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Natural outdoor environments and mental health: Stress as a possible mechanism

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ABSTRACT

Introduction: Better mental health has been associated with exposure to natural outdoor environments (NOE). However, comprehensive studies including several indicators of exposure and outcomes, potential effect modifiers and mediators are scarce.

Objectives: We used novel, objective measures to explore the relationships between exposure to NOE (i.e. residential availability and contact) and different indicators of mental health, and possible modifiers and mediators.

Methods: A nested cross-sectional study was conducted in: Barcelona, Spain; Stoke-on-Trent, United Kingdom; Doetinchem, Netherlands; Kaunas, Lithuania. Participants' exposure to NOE (including both surrounding greenness and green and/or blue spaces) was measured in terms of (a) amount in their residential environment (using Geographical Information Systems) and (b) their contact with NOE (using smartphone data collected over seven days). Self-reported information was collected for mental health (psychological wellbeing, sleep quality, vitality, and somatisation), and potential effect modifiers (gender, age, education level, and city) and mediators (perceived stress and social contacts), with additional objective NOE physical activity (potential mediator)

Abbreviations: NOE, natural outdoor environments; NDVI, Normalized Difference Vegetation Index; IQR, interquartile range; SF-36, 36-item Short Form Health Survey Questionnaire; 4DSQ, four-dimensional symptom questionnaire

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derived from smartphone accelerometers.
Results: Analysis of data from 406 participants showed no statistically significant associations linking mental health and residential NOE exposure. However, NOE contact, especially surrounding greenness, was statistically significantly tied to better mental health. There were indications that these relationships were stronger for males, younger people, low-medium educated, and Doetinchem residents. Perceived stress was a mediator of most associations, and physical activity and social contacts were not.
Conclusions: Our findings indicate that contact with NOE benefits mental health. Our results also suggest that having contact with NOE that can facilitate stress reduction could be particularly beneficial.

1. Introduction

Existing evidence shows that exposure to natural outdoor environments (NOE) is beneficial for human health, including mental health (Carter and Horwitz, 2014; Richardson et al., 2013; Sturm and Cohen, 2014; Triguero-Mas et al., 2015; de Vries et al., 2013). Few studies in this area have focused on more than one aspect of mental health (van den Berg et al., 2016; Triguero-Mas et al., 2015). There has also been a common focus on mental health benefits of green space or blue space (i.e. sea, lakes, rivers, etc.). Researchers have rarely considered the potentially beneficial role of all NOE (an exception is Richardson et al., 2013). Moreover, the choice of NOE exposure indicators (e.g. surrounding greenness availability around residence, contact with green and/or blue spaces, etc.) and related implications for the NOE-mental health association remain unclear. This could have implications when investigating the links, underlying mechanisms and potential differences by social group (for an overview and a framework see Hartig et al., 2014).

In terms of the social patterning of NOE-health relationships, some findings suggest that people of low socioeconomic status (SES) may benefit more from NOE exposure (van den Berg et al., 2016; Dadvand et al., 2012a, 2012b; McEachan et al., 2015; de Vries et al., 2003). Other studies suggest that the health benefits of NOE vary by gender, age and cultural background (Astell-Burt et al., 2014; Dadvand et al., 2014). Yet, these differences are not well-established for mental health outcomes given the small number of studies exploring them (van den Berg et al., 2016; McEachan et al., 2015; Triguero-Mas et al., 2015; de Vries et al., 2003).

In terms of the mechanisms thought to explain the NOE-health relationship, reduction of stress, increased social interactions and increased physical activity have all been suggested as possible mechanisms underlying physical and mental health benefits of NOE (Hartig et al., 2014; Markevych et al., 2017). To date, the evidence on whether physical activity lies on the mechanistic path is mixed, while the evidence for stress and social interactions is reduced but consistent (Markevych et al., 2017).

This study aimed to explore: (i) the associations between NOE exposure (including both residential availability and contact with NOE) and mental health; (ii) whether these relationships were modified by gender, age, education, and city; and (iii) whether stress, social contacts or physical activity mediated these associations.

2. Methods

2.1. Study population

The Positive Health Effects on the Natural Outdoor environment in TYPical populations of different regions in Europe (PHENOTYPE) project aimed to investigate some of the mechanisms underpinning the commonly observed NOE-health relationships (Nieuwenhuijsen et al., 2014). PHENOTYPE collected data from four European cities: Barcelona (Spain), Stoke-on-Trent (United Kingdom), Doetinchem (The Netherlands) and Kaunas (Lithuania). Cities were selected to represent different European regions. The high-intermediate population density of these cities exemplified the type of area where most of Europeans live. Moreover, these cities provided diversity in typology, size and amount of NOE (Nieuwenhuijsen et al., 2014; Smith et al., 2017).

Data reported here were collected from a subsample of participants from a larger study (Nieuwenhuijsen et al., 2014). In the larger study, study neighbourhoods were selected in each city, sampled to maximise variability in residential availability of NOE and neighbourhood socioeconomic status (described in detail elsewhere (Smith et al., 2017)). Within each neighbourhood, adults (18–75 years) were randomly recruited to participate in a face-to-face survey (n = 3946). All the 3946 participants were invited to take part in another part of the study. Those interested were included in the present study if they were able to walk 300 m on ground level. The only exception to this sampling approach was in Stoke-on-Trent, where further mail shots to randomly selected households in the study neighbourhoods and opportunistic sampling within the area were required to boost the sample (see Supplemental material - Table S1). As a result, approximately half of Stoke-on-Trent participants were from the original random sample. The final study sample was 406: Barcelona (n = 107), Stoke-on-Trent (n = 90), Doetinchem (n = 105), and Kaunas (n = 104) inhabitants.

The study was conducted in accordance with Declaration of Helsinki principles. Ethical approvals were obtained from each of the relevant bodies: Clinical Research Ethics Committee of the Municipal Health Care (CEIC PS-MAR), Barcelona, Spain (2012/4978/I); Staffordshire University Faculty of Health Science ethics committee, United Kingdom; Medical Ethical Committee of the University Medical Centre Utrecht, Netherlands; Lithuanian Bioethics Committee, Lithuania (2012-04-30 Nr. 6B-12–147). Moreover, all participants provided written informed consent before taking part. Each participant received financial compensation on completion of the study (retail voucher or money depending on the country).

2.2. Design

Participants were asked to complete a daily diary and wear a smartphone with the CalFit application installed for seven consecutive days. The start (and finish) day of the study was always a weekday.

In the daily diary participants were asked to record the time periods when they had not worn the smartphone and the activities they undertook during those periods. They were also asked to complete a series of questions in the morning when they started to wear the smartphone (questions on psychological wellbeing, somatisation, vitality, and sleep quality) and in the evening when removing the smartphone (psychological wellbeing, somatisation, vitality).

Each participant carried the smartphone on a belt attached to the waist. Instructions were given to each participant to remove the belt only when performing activities that could damage the smartphone (e.g., aquatic activities), when sleeping, and when charging the smartphone battery. The open-source CalFit software runs on Android operating system smartphones. CalFit uses the Global Positioning System (GPS) receivers in smartphones to collect information on location. This information was treated to determine the contact with NOE (Supplemental material - page 5). CalFit uses the accelerometer motion sensor to collect valid information on physical activity (Donaire-Gonzalez et al., 2013; de Nazelle et al., 2013; Triguero-Mas et al., 2017) and to determine non-wear time. Wear-time of at least 10 h per day was

considered valid and included in analysis (Donaire-Gonzalez et al., 2013; Heil et al., 2012; Matthews et al., 2012). This objective approach to physical activity measurement was used given the issues with self-reported physical activity. Moreover, using smartphones had the additional benefit of simultaneous GPS recording for location specific physical activity measurement with a single device, which was thought to be preferable for participants.

2.3. Measures

2.3.1. Exposure to NOE

2.3.1.1. Residential availability of NOE. The residential address of each participant was geocoded and, using GIS, residential exposure was determined using a 300 m buffer around the home. The 300 m buffer was chosen for consistency with European recommendations (van den Bosch et al., 2016; European Commission, 2001) and based on evidence that use of NOE might decline at distances greater than 300–400 m (Gascon et al., 2015; Grahn and Stigsdotter, 2003).

a) *Presence of green and/or blue spaces*: The presence/absence of green and/or blue spaces was derived from Urban Atlas 2006 (European Environment Agency, 2014) for three of the cities, and Top10NL 2006 (The Netherlands' Cadastre. Land Registry and Mapping Agency) for Doetinchem. Both used a 1:10,000 scale and a minimum represented unit of 0.25 ha (Top10NL was adapted to be consistent with Urban Atlas). The categories of NOE included were: (i) urban green space, (ii) agricultural, semi-natural and wetland areas, (iii) natural forests and plantations, and (iv) water bodies. We determined presence/absence of green and/or blue spaces within circular and network buffers. Network buffers were defined using the road network, but excluding roads that were inaccessible to pedestrians (e.g. limited-access freeways, toll roads, and on/off ramps), using Network Analyst tools, ArcGIS 10. As too few people had green and/or blue spaces within residential circular buffer, and we believed that network buffer is a better estimate of exposure to NOE, we used network buffers for our analyses.
b) *Surrounding greenness availability*: Surrounding greenness was determined using the average of the Normalized Difference Vegetation Index (NDVI) within a straight-line buffer around residence. NDVI was derived from satellite images provided at 30 m × 30 m spatial resolution. Specifically, we used images from Landsat 5 (US Geology Survey, 2014a) for Kaunas and Stoke-on-Trent and from Landsat 8 (US Geology Survey, 2014b) for Barcelona and Doetinchem. NDVI is an indicator of green vegetation density based on the difference between visible red and near-infrared surface reflectance. NDVI values range from −1 to +1, with higher values indicating high density of green vegetation (Weier and Herring, 2000). To cover the entire study region for each city, we required four Landsat images in total. We aimed to find cloud-free images within the greenest season (May to September) between 2011 and 2013, the relevant period for this study. Based on this search we obtained an image from 16th April 2013 for Barcelona, 21st April 2011 for Stoke-on-Trent, 21st July 2013 for Doetinchem, and 8th June 2011 for Kaunas. We used the NDVI data excluding big water bodies, following PHENOTYPE project guidelines (Supplemental material - page 6).

2.3.1.2. Contact with NOE. Participants' location was assessed using the GPS and network signal from smartphones. This information was later processed using GIS to determine the NOE exposure for each minute of wear time.

a) *Contact with green and/or blue spaces*: Exposure to NOE (i.e. green and blue spaces) or non-NOE in each sampled minute was defined as the presence/absence of green or blue spaces within 50 m of each location point. Different datasets were needed to determine this presence/absence. We used Urban Atlas 2006 if the point was inside this dataset city limits (but for points inside Doetinchem city limits we used an adapted version of the Top10NL 2006). For the other points, CORINE Land Cover 2006 (CLC2006) was used. CORINE had a 1:100,000 resolution and minimum represented units of 25 ha. We used these data to obtain the percentage of total wear-time over the week that was spent in NOE, which was then used to create tertiles of NOE exposure for analysis (1 = < 3%; 2 = 3–16%; 3 = > 16%), where 3 was the reference category.
b) *Contact with surrounding greenness*: Exposure to surrounding greenery in each sampled minute was defined as the median NDVI within 50 m of each location point. NDVI was derived from the same Landsat satellite images described in 2.3.1.1.b. We used these data to obtain weekly median NDVI of the locations in which participant had been.
Median NDVI was expressed per interquartile range (IQR) increase in exposure. This IQR was calculated in reference to the pooled dataset (i.e. all the cities had the same IQR assigned).

2.3.2. Outcomes: indicators of mental health

Various mental health indicators were derived: psychological well-being, no somatisation, vitality and sleep quality.

2.3.2.1. Psychological wellbeing. Psychological wellbeing during the measurement week was self-assessed every morning and evening using the daily diaries. An adaptation from a subscale of The Medical Outcome Study Short Form (SF-36) general health survey – mental health dimension was used to measure momentary psychological wellbeing (rather than psychological wellbeing in the last month). Specifically, in the evening, participants were asked: today, have you felt: (i) "so down in the dumps nothing could cheer you up?", (ii) "downhearted and blue?", (iii) "you were a happy person?", (iv) "you were a nervous person?", and (v) "calm and peaceful?". Each item had six possible responses (all of the time, most of the time, a good bit of the time, some of the time, a little of the time, none of the time). For three items (i, ii and iv) the answers were scored as all of the time with a 1 and successively until none of the time with a 6. For two items (iii and v) the answers were inversely scored. The final index was a composite measure based on the sum of scored responses to the items. For the participants that answered only three or four of the five items, the missing items were estimated as the average score of the answered items to calculate the final index. For participants answering less than three items, a final index was not calculated. The final index was transformed to a 0 − 100 scale according to the guidelines (Ware et al., 1993):

$$\text{Transformed final index} = \frac{\text{Final items sum score} - 5}{25} * 100$$

Low scores of the transformed index indicated feelings of nervousness and depression, and higher scores indicated feeling peaceful, happy and calm. An average of all the evening transformed final indices (to be used in the main analyses) and an average of the morning ones (for sensitivity analyses, index derivation was similar to the evening one, see Supplemental material – page 7 for a detailed explanation) were calculated for each participant, where higher scores reflected greater psychological wellbeing (indicative of better mental health).

2.3.2.2. No somatisation. The lack of somatisation, as an indicator of good mental health, was self-assessed every morning and every evening using the daily diaries. Seven questions were used from an adaptation of the four-dimensional symptom questionnaire (4DSQ) (Terluin et al., 2006) to measure daily lack of somatisation (rather than in the last week) with two additional questions. Specifically, in the evening, participants were asked: Today, have you suffered from: (i) dizziness/light-headed, (ii) painful muscles, (iii) back and/or shoulder pain, (iv) headache, (v) nausea, (vi) pain in the abdomen or stomach area, (vii) pain in the chest, (viii) ache in the back of the head, (ix) fatigue. The

4DSQ items were from item (i) to (vii). Each item had five possible responses scored (1 = very often, 2 = often, 3 = regularly, 4 = sometimes, 5 = no). We constructed a sum score of all the items ranging between 9 and 45, with high scores indicating no perceived somatisation symptoms. An average was calculated from all the evening scores of each participant (for main analyses) and an average morning score was calculated to be used in sensitivity analyses (see Supplemental material – page 8 for a detailed explanation of score derivation). Higher scores of no somatisation were indicative of better mental health.

2.3.2.3. Vitality. Vitality was self-assessed every morning and every evening using the daily diaries. An adaptation of a subscale of SF-36 general health survey vitality dimension was used to measure momentary vitality instead of vitality in the last month. Specifically, in the evening, participants were asked: today, have you felt: (i) full of pep, (ii) you had a lot of energy, (iii) worn out, (iv) tired. Each item had six possible answers (all of the time, most of the time, a good bit of the time, some of the time, a little of the time, none of the time). For two items (i and ii) the answers were scored as none of the time with a 1 and successively until all of the time with a 6. For the other two items (iii and iv) the answers were scored inversely. The final index was a composite measure based on the sum of item scores. For the participants that answered only three of the four items, the missing items were computed as the average score of the answered items to calculate the final index. For participants answering less than three items, final index was not calculated. As above, the final index was transformed to a 0–100 scale according to the guidelines (Ware et al., 1993) as:

$$Transformedfinalindex = \frac{Finalitemssumscore - 4}{20} * 100$$

Low scores of the transformed index indicated feeling tired and worn out, and higher scores indicating feeling full of energy. An average of all the evening transformed final indices (to be used in the main analyses) and another of all the morning ones (to be used in sensitivity analyses, see Supplemental material – page 9 for derivation) were calculated for each participant. Higher scores of average week vitality reflected higher vitality (indicative of better mental health).

2.3.2.4. Sleep quality. Sleep quality was self-assessed using a question developed specifically for this study, which was completed every morning using the daily diaries. Under the heading of "Please describe how you slept last night", participants were asked to respond to the statement "I did sleep well?", with yes or no. Sleep quality for the week was calculated as the number of nights on which participants reported to have slept well. Higher values indicated higher sleep quality (indicative of better mental health).

2.3.3. Mediators

2.3.3.1. Perceived stress. Perceived stress was assessed every evening using a self-developed question included in the daily diaries: "Please, indicate how stressed have you felt during your day on this scale regarding overall stress (in general terms)". Reponses were recorded using a visual scale from 0 ("none") to 10 ("as bad as it could be"), with a mid-point labelled "usual stress level" (Supplemental material – page 10).

2.3.3.2. Social contacts. Information on social contacts was obtained in the face-to-face survey. We collected information on three aspects:

a) Social cohesion was assessed using the five-item social cohesion and trust scale (Sampson et al., 1997). Each item had five possible answers that are scored from one to five, with inverse scoring on those items negatively stated Scores ranged from 5 to 25, with higher scores indicating higher levels of social cohesion.
b) Neighbourhood attachment was assessed using three questions: "I feel attached to this neighbourhood", "I feel at home in this neighbourhood", and "I live in a nice neighbourhood were people have a sense of belonging". Each question was scored on a five-point scale (1 = strongly disagree to 5 = strongly agree). A sum score of all the questions was calculated (3 to 15), with higher score indicating stronger neighbourhood attachment.
c) Individual social contacts were assessed using the question: "How often do you have contact with your neighbours?". Response categories ranging from daily to seldom or never, were then dichotomised into "once per month or more" and "less than once per month".

2.3.3.3. Physical activity. Physical activity was assessed using CalFit-accelerometer data combined with time-matched CalFit-recorded location points. We evaluated light-to-vigorous intensity physical activity in NOE as duration (minutes) of physical activity at intensity ≥ 1.5 METS. From this, we determined the percentage of total wear-time over the week that was spent in light-to-vigorous intensity physical activity in NOE.

2.3.4. Covariates

Information on the city of residence, age, gender and education was obtained in the face-to-face survey. Information on neighbourhood socioeconomic status was derived from locally available indicators. These variables were included as potential covariates in our models.

2.4. Statistical analyses

We conducted complete cases analyses for each health outcome (n = 406 for sleep quality, n = 403 for the other health outcomes). We fitted linear regression models with adjustment for covariates to estimate the associations between NOE exposure and (i) psychological wellbeing, (ii) somatisation, (iii) vitality. Poisson regression models adjusted by covariates were used to investigate the relationship between NOE exposure and sleep quality. Each NOE exposure indicator was included in a separate model.

Effect modification by a number of factors (gender, age, education level, and city) was explored in two ways: (i) including interaction terms between these factors and NOE exposure indicators, and (ii) fitting stratified analyses by these factors.

Mediation was evaluated using the Baron and Kenny approach (Baron and Kenny, 1986) in R statistical package (version 3.1.0). Statistical significance was set at p-value ≤ 0.05.

2.5. Sensitivity analyses

2.5.1. Associations with average week morning mental health outcomes

We repeated the main analyses for contact with NOE using the average of morning scores for the various measures of mental health. This was appropriate to evaluate the robustness of our findings for average evening scores,

2.5.2. Acute associations (weekly changes and daily changes)

To explore if acute changes (i.e. changes over the week and changes over the day) had an impact on our outcomes, we performed two sets of analyses. First, to investigate changes over the week, we repeated the main analyses investigating the link between contact with NOE through the week and changes over the week in psychological wellbeing, vitality and somatisation. These week changes were assessed as last evening minus first morning scores. Second, to study changes over the day, we used contact with NOE on each day (i.e. percentage of time per day in NOE). In this second set of analyses, for sleep quality, we used binomial mixed effects models with subject as a random effect. Meanwhile, for the other health outcomes (psychological wellbeing, vitality daily change, no somatisation) daily changes were evaluated as the

difference between evening and morning scores, and were investigated in relation to daily NOE contact using mixed effects models with subject as a random effect.

3. Results

Of 8760 adults who were approached, 431 participated (4.92%), from which 406 (94.20%) were included in analyses (for city-specific details see Supplemental material – Table 1). The sociodemographic characteristics of study participants, prevalence of outcomes, and description of indicators of natural outdoor environments and mediators are presented in Table 1.

There were few statistically significant (Kruskal-Wallis tests, Chi-squared tests and posthoc tests p-values ≤ 0.05) differences in participant characteristics between cities (Table 1 and Supplemental material - Table S2). Participants in Kaunas were most highly educated and Doetinchem participants were older than in other cities. In Barcelona, the percentage of participants with a green and/or blue space within 300 m buffer of their home was lower than in other cities. Doetinchem participants had less contact with green and/or blue spaces than in the other cities. Contrary, Barcelona participants had more (medium-high) contact. Participants in Barcelona and Kaunas reported statistically significantly higher levels of stress than those in Stoke-on-Trent and Doetinchem. Kaunas participants reported statistically significantly higher scores of neighbourhood attachment compared with the other cities. Finally, a higher percentage of Doetinchem participants reported a high frequency of contacts with neighbours than in Kaunas.

3.1. The association between exposure to NOE and indicators of mental health

Residential availability of NOE was not tied to any of the mental health indicators (Fig. 1). That is, the 95% confidence interval (CI) of the incidence rate ratio of week sleep quality included 1.00, and the confidence intervals of the other mental health indicators included zero.

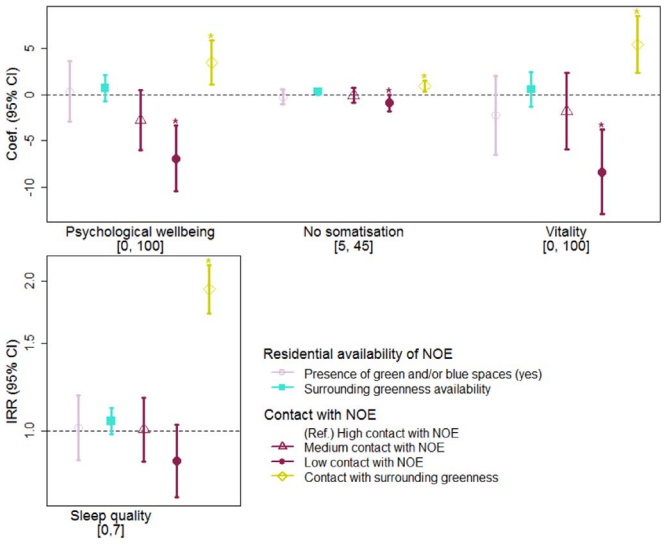

Fig. 1. Adjusted models for exposure to NOE (both residential availability and contact with NOE) and average evening week values of mental health. Note: Linear regression models (coefficient and 95% CI reported) for all the outcomes with the exception of sleep quality that was modelled as a Poisson model (IRR and 95% CI reported). Models include neighbourhood socioeconomic status, city, gender, age and education level as covariates. Estimates in italics indicate that contact with NOE is statistically significantly associated to the outcome in the expected direction. * Statistically significant associations (p-value $\leq$ 0.05). NOE for Natural Outdoor Environments.

Table 1
Descriptive statistics of sample sociodemographic characteristics, health outcomes, exposure and potential mediators, by city of residence.

Variable	Total	Barcelona	Stoke-on-Trent	Doetinchem	Kaunas
Subjects	406	107	90	105	104
Sampled time over the measurement period [minutes: median (IQR)]	6627.00 (3615.50)	7010.00 (3252.00)	6703.00 (3009.00)	6487.00 (3651.00)	5947.00 (3125.00)
Sociodemographic characteristics					
Gender, *females* [n (%)]	216.00 (53.20)	50.00 (46.73)	51.00 (56.67)	58.00(55.24)	57.00 (54.81)
Age [years: median (IQR)]	51.00 (26.00)	40.00 (23.00)	43.50 (28.75)	59.00(16.00)	55.00 (23.25)*
Education, *low-medium* [n (%)]	175.00 (43.10)	49.00 (45.79)	47.00 (52.22)	53.00 (50.48)	26.00 (25.00)*
Neighbourhood socioeconomic status [n (%)]					
Low	124.00 (30.54)	43.00 (40.19)	22.00 (24.44)	32.00 (30.48)	27.00 (25.96)
Medium	137.00 (33.74)	38.00 (35.51)	32.00 (35.56)	31.00 (29.52)	36.00 (34.62)
High	145.00 (35.71)	26.00 (24.30)	36.00 (40.00)	42.00 (40.00)	41.00 (39.42)
Outcomes (based on evening information)					
Psychological wellbeing [n.u.: median (IQR)]	84.00 (17.18)	78.67 (14.20)	82.67 (20.00)	88.00 (9.00)	84.73 (15.83)
No somatisation [n.u.: median (IQR)]	43.50 (2.84)	43.50 (3.00)	43.40 (3.83)	44.00 (2.47)	43.50 (3.00)
Vitality [n.u.: median (IQR)]	72.50 (25.00)	67.50 (25.21)	63.33 (33.33)	80.83 (16.25)	72.75 (21.35)
Sleep quality [nights: median (IQR)]	3.00 (3.00)	3.00 (2.00)	2.00 (3.00)	3.00 (3.00)	2.50 (3.00)
Exposure					
Presence of green and/or blue spaces, *none* [n (%)]	119 (29.31)	63 (58.88)	19 (21.11)	3 (2.86)	34 (32.69)*
Surrounding greenness availability [n.u.: median (IQR)]	4.19 (2.07)	2.48 (1.00)	3.84 (1.00)	4.34 (1.00)	5.55 (1.00)*
Contact with green and/or blue spaces [n (%)]					
Low (< 3% of the time)	148.00 (36.45)	17.00 (15.89)	32.00 (35.56)	63.00 (60.00)	36.00 (34.62)
Medium (3–16% of the time)	122.00 (30.05)	52.00 (48.60)	32.00 (35.56)	7.00 (6.67)	31.00 (29.81)
High (>16% of the time)	136.00 (33.50)	38.00 (35.51)	26.00 (28.89)	35.00 (33.33)	37.00 (35.58)
Contact with surrounding greenness [n.u.: median (IQR)]	1.40 (0.99)	0.73 (0.54)	1.54 (0.68)	1.74 (0.85)	1.65 (0.62)
Mediators					
Perceived stress [n.u.: median (IQR)]	2.17 (3.00)	3.10 (3.43)	1.80 (2.65)	1.63 (2.4)	2.79 (3.19)*
Social contacts indicators					
Social cohesion [n.u.: median (IQR)]	12.00 (5.00)	13.00 (4.75)	11.00 (4.50)	11.00 (4.00)	14.00 (4.00)
Neighbourhood attachment [n.u.: median (IQR)]	7.00 (3.00)	6.00 (4.00)	6.00 (3.00)	6.00 (3.00)	9.00 (3.00)*
Frequency of contacts with neighbours, *low* [n (%)]					*
Low (less than once a month)	56.00 (13.79)	19.00 (17.76)	9.00 (10.00)	7.00 (6.67)	21.00 (20.19)
Physical activity indicators					
NOE light-to-vigorous physical activity (time) [%: median (IQR)]	3.35 (4.88)	1.61 (3.45)	2.34 (3.38)	6.55 (4.52)	3.12 (4.02)

Note: n.u. indicates no units.
* Indicate those variables statistically significantly different between cities according to Chi-squared or Kruskal-Wallis tests.

Contrary, the estimates consistently showed that more contact with NOE was related to better mental health. However, only contact with surrounding greenness (rather than specific green/blue spaces) was statistically significantly associated to better mental health across all the indicators (Fig. 1). In particular, the rate of sleeping well was 92% higher in those with surrounding greenness contact compared to people without contact with surrounding greenness. Similarly, scores of psychological wellbeing, no somatisation and vitality were between 0.92 and 5.38 higher in those with surrounding greenness contact.

3.2. Potential effect modifiers

No consistent evidence was found for gender, age, education or city as effect modifiers. Very few statistically significant interaction terms between potential modifiers and contact with NOE were found (Supplemental material - Table S3). However, findings were more consistent and usually stronger for males, younger participants, low-medium educated participants and those living in Doetinchem (Tables 2 and 3).

3.3. Potential mediators

When looking at the potential mediators, only perceived stress fulfilled the criteria of being tied to the NOE exposure and outcome variable(s) (data now shown). Moreover, physical activity indicators satisfied this criterion only for contact with green and/or blue spaces (data not shown). Therefore, only these mediators were further explored.

Higher perceived stress was related to worse mental health (i.e. lower psychological wellbeing, higher somatisation, lower vitality) after adjustment (one at a time) for contact with green and/or blue spaces and contact with surrounding greenness (Table 4). Perceived stress completely mediated the relationship between contact with green and/or blue spaces and lack of somatisation. That is, when including perceived stress in the model, the association between no somatisation and the exposure variable disappeared. For the other models, stress partially mediated the associations. For example, the estimates of the benefits of contact with surrounding greenness on mental health went from 3.46 (95% CI: 1.08, 5.84) to 1.97 (95% CI: 0.03, 3.90) for psychological wellbeing, from 0.92 (95% CI: 0.34, 1.51) to 0.70 (95% CI: 0.15, 1.25) for lack of somatisation, and from 5.38 (95% CI: 2.32, 8.45) to 3.90 (95% CI: 1.17, 6.63) for vitality.

3.4. Sensitivity analyses

The estimations and their statistical significance found in the main analyses were consistent when evaluating the associations for average week morning outcomes for the various mental health indicators (Supplemental material – Table S4). However, there were differences in estimations and their statistical significance when evaluating the relationships between NOE contact and changes in mental health indicators over the week or over the day. Findings were not consistent with the main analyses and did not show discernible patterns (Supplemental material – Tables S5 and S6).

4. Discussion

We found that contact with NOE, particularly when measured using surrounding greenness, was tied to better mental health. There was no association with residential availability of NOE. We also found some evidence that the relationships were stronger for males, younger people, those with low-medium education, and residents of Doetinchem. Finally, we found that stress reduction was a mediator of most associations, but physical activity or social cohesion were not.

Our differential findings for the relationship between NOE exposure and mental health when using residential availability of NOE or contact with NOE are novel. These findings highlight the importance of which method is used to characterise NOE exposure. The existing literature

Table 2
Adjusted models for contact with NOE and average evening week values of mental health stratified by gender or by age.

Outcomes and stratification groups		Contact with green and/or blue spaces			Contact with surrounding greenness
		High	Medium Coef. (95% CI)	Low Coef. (95% CI)	Coef. (95% CI)
Males					
	Psychological wellbeing	ref	−3.48 (−7.98, 1.01)	*−9.14 (−14.42, −3.86)*[*]	3.38 (−0.15, 6.90)
	No somatisation	ref	−0.18 (−1.27, 0.91)	−1.10 (- 2.38, 0.18)	*1.05 (−0.22, 1.88)*[*]
	Vitality	ref	−2.81 (−8.71, 3.07)	*−11.62 (−18.54, −4.70)*[*]	*6.23 (1.65, 10.80)*[*]
	Sleep quality§	ref	0.94 (0.77, 1.15)	*0.74 (0.58, 0.96)*[*]	*2.02 (1.72, 2.38)*[*]
Females					
	Psychological wellbeing	ref	−2.54 (−7.15, 2.08)	*−5.00 (−9.79, −0.21)*[*]	4.01 (0.77, 7.24)[*]
	No somatisation	ref	−0.16 (−1.35, 1.03)	−0.63 (- 1.86, 0.61)	*0.84 (0.06, 1.73)*[*]
	Vitality	ref	−1.52 (−7.55, 4.50)	−5.56 (−11.81, 0.69)	*5.27 (1.05, 9.49)*[*]
	Sleep quality§	ref	1.10 (0.88, 1.36)	1.02 (0.81, 1.28)	*1.85 (1.59, 2.16)*[*]
Age below or equal to city median age value					
	Psychological wellbeing	ref	−3.28 (−7.83, 1.27)	*−9.34 (−14.52, −4.17)*[*]	6.82 (3.35, 10.29)[*]
	No somatisation	ref	−0.78 (−1.90, 0.34)	*−1.29 (−2.56, −0.01)*[*]	*1.54 (0.70, 2.38)*[*]
	Vitality	ref	−2.37 (−7.87, 3.14)	*−10.91 (−17.17, −4.66)*[*]	*8.49 (4.30, 12.68)*[*]
	Sleep quality§	ref	1.07 (0.87, 1.32)	0.82 (0.64, 1.05)	*2.13 (1.80, 2.51)*[*]
Age above the city median age value					
	Psychological wellbeing	ref	−2.95 (−7.40, 1.49)	*−5.61 (−10.38, −0.83)*[*]	0.54 (−2.62, 3.70)
	No somatisation	ref	0.37 (- 0.78, 1.52)	−0.87 (- 2.11, 0.36)	0.51 (−0.30,1.32)
	Vitality	ref	−2.17 (−8.47, 4.14)	*−6.89 (−13.67, −0.11)*[*]	3.30 (−1.15, 7.74)
	Sleep quality§	ref	0.93 (0.75, 1.15)	0.92 (0.73, 1.16)	*1.83 (1.57, 2.13)*[*]

Note: Linear regression models (coefficient and 95% CI reported) for all the outcomes with the exception of sleep quality (§) that was modelled as a Poisson model (IRR and 95% CI reported). Models include city, neighbourhood socioeconomic status, and education level as covariates. Models stratified by gender also include age as a covariate. Models stratified by age also include gender as a covariate. Estimates in italics indicate that contact with NOE is statistically significantly associated to the outcome in the expected direction.
NOE for Natural Outdoor Environments.
[*] Statistically significant associations (p-value ≤ 0.05).

Table 3
Adjusted models for contact with NOE and average evening week values of mental health stratified by education or by city.

Outcomes and stratification groups		Contact with green and/or blue spaces			Contact with surrounding greenness
		High	Medium Coef. (95% CI)	Low Coef. (95% CI)	IRR (95% CI)
Low-medium education level					
	Psychological wellbeing	ref	−4.76 (−10.13, 0.62)	*−12.11 (−18.03, −6.20)**	*4.61 (0.66, 8.56)**
	No somatisation	ref	−0.65 (- 2.09, 0.78)	*−1.64 (- 3.23, −0.06)**	1.53 (0.52, 2.54)*
	Vitality	ref	−2.19 (−9.09, 4.72)	*−11. 76 (−19.36, −4.16)**	*5.09 (0.09, 10.09)**
	Sleep quality§	ref	1.13 (0.89, 1.44)	0.92 (0.70, 1.20)	*2.00 (1.68, 2.39)**
High education level					
	Psychological wellbeing	ref	−1.45 (−5.33, 2.42)	*−4.58 (−8.93, −0.23)**	*2.89 (0.01, 5.77)**
	No somatisation	ref	0.36 (- 0.56, 1.28)	−0.32 (−1.35, 0.71)	0.49 (- 0.19, 1.17)
	Vitality	ref	−1.65 (−6.87, 3.57)	*−6.98 (−12.84, −1.12)**	*5.92 (2.07, 9.78)**
	Sleep quality§	ref	0.92 (0.76, 1.11)	*0.78 (0.62, 0.97)**	*1.92 (1.67, 2.22)**
Barcelona					
	Psychological wellbeing	ref	1.04 (−6.13, 8.20)	−6.19 (−13.09, 0.72)	2.77 (−3.62, 9.15)
	No somatisation	ref	1.26 (,−0.38, 2.89)	−0.54 (2.11, 1.03)	−0.22 (- 1.68, 1.24)
	Vitality	ref	4.61 (−5.84, 15.05)	−3.56 (−13.63, 6.50)	0.44 (−8.74, 9.63)
	Sleep quality§	ref	1.01 (0.72, 1.41)	0.85 (0.61, 1.19)	*1.87 (1.42, 2.47)**
Stoke-on-Trent					
	Psychological wellbeing	ref	−4.81 (−13.88, 4.26)	−5.96 (−14.68, 2.77)	3.42 (−3.26, 10.09)
	No somatisation	ref	−1.86 (- 4.24, 0.52)	−1.68 (- 3.97, 0.61)	1.90 (0.18, 3.62)*
	Vitality	ref	−2.25 (−13.15, 8.66)	−9.63 (−20.11, 0.86)	3.83 (−4.28, 11.93)
	Sleep quality§	ref	1.03 (0.74, 1.45)	0.93 (0.66, 1.30)	*1.78 (1.39, 2.28)**
Doetinchem					
	Psychological wellbeing	ref	−3.97 (−8.48, 0.53)	*−9.91 (−19.09, −0.74)**	*4.40 (1.54, 7.25)**
	No somatisation	ref	0.30 (- 0.98, 1.58)	−0.60 (−3.21, 2.01)	1.48 (0.71, 2.25)*
	Vitality	ref	−4.21 (−11.04, 2.61)	−10.40 (−24.30, 3.51)	*7.77 (3.60, 11.94)**
	Sleep quality§	ref	0.92 (0.71, 1.20)	0.63 (0.34, 1.19)	*1.93 (1.63, 2.28)**
Kaunas					
	Psychological wellbeing	ref	−0.41 (−6.00, 5.17)	−2.85 (−8.82, 3.12)	2.33 (−2.29, 6.95)
	No somatisation	ref	0.03 (−1.23, 1.28)	−0.06 (−1.40, 1.28)	−0.48 (- 1.51, 0.56)
	Vitality	ref	−1.36 (−7.92, 5.20)	−4.48 (−11.49, 2.52)	4.47 (−0.93, 9.87)
	Sleep quality§	ref	1.08 (0.80, 1.44)	1.01 (0.73, 1.40)	*1.99 (1.53, 2.60)**

Note: Linear regression models (coefficient and 95% CI reported) for all the outcomes with the exception of sleep quality (§) that was modelled as a Poisson model (IRR and 95% CI reported). Models include neighbourhood socioeconomic status, gender and age as covariates. Models stratified by education level also include city as a covariate. Models stratified by city also include education level as a covariate. Estimates in italics indicate that contact with NOE is statistically significantly associated to the outcome in the expected direction.
NOE for Natural Outdoor Environments.
* Statistically significant associations (p-value ≤ 0.05).

shows apparently beneficial associations between residential NOE exposure and mental health using a wide range of measures (Astell-Burt et al., 2013; Carter and Horwitz, 2014; van Dillen et al., 2012; McEachan et al., 2015; Richardson et al., 2013; Sturm and Cohen, 2014; de Vries et al., 2013). The previous evidence is based on bigger sample sizes than the present study, so it could be that our study lacked statistical power to detect the relationship between residential NOE exposure and mental health, and/or that in other studies residential NOE exposure acts as a (poorer) surrogate of contact with NOE. Furthermore, Picavet et al.'s (2016) Doetinchem study found links for several mental health indicators (depressive complaints, depression, role limitation due to emotional problems) with exposure to NOE within 1 km of the home, but not NOE exposure within 125 m. So we believe that the exposure indicators used in previous studies may have been better proxies of actual contact with NOE than our 300 m buffer measure. Using bigger buffer sizes (Astell-Burt et al., 2013) could allow researchers to capture, not only residential NOE exposure, but also help to reflect exposure when commuting or at work. Moreover, using ground-based objective quality and quantity measures (i.e. from audits) or subjective measures (Carter and Horwitz, 2014; van Dillen et al., 2012; Sturm and Cohen, 2014; de Vries et al., 2013) could capture additional factors that influence the extent to which people engage with their local NOE.

Our finding that more contact with NOE is tied to better mental health is in accordance with the only other study that has explored visits to NOE (self-reported) and mental health using data from participants of the larger PHENOTYPE study (van den Berg et al., 2016). However, our study adds indications that assessing NOE as surrounding greenness or green/blue spaces may be controversial as well. These differential results between exposure indicators may be explained by exactly what is captured by each exposure variable. Contact with NOE includes both green and blue space, but only those that are publically accessible and larger than 0.5 ha. Meanwhile, contact with surrounding greenness includes all types of green spaces, including private spaces and small spaces such as gardens and street trees (Mitchell et al., 2011).

Some evidence of effect modification by gender, age, education and city was found. Greater consistency and strength of associations for males compared with females is in line with a UK study that found lower cardiovascular and respiratory disease mortality rates with higher residential green space in men, but not women (Richardson and Mitchell, 2010). As the authors suggested, these differences could be hypothesized to be due to the concerns that women have for their personal safety in Richardson and Mitchell (2010). Such fears could reduce the likelihood of women visiting NOE, whilst also reducing the potential benefit of engaging with these environments. Alternatively, these fears might result in women having a lower preference than men for remote natural settings (Richardson and Mitchell, 2010), which potentially have the greatest potential to contribute to benefit mental health. This concerns would not let them restore as much as men, or might result in a lower preference for remote natural settings (Richardson and Mitchell, 2010), which are potentially the ones with higher restoration potential.

Findings of more consistent and stronger relationships for younger people are in partial agreement with those of a longitudinal study by

Table 4
Adjusted models for contact with NOE and average evening week values of mental health with mediator included.

Outcomes and potential mediators	Contact with green and/or blue spaces				Contact with surrounding greenness	
	Exposure			mediator	Exposure	mediator
	High	Medium Coef. (95% CI)	Low Coef. (95% CI)	Coef. (95% CI)	Coef. (95% CI)	Coef. (95% CI)
Psychological wellbeing						
Perceived stress	ref	−2.47 (−5.06, 0.12)	*−4.44 (−7.30, −1.58)**	*−4.21 (−4.78, −3.64)**	*1.97 (0.03, 3.90)**	*−4.25 (−4.82, −3.67)**
NOE light-to-vigorous physical activity (time)	ref	−2.34 (−5.59, 0.91)	*−5.70 (−9.60, −1.81)**	0.22 (−0.09, 0.53)	–	–
No somatisation						
Perceived stress	ref	−0.07 (−0.82, 0.67)	−0.53 (−1.36, 0.29)	*−0.64 (−0.80, −0.47)**	*0.70 (0.15, 1.25)**	*−0.63 (−0.79, −0.47)**
NOE light-to-vigorous physical activity (time)	ref	0.01 (−0.80, 0.82)	−0.57 (−1.54, 0.40)	0.06 (- 0.02, 0.14)	–	–
Vitality						
Perceived stress	ref	−1.53 (−5.21, 2.15)	*−5.83 (−9.90, −1.75)**	*−4.26 (−5.08, −3.45)**	*3.90 (1.17, 6.63)**	*−4.29 (−5.10, −3.48)**
NOE light-to-vigorous physical activity (time)	ref	−1.28 (−5.49, 2.93)	*−6.89 (−11.93, −1.84)**	0.27 (−0.13, 0.67)	–	–
Sleep quality§						
Perceived stress		–	–	–	*1.89 (1.69, 2.11)**	0.97 (0.94, 1.00)
NOE light-to-vigorous physical activity (time)		–	–	–	–	–

Note: Linear regression models (coefficient and 95% CI reported) for all the outcomes with the exception of sleep quality (§) that was modelled as a Poisson model (IRR and 95% CI reported). Models include city, neighbourhood socioeconomic status, gender, age, and education level as covariates. Estimates in italics indicate that NOE is statistically significantly associated to the outcome or the mediator in the expected direction.
NOE for Natural Outdoor Environments.
* Statistically significant associations (p-value ≤ 0.05).

Astell-Burt et al. (2014). They found that amount of residential green space improved mental health of young males in Britain, while for females, the benefits were only observed in those aged 45 years or older. We were unable to explore effect modification by age and gender at the same time, so our analysis was unable to support or refute this effect.

Our findings of more consistent and stronger associations for those with low-medium education attainment, a proxy socio-economic status indicator, agree with previous research (Dadvand et al., 2012a, 2012b; McEachan et al., 2015). However, the existing evidence is from studies of residential NOE (not contact) and theorized that stronger findings for more disadvantaged groups were probably explained for these groups spending more time near their homes and consequently more time in their immediate neighbourhood environment. Our data, however, do not fully support this assertion. The differences could be explained by high and low socio-economic groups being able to use a range of services, irrespectively of their proximity to home, but that more advantaged groups might be less dependent on freely available facilities and have more options to improve their mental health (i.e. able to pay for mental health services) compared with disadvantaged groups.

Our results of more consistent relationships for Doetinchem are novel, but are indicative of the effect of cultural context on the relationship between health and NOE reported elsewhere (Dadvand et al., 2014). In this earlier longitudinal study, a link between residential surrounding greenness and birth weight was reported for White British participants, but not for those of Pakistani origin.

The finding that perceived stress (but physical activity or social cohesion) partially mediated all associations, is in line with a previous analysis of data from four Dutch cities (de Vries et al., 2013). Only two studies had previously investigated the potential factors in the causal pathway between NOE exposure and psychological wellbeing and somatisation (Richardson et al., 2013; de Vries et al., 2013), but none has explored NOE contact or other mental health indicators (such as vitality or week sleep quality). Our findings indicate that it is not necessarily the intensity of activity undertaken in a NOE that benefits health, but the reduction of stress that visiting the NOE confers (de Vries et al., 2013).

We are unaware of previous studies on the impact of NOE contact in weekly and daily changes in mental health. The lack of identifiable patterns when we evaluated weekly and daily changes is suggestive of a more chronic rather than acute effect of contact with NOE on mental health. The small changes in NOE exposure observed over the course of a day or a week were perhaps insufficient to promote a change in mental health. Rather, our analyses of NOE contact and average mental health across a week (measured in the evening or morning) better represented habitual NOE engagement and mental health status of our subjects.

4.1. Strengths and limitations

Previous published studies on the link between NOE exposure and mental health outcomes are generally limited to residential NOE exposure, and often just green or blue space. The present study is the first to use objectively assessed contact with NOE (green and blue spaces) and repeated measures of various mental health indicators in multiple cities. This makes it the first study to explore the aforementioned associations, mediators and effect modifiers in different geographical areas (using consistent methods), providing insight regarding the implications of NOE characterisation and on effects over time.

Several of our NOE exposure measures used land cover and land use information from 2006, which may not capture the situation during our period of interest. However, taking into account the economic situation in Europe since 2008, the land use and land cover information for 2006 can be assumed to be representative of 2013. In fact, the recently published Urban Atlas 2012 shows small green and or/blue spaces use differences for Barcelona, Stoke-on-Trent and Kaunas compared with information from Urban Atlas 2006 (European Environment Agency, 2016).

We were unable to explore the differences by ethnic group. Moreover, the study sample size limited the statistical power to test for interactions and prevented stratification by several potential effect modifiers simultaneously. Future studies should take these factors into account, whilst exploring relationships in different cities with a range of cultural contexts.

Our measures of mental health outcomes were assessed with adapted versions of self-reported questionnaires. The indicators we used for lack of somatisation symptoms, sleep quality and perceived stress indicators were not standardized and validated tools. Moreover, our exposures, outcomes and mediators are not exactly temporally matched. We used the best measurement tools available, but they may induce measurement error to our analyses. Validation studies would be

needed. Moreover, future studies should try to improve temporal pairing.

The main gap in the current NOE-health literature is longitudinal studies. We were not able to establish if the exposures preceded the outcome because we did not find effects over a day or a week. Future research may shed more light on potential associations on changes over longer time periods (e.g. monthly or seasonal changes).

4.2. Policy implications

It has recently been estimated that mental health disorders in 2010 cost US$2.5·1012 worldwide, including both direct and indirect costs. Moreover, it has been predicted that by 2030 this amount could rise to US$6.0·1012 (Bloom et al., 2011). Our study provides evidence for a substantial link between contact with NOE and mental health. Moreover, although findings of this study did not indicate an association between residential NOE and mental health, the potential health effects of residential NOE cannot be dismissed. Mental health awareness needs to be integrated into all policies. Specifically, measures to improve the mental health of populations should include initiatives which explicitly address the links between urban planning and mental health. When doing so, special emphasis should be put on using NOE exposure indicators that are good proxies of NOE contact.

5. Conclusions

Population mental health could benefit from environmental interventions aiming to increase public contact with NOE. In particular our data suggest focusing on surrounding greenness contact and NOE typologies or characteristics that enhance stress reduction to maximise the mental health potential of contact with NOE.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2017.08.048.

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