunas} = 31.5$). Perceived greenness showed a statically significant association with the total minutes of physical activity in Stoke-on-Trent and Kaunas, but not in the other two cities.

When putting all NOE indicators in one model, perceived greenness, time spent in the NOE and importance of the NOE for health-related activities were statistically significantly related to the total minutes of physical activity (data not shown). Time spent in the NOE was also statistically significant in all individual cities. Importance of the NOE for health-related activities was statistically significant in all cities except Kaunas. For the other variables there was no clear pattern for the individual cities (data not shown).

(ii) Social contacts with neighbors

Pooled analyses showed that a higher score for streetscape quality, a higher score for perceived greenness, greater satisfaction with the NOE, more time spent in the NOE and greater perceived importance of the NOE for health-related activities were all statistically significantly associated with a higher frequency of social contacts with neighbors (range 1–5) (Table 3). Effect sizes were again small (respectively 0.019, 0.042, 0.031, 0.002 and 0.044). While for mean NDVI within 300 m a statistically significant association was found ($\beta_{pooled} = 0.811$), it was not for the nearest NOE within 300 m. Again differences were found between cities. For example, a higher sum score for perceived greenness was associated with an increase in social contacts with neighbors in all cities except for Doetinchem. In Stoke-on- Trent, NDVI was statistically significantly associated with social contacts with neighbors and was strong ($\beta_{pooled} = 3.201$), while for the other cities there was no statistically significant association. A higher streetscape quality was associated with more social contacts in Kaunas, but not in the other cities.

When all indicators for the NOE were put into the same model it

Table 2
Results of multilevel analyses for physical activity (minutes per week) (β, 95%-CI, n; pooled and for individual cities).

	Pooled	Barcelona	Stoke-on-Trent	Doetinchem	Kaunas
Mean NDVI within 300 m	55.6	−17.3	221.9	242.5	−275.6
n	(−113.8, 225.0)	(−256.4, 221.9)	(−96.9, 540.6)	(−86.5, 571.6)	(−750.1, 198.9)
	3746	1000	950	822	962
NOE within 300 m (yes/no) (%)	15.9 (−27.6, 59.3)	25.4 (−19.9, 70.6)	47.8 (−76.4, 171.9)	−340.5 (−1184.7, 503.7)	5.4 (−889.6, 100.3)
n	3746	1000	950	822	962
Quality of natural features	2.1	0.1	6.6	9.7	0.0
	(−2.4, 6.6)	(−6.2, 6.4)	(−3.4, 16.6)	(−0.7, 20.0)	(−9.9, 10.0)
n	3748	1002	951	822	963
Perceived greenness	9.6[§]	−0.7	11.9[§]	7.4	17.8[§]
(sum score)	(5.1, 14.2)	(−7.4, 6.0)	(6.5, 17.4)	(−4.1, 18.9)	(4.6, 31.1)
n	3741	999	946	822	962
Satisfaction with the NOE	3.1	−1.5	5.1	−2.4	9.4
(sum score)	(−1.4, 7.6)	(−8.0, 5.0)	(−0.4, 10.5)	(−14.1, 9.3)	(−3.5, 22.3)
n	3736	994	946	822	962
Total time spent in the	1.3[§]	1.6[§]	0.8[§]	3.2[§]	1.1[§]
NOE (hours)	(1.0, 1.5)	(1.1, 2.1)	(0.5, 1.1)	(2.3, 4.1)	(0.6, 1.6)
n	3564	972	938	792	850
Importance of NOE for health-related activities (sum score)	18.6[§]	19.8[§]	11.3[§]	9.5	31.5[§]
	(13.9, 23.2)	(11.4, 28.3)	(6.3, 16.3)	(−2.7, 21.8)	(19.2, 43.7)
n	3741	998	948	821	962

*Levels included: neighborhood level and individual level; adjusted for age, gender, educational level; variables included in model separately.
[§] $p < 0.05$.

Table 3
Results of multilevel analyses for social contacts with neighbours (β, 95%-CI, n; pooled and for individual cities).

	Pooled	Barcelona	Stoke-on-Trent	Doetinchem	Kaunas
Mean NDVI within 300 m	0.811[§]	0.339	3.201[§]	−0.396	0.540
	(0.245, 1.378)	(−1.220, 1.899)	(2.058, 4.343)	(−1.175, 0.383)	(−0.618, 1.698)
n	3737	998	943	822	962
NOE within 300 m (yes/no) (%)	0.051 (−0.088, 0.191)	0.194 (−0.060, 0.449)	−0.450 (−0.974, 0.075)	0.689 (−0.993, 2.371)	−0.012 (−0.245, 0.221)
n	3737	998	943	822	962
Quality of natural features	0.019[§]	0.005	0.031	0.006	0.030[§]
	(0.002, 0.037)	(−0.039, 0.049)	(−0.013, 0.075)	(−0.023, 0.035)	(0.008, 0.052)
n	3739	1000	944	822	963
Perceived greenness (sum score)	0.042[§]	0.068[§]	0.035[§]	0.008	0.060[§]
	(0.029, 0.055)	(0.0400, 0.095)	(0.012, 0.058)	(−0.016, 0.032)	(0.029, 0.093)
n	3732	997	939	824	962
Satisfaction with the NOE (sum score)	0.031[§]	0.029[§]	0.041[§]	−0.003	0.053[§]
	(0.019, 0.044)	(0.005, 0.053)	(0.018, 0.064)	(−0.027, 0.020)	(0.021, 0.084)
n	3728	992	940	822	962
Total time spent in the NOE (hours)	0.002[§]	0.005[§]	0.002[§]	0.002[§]	0.002[§]
	(0.002, 0.003)	(0.003, 0.007)	(0.001, 0.003)	(0.000, 0.004)	(0.000, 0.003)
n	3556	971	931	792	850
Importance of NOE for health-related activities (sum score)	0.044[§]	0.050[§]	0.043[§]	0.054[§]	0.042[§]
	(0.031, 0.057)	(0.020, 0.080)	(0.022, 0.064)	(0.030, 0.078)	(0.012, 0.073)
n	3732	996	941	821	962

Levels included: neighborhood level and individual level; adjusted for age, gender, educational level; variables included in model separately.
[§] $p < 0.05$.

appeared that importance of the NOE for health-related activities was statistically significant in all cities, and approaching statistical significance in the pooled data (p = 0.05). Time spent in the NOE and perceived greenness showed a statistically significant relation in the pooled data, but there was no consistent pattern for the individual cities.

(iii) Mental well-being

For the pooled data, perceived greenness, satisfaction with the NOE, time spent in the NOE and importance of the NOE for health-related activities were statistically significantly and positively associated with mental well-being (transformed MHI5-score (range 8–100)). However, the strength of these associations was generally weak. For every point in increase in the sum score for perceived greenness, the MHI5-score increased with only 0.331. For every point in increase in the sum score for satisfaction with the NOE, this was 0.591. For every extra hour spent in NOE, this was only 0.023. For every point in increase in the sum score for importance of the NOE for health-related activities, this was 0.318. Analyses of individual cities showed some differences again. While perceived greenness was statistically significant associated with better mental well-being in Barcelona and Kaunas ($\beta_{Barcelona} = 0.415$ and $\beta_{Kaunas} = 0.735$), it was not in Stoke-on-Trent and in Doetinchem. While being more satisfied with the NOE was statistically significantly associated with better mental well-being in Barcelona, Kaunas and in Doetinchem ($\beta_{Barcelona} = 0.739$; $\beta_{Kaunas} = 0.517$; $\beta_{Doetinchem} = 0.924$), this was not the case in Stoke-on-Trent. Importance of NOE for health-related activities showed a statistically significant positive association with mental well-being in Stoke-on-Trent only. For time spent in the NOE all cities showed statistically significant associations, but the strength of the associations varied again between the cities (e.g. $\beta_{Doetinchem} = 0.047$ vs. $\beta_{Kaunas} = 0.016$).

Table 4
Results of multilevel analyses for mental well-being (MHI-5) (β, 95%-CI, n; pooled and for individual cities).

	Pooled	Barcelona	Stoke-on-Trent	Doetinchem	Kaunas
Mean NDVI within 300 m	6.403	5.854	11.271	9.347	−2.784
	(−0.870, 13.677)	(−10.384, 22.092)	(−8.099, 30.641)	(−1.515, 20.209)	(−17.175, 11.608)
n	3722	996	942	810	962
NOE within 300 m (yes/no) (%)	0.474 (−1.321, 2.278)	0.575 (−2.243, 3.393)	3.643 (−3.883, 11.168)	9.910 (−16.319, 36.140)	−0.172 (−3.072, 2.728)
n	3722	996	942	810	962
Quality of natural features	0.195	0.362	0.340	0.204	−0.004
	(−0.020, 0.410)	(−0.062, 0.787)	(−0.307, 0.988)	(−0.144, 0.553)	(−0.285, 0.278)
n	3724	998	943	810	963
Perceived greenness (sum score)	0.331[§]	0.415[§]	−0.135	0.340	0.735[§]
	(0.154, 0.507)	(0.0843, 0.748)	(−0.459, 0.188)	(−0.023, 0.703)	(0.331, 1.138)
n	3717	995	938	810	962
Satisfaction with the NOE (sum score)	0.591[§]	0.739[§]	0.231	0.924[§]	0.517[§]
	(0.423, 0.759)	(0.447, 1.031)	(−0.090, 0.551)	(0.560, 1.287)	(0.125, 0.910)
n	3712	990	938	810	962
Total time spent in the NOE (hours)	0.023[§]	0.027[§]	0.025[§]	0.047[§]	0.016[§]
	(0.013, 0.032)	(0.003, 0.051)	(0.007, 0.042)	(0.018, 0.075)	(0.000, 0.031)
n	3542	968	931	781	850
Importance of the NOE for health-related activities (sum score)	0.318[§]	0.272	0.352[§]	0.137	0.342
	(0.144, 0.493)	(−0.101, 0.645)	(0.059, 0.646)	(−0.247, 0.521)	(−0.037, 0.720)
n	3717	994	940	809	962

*Levels included: neighborhood level and individual level; adjusted for age, gender, educational level; variables included in model separately.
[§] $p < 0.05$.

The results of the analysis of the pooled data with all variables for the NOE included in one model, showed statistically significant associations for almost all indicators related to use and experience of NOE, except for perceived greenness. For individual cities no general pattern was found (data not shown).

4. Discussion

4.1. Main findings

Use of the NOE was positively and statistically significantly associated with all three outcome variables in our study, although effect sizes were generally small. More time spent in the NOE was associated with slightly more minutes of physical activity, higher frequencies of social contacts with neighbors, and higher scores of mental well-being. Spending time in the NOE is therefore likely to have a slight positive effect on health, as also suggested in other studies (Hartig et al., 2014; Nieuwenhuijsen et al., 2014; van den Berg et al., 2015). The results of this study also indicate that most natural environment visits take place near the home and are of short duration (< 2 h). Visits further away generally occur less frequently, but last longer. There is evidence from some experimental studies that improvements in mood occur within 5 min of exposure (Barton and Pretty, 2010), and that cognitive benefits are observed after longer exposures of between 20 and 50 min (Berman et al., 2008; Gidlow et al., 2016; Hartig et al., 2003; Laumann et al., 2003). However, for other suggested mechanisms such as physical activity and social contacts, insights regarding the minimum (or maximum) length and frequency of visits required to elicit beneficial effects in health are limited, particularly from non-experimental studies.

Our descriptive data indicated that visits to the NOE were most frequent in Doetinchem and Kaunas, the greenest cities in this study. At the same time, several studies have indicated that greenness is not the only determinant of use - accessibility, maintenance, suitability for activities, and safety are also relevant (Lee et al., 2015; Leslie et al., 2010; Mowen et al., 2007; Ou et al., 2016; Seaman et al., 2010). In Kaunas, many people owned a dog, which may help to explain the high frequency of NOE visits compared with participants from the other three cities.

People's experience of NOE may also determine use (Hartig et al., 2014; Lee et al., 2015; Lin et al., 2014; Seaman et al., 2010). From this study we learned that these experiences of NOE are also important predictors for physical activity, social contacts with neighbors, and mental well-being. It is, therefore, important to consider these experiences, not only to understand the underlying mechanism, but also to understand what motivates people to visit a NOE. In a broader sense, considering the importance of use and experience of NOE, and the relevance of the local context, it is clear simply offering a certain amount of NOE within 300 m might not confer health benefits. In addition, involving potential users of the NOE in the design process and organizing activities in the NOE to stimulate use may make new and existing NOEs more beneficial for health.

Contrary to our expectations and many previous studies (e.g. Almanza et al., 2012; Beyer et al., 2014; Dadvand et al., 2012; Sarkar et al., 2015; Triguero-Mas et al., 2015), we did not find a general statistically significant association between the GIS-measured surrounding greenness (NDVI within 300 m) or distance to the NOE from the home and physical activity, social contacts with neighbors and mental well-being. It could be that the GIS-derived indicators are relatively crude and that indicators that use network buffers or take into account typology, purpose, function etc. of the NOE would have identified an association. Another potential explanation (not explored here) is that there is a non-linear association. There may for example be a threshold or optimum for the amount of green space in relation to health.

Our findings did generally not confirm the association between the outcome variables and the quality of natural features either. An exception was the small, statistically significant positive association with

social contacts with neighbors in the pooled data and in Kaunas. This general lack of association with quality of natural features is contrary to the findings of de Vries et al. (2013) and other studies (Björk et al., 2008; Sugiyama and Ward Thompson, 2008; van Dillen et al., 2012), and may be explained by the fact that we only used limited information of the streetscape audit. Potentially other, more specific dimensions of the streetscape audit do show an association. We recommend such analyses for future research. It should also be noted that the streetscape audit only assesses the quality of the NOE as viewed from the street, whereas local residents who know the quality of the NOE from visiting it in their area may have a very different experience. Although not exactly the same, participants' satisfaction with (elements of) the NOE, as included in in our analyses, may also provide some impression of the quality of the NOE (Table 1 and Supplemental Material, Table S5).

Finally, we found considerable differences between cities in exposure, use and experience of NOE, in the outcome variables, and in the associations between NOE indicators and outcome variables. Differences in exposure were expected, since this was part of the study design. The cities involved offered variation in NOEs, to gain a broad insight into the underlying mechanism of NOE and health. However, differences in use and experience of NOE, and in the associations between exposure and outcome variables were not something we expected beforehand. These results emphasize the importance of considering the local context in NOE and health research. This may also help to explain why we do not see the same associations between NOE and health replicated in all studies on this topic, in which the majority of evidence points towards a beneficial association, but not all. It also raises the question to what extent it is possible to establish one generalized association for NOE and health indicators considering these differences between cities.

4.2. Strengths and weaknesses

Few studies have examined the different mechanisms underlying the beneficial effects of NOE on health at the same time, and none of them have examined such a large number of objective and subjective NOE indicators. This exploratory study aimed to do so, using primary data, specifically gathered to investigate the underlying mechanisms of the beneficial effects of NOE on health.

We collected data in four cities using a consistent approach. This made it possible to pool and compare data from these four cities. The differences observed between cities are therefore likely to be genuine differences rather than the result of methodological differences.

The variation in NOEs in the different cities made it possible to investigate potential mechanisms across a broad spectrum of NOEs, in settings with a large amount of NOEs (e.g. Doetinchem), and with limited availability (e.g. Barcelona).

While many studies on nature and health have focused only on exposure to NOE using amount of greenness or distance to a natural environment, this study also considered quality, use, and experience of the NOE. This was possible because we used a combination of data collection methods - remote sensing, GIS, audit, and a questionnaire survey (Nieuwenhuijsen et al., 2014).

Other studies often consider only one mechanism. This study collected data on several mechanisms at the same time – physical activity, social contacts and stress reduction through relaxation. This makes it possible to investigate the different mechanisms simultaneously.

We recognize also a number of limitations. First, although we used a consistent approach in the four cities, there was some unavoidable local variation in practice, for example with regard to the type of survey (face-to-face or postal) or recruitment via postal or face-to-face invitation.

Second, the response rate was low, especially in Doetinchem (8%), despite the attempts to increase the response rate of the questionnaire survey, such as additional sampling, reminders, coverage in local newspaper, and including of local people as interviewees. This may be

explained by the fact that people first needed to return a postal answer card with their permission before they could be approached for a face-to-face interview. In Barcelona and Stoke-on-Trent, where people were approached directly (following an initial mail-out), the response rate was higher. Thirdly, non-response analyses in Doetinchem and comparisons with the general population indicated that the study population was not representative of the general population of the four cities included in this study. Compared with the city average, the study population was more highly educated than the general population in all cities except for Stoke-on-Trent. In Doetinchem study participants were older and with a higher proportion of males than females (with the city average), and gave more importance to activities in the NOE than non-responders. It limits generalizability of findings to the general population.

Fourth, this study was cross-sectional, which prevents any inferences regarding causation or the direction of the associations (e.g. whether those with good mental well-being tend to perceive their environment as more green and spend more time in it, or if the perception of and time spent in local green space enhances mental well-being).

Fifth, we used mental well-being as a proxy to explore the mental stress reduction pathway, since this process cannot be assessed in a cross sectional, nonexperimental study is ours. Mental well-being, however, can be directly related with stress reduction, is sensitive for changes in circumstances, and can be measured in a reliable and valid way with MHI-5 (Ware, 2000) in questionnaire surveys in cross sectional studies. However, there may be alternative measures that can be used in future studies to investigate this pathway.

Sixth, as an indication for quality of the NOE we used street view audit data. However, using audit of the main areas of NOE within 300 m that a participant may visit, may provide a more accurate picture of quality of the NOE.

4.3. Future research

Based on the results of this study, we suggest that future research in this area pays more attention to use and experience of NOE, since they appeared to be fairly consistently and often statistically significantly related with physical activity, social contacts and mental well-being, and are therefore important to consider in studies. For example, further investigating the length and frequency of visits to NOE in relation to health outcomes would be worthwhile to further understand if there an optimum level of exposure and if this differs between subpopulations. In addition, it would be useful to better understand what characteristics of the NOE and what personal characteristics determine whether people use green space, and for what activities. This information can be used, for example, by urban designers, to create a NOE to maximize the potential health benefits.

Using more detailed exposure measures describing amount, access and quality of the NOE may further increase our insight in the underlying mechanism of NOE and health. This could be indicators that take into account typology, purpose, function of the NOE, and indicators that describe more specific dimensions of quality such as presence of facilities, incivilities, or acoustic quality.

5. Conclusions

This study showed that use (time spent in NOEs) and - less consistently- experience (perceived greenness, satisfaction with the NOE and importance of the NOE for health-related activities) were related to physical activity, social contacts and mental well-being, important outcome variables in studies of NOE and health. Therefore, use and experience of the NOE are important indicators to consider in studies on nature and health. Contrary to findings elsewhere, amount and quality of the NOE did not show a consistent pattern in their relation to participants' physical activity, social contacts with neighbors or mental well-being. There were large differences between the four study areas,

not only in exposure, but also in use and experience of NOE, and in the associations of these indicators with physical activity, social contacts with neighbors, and mental well-being. This underlines the importance of considering the local context.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2019.105173.

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