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Momentary mood response to natural outdoor environments in four European cities

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ABSTRACT

Exposure to natural outdoor environments (NOE) has been shown in population-level studies to reduce anxiety and psychological distress. This study investigated how exposure to one's everyday natural outdoor environments over one week influenced mood among residents of four European cities including Barcelona (Spain), Stoke-on-Trent (United Kingdom), Doetinchem (The Netherlands) and Kaunas (Lithuania). Participants (n = 368) wore a smartphone equipped with software applications to track location and mood (using mobile ecological momentary assessment (EMA) software), for seven consecutive days. We estimated random-effects ordered logistic regression models to examine the association between mood (positive and negative affect), and exposure to green space, represented by two binary variables indicating exposure versus no exposure to NOE using GPS tracking and satellite and aerial imagery, 10 and 30 min prior to participants' completing the EMA. Models were adjusted for home city, day of the week, hour of the day, EMA survey type, residential NOE exposure, and sex, age, education level, mental health status and neighbourhood socioeconomic status. In addition, we tested for heterogeneity of effect by city, sex, age, residential NOE exposure and mental health status. Within 10 min of NOE exposure, compared to non-exposure, we found that overall there was a positive relationship with positive affect (OR: 1.39, 95% CI: 1.06, 1.81) of EMA surveys, and non-significant negative association with negative affect (OR: 0.80, 95% CI: 0.58, 1.10). When stratifying, associations were consistently found for Stoke-on-Trent inhabitants and men, while findings by age group were inconsistent. Weaker and less

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consistent associations were found for exposure 30 min prior to EMA. Our findings support increasing evidence of psychological and mental health benefits of exposure to natural outdoor environments, especially among urban populations such as those included in our study.

1. Introduction

It has been argued that our primary response to environments is affective (Ittelson, 1973). Exposure to nature has been shown to affect various aspects of mental health, including cognitive function, depression, and mood (Hartig et al., 2014; Kondo et al., 2018a). The inspiration for much of this work is often attributed to one of several concepts and theories. E.O. Wilson's biophilia hypothesis is one, which poses that humans naturally affiliate with nature due to our innate dependence upon it for survival (Kellert and Wilson, 1995). Two related prevailing theories are Attention Restoration Theory (ART) and Stress Reduction Theory (SRT) (Kaplan and Kaplan, 1989; Ulrich, 1979). Although neither are grounded in the affective sciences – with ART focused on attention overload and cognitive restoration, and SRT on recovery from physiological stress - feeling stressed is a mood state. Stress reduction theory specifically poses that natural environments improve affective states through stress recovery and lowered physiological arousal (Ulrich, 1983; Ulrich et al., 1991b). In the foundational theoretical works, their accompanying studies (e.g. Ulrich et al. (1991b)), and in following work, mood is frequently discussed and measured as a critical outcome of nature exposure.

The natural outdoor environments (NOE), including green vegetation and blue water resources, may matter for the mental health of residents especially in urban areas. A growing number of studies have measured mood in response to exposure to NOE compared to urban or built stimuli (Beil and Hanes, 2013; Berman et al., 2008; Bratman et al., 2015; Butryn and Furst, 2003; Gidlow et al., 2016; Grazuleviciene et al., 2016; Hartig et al., 1991; Hull and Michael, 1995; Mayer et al., 2009; Ryan et al., 2010; Song et al., 2015, 2014, 2013; Triguero-Mas et al., 2017b; Tyrväinen et al., 2014; Ulrich et al., 1991a). Much of this work has focused on 'positive' or 'negative' mood more generally and singular findings suggest positive associations between NOE exposure and happiness, sense of vitality and negative associations with feelings of anger and depressive symptoms (Berman et al., 2008; Bratman et al., 2015; Hartig et al., 1991; Ryan et al., 2010). Another commonly reported affective response to nature is a sense of relaxation and calm (Davis et al., 2016; Herzog and Barnes, 1999; Korpela and Hartig, 1996). While some studies have found no difference in various measurements of mood in response to exposure to natural versus non-natural environments (Butryn and Furst, 2003; Grazuleviciene et al., 2016; Hull and Michael, 1995), most studies have found a positive association between mood and nature exposure (Kondo et al., 2018a). However, many previous studies have largely relied on small and/or non-representative samples, and they focus on brief, often one-time exposures to a singular (sometimes choreographed) environment (Kondo et al., 2018a, 2018b). An exception to this is larger scale population-level studies which have begun to link *residential* green space with well-being (White et al., 2013). Questions remain regarding affective response to environments within everyday routines, including both residential and non-residential exposures. It is important to capture these multiple, and perhaps cumulative exposures, because there may be different mechanisms of association with health for each.

The association between NOE and mood might differ by population subgroup. Research has found that individuals with low socioeconomic status (SES) receive, in general greater health benefits from NOE exposure than high SES groups (Dadvand et al., 2012a, 2012b; de Vries et al., 2003; McEachan et al., 2016; Mitchell et al., 2015; van den Berg et al., 2016). Positive associations between health outcomes and NOE exposure can also vary by age, sex and cultural background (Astell-Burt et al., 2014; Dadvand et al., 2014a). More significant positive associations between affect and exposure to natural environments have been found for individuals with high stress or fatigue levels (Bratman et al., 2012; Greenwood and Gatersleben, 2016) and those that engage in physical activity in nature (Bratman et al., 2015). However, the remaining small number of studies that have explored heterogeneity of effect for mental health outcomes specifically have reported inconsistent findings; green space exposure can be positively associated with affect for women, elderly and those with lower education (de Vries et al., 2003; McEachan et al., 2016; Triguero-Mas et al., 2015; van den Berg et al., 2016), while others have found more positive association for men (Triguero-Mas et al., 2017a).

Emotional well-being is related to other aspects of health. For example, well-being and positive affect have been found to be associated with a variety of health outcomes (Diener et al., 2017; Pressman and Cohen, 2005). Research has documented relationships between positive affect with everything from the common cold (Cohen et al., 2003), physical activity (Watson, 1988) and diet (Cohen et al., 2003) to increased longevity and better cardiovascular health and birth outcomes (Chida and Steptoe, 2008; Cohen et al., 2016; Diener and Chan, 2011; Klonoff-Cohen et al., 2001; Kok et al., 2013).

This study aims to fill a critical gap in existing nature exposure studies by investigating whether exposure to everyday natural outdoor environments over time is associated with momentary mood among residents of four European cities. We investigate everyday NOE, as opposed to a choreographed exposure condition, in order to capture typical mood responses within individual's daily routines. As a secondary aim, we explored the potential differential associations between natural outdoor environments and mood by population subgroup.

2. Methods

2.1. Data

The data analyzed for this study are part of the PHENOTYPE (The Positive Health Effects on the Natural Outdoor environment in TYPical populations) project (Nieuwenhuijsen et al., 2014). The PHENOTYPE project was designed to disentangle the mechanisms behind the relationships between natural environments and human health. PHENOTYPE collected data in four cities from different regions of Europe: Barcelona (Spain), Stoke-on-Trent (United Kingdom), Doetinchem (The Netherlands) and Kaunas (Lithuania). These cities, and the neighborhood sampling units within them, were not based on representative sample. However, the cities provide a range of environments in which most Europeans reside in terms of population density. In addition, the neighborhood units were selected to represent a variety of SES backgrounds and NOE typology, size and quantity (Nieuwenhuijsen et al., 2014; Smith et al., 2017).

Barcelona, located in the Northeast of Spain, is the country's second-largest city, and in 2011 it had 1,631,259 inhabitants and a size of 102 km^2. Stoke-on-Trent is located in the geographic centre of England. The city consists of multiple towns, and in 2010 it had a total size of 304 km^2 and 363,421 inhabitants. Doetinchem is a medium-sized city located in the eastern part of the Netherlands. In 2012 the city had 56,252 inhabitants and a size of 80 km^2. Kaunas is the second-largest city in Lithuania, and in 2011 had 319,213 inhabitants and a size of 156 km^2.

Natural outdoor environments (NOE) were defined as all spaces with vegetation or water bodies including mainly urban parks, biodiversity areas, playgrounds, sport fields, squares, gardens, allotments, private gardens, street trees, forests, agricultural land, lakes, ponds, rivers, canals, and beaches. Natural environment characteristics of the study areas within each city are described in Smith et al. (2017), and were characterised for this study using local data sources. NOE categories are defined in detail in Smith et al. (2017), and size and percent cover are given in Table 1. NOE comprised 27% of Barcelona, 39% of Kaunas, 72% of the study area in Doetinchem, and 74% of Stoke-on-Trent. The prominent NOE categories varied by city. Urban parks comprise the majority of Barcelona's urban NOE but comprise only between 12 and 17% of urban NOE in other cities. Semi-natural areas comprised 30% of NOE in Stoke-on-Trent, but only between 3 and 11% in other cities. Formal civic space comprised the majority (70%) of urban NOE in Kaunas, and 27% in Barcelona, but only 0.2 and 2.2 percent in Stoke-on-Trent and Doetinchem, respectively. In addition, while almost 90% of non-urban NOE in Stoke-on-Trent and 84% in Doetinchem, was rural or agricultural land, neither Barcelona nor Kaunas contained these types of NOE. Land use in and around each city is shown in Smith et al. (2017). A sample of streetscapes are shown in Fig. 1.

2.2. Procedures

The data collected for this study are from a subsample of participants from the larger PHENOTYPE study (Nieuwenhuijsen et al., 2014). In each city, we selected study neighbourhoods with maximum variability in NOE characteristics and SES (sampling process described by Smith et al. (2017) in detail). Within each study neighbourhood, we recruited adults (18–75 years) using a random process to participate in an in-person survey (n = 3946). We invited all survey participants able to walk 300 m on level ground to participate in the momentary mood response part of the study. The only exception to this approach was in Stoke-on-Trent, where, apart from the original random sample, it was necessary to recruit further participants. We did this by mailing recruitment flyers to randomly selected addresses (within the 30 study neighbourhoods) and through opportunistic recruitment in the study neighbourhoods (see Table 2). Approximately half of Stoke-on-Trent participants were from the original random sample. The final study sample included 368 participants in Barcelona (n = 94), Stoke-on-Trent (n = 93), Doetinchem (n = 77), and Kaunas (n = 104). Background demographic information (education level, neighbourhood SES) was not recorded for eight participants (three in Stoke-on-Trent and five in Kaunas), and age was not recorded for 10 participants (four in Stoke-on-Trent and six in Kaunas).

We asked participants to wear a smartphone, equipped with software applications to track location and physical activity (CalFit software), and mood (using mobile Ecological Momentary Assessment (EMAs) software, for seven consecutive days. The start and end days of the study were always weekdays.

Participants wore the smartphone attached to a belt around their waist, and took it off when performing activities that could damage the smartphone (e.g., swimming), when sleeping, and when charging the smartphone battery. Participants also completed daily diary entries during that week. In the daily diary we asked participants to record the time periods when the smartphone was not worn, and the activities they undertook during those periods. Participants received compensation at the end of monitoring (either through a retail voucher or cash, depending on the country).

CalFit uses the smartphones' Global Positioning System (GPS) receivers and mobile telecommunications technology (network) to collect information on location, for the purpose of determining contact with NOE. CalFit is also programed to collect information on physical activity using the smartphone accelerometer motion sensor (Donaire-Gonzalez et al., 2013). We used the physical activity information to measure wear time for each participant to determine eligibility for inclusion. We included data only from participants with wear-time of at least 10 h per day (Heil et al., 2012; Matthews et al., 2012).

We employed mobile Ecological Momentary Assessment (EMA) software to measure momentary mood response. We programmed the EMA questions to pop-up randomly between 8am and 10 pm during the seven-day study period. The software used GPS to reduce EMA prompts by 50% when participants were likely indoors. The software prompted participants to fill out the EMA survey with the phone's ring and vibrate functions. Participants were instructed to stop their activity and complete the short EMA sequence of questions as soon as possible. If an EMA alert occurred when participants were unable to respond (e.g., when driving or bathing), participants were instructed to ignore it. Completing an EMA survey took around one minute and each participant had a period of 10 min to complete it. If the participant did not complete the survey within that 10-minute window, the phone would continue to ring or vibrate every two minutes until the participant completed the survey. Surveys completed within a 30-minute window between the alarm and data entry were coded as *scheduled* EMAs. If the elapsed time between alarm and data entry was more than 30 min, the survey was coded as an *unscheduled* EMA.

Participants could also answer the EMA questions manually (unscheduled EMAs). Surveys that were recorded when the mobile phone was operating at low battery (n = 56) were included in the unscheduled EMA group because EMA survey timing could have been affected by battery levels. In some cases, participants did not complete

Table 1
NOE characteristics of the study areas within four cities.

		Barcelona		Stoke-on-Trent		Doetinchem		Kaunas	
Category	Definition	ha	%	ha	%	ha	%	ha	%
Urban NOE									
Parks	Urban parks	657.1	61.7	527.3	11.7	71.0	17.1	743.8	15.6
Semi-natural/natural	Biodiversity, protected or conservation areas, nature reserves, heritage sites	3.2	0.3	1347.7	29.8	34.8	8.4	509.1	10.7
Formal recreation	Playgrounds and sports fields (not within parks)	1.4	0.1	729.1	16.1	3.2	0.8	0.0	0.0
Civic space	Squares, gardens	292.0	27.4	7.8	0.2	9.2	2.2	3332.2	69.7
Functional/ amenity	Allotment, cemetery, amenity spaces, institutional (schools, hospital grounds, etc)	34.0	3.2	1111.1	24.5	100.4	24.1	1.3	0.0
Natural/green corridor	Tree-free/natural pathways, trails and cycle paths	73.6	6.9	176.7	3.9	57.7	13.9	54.3	1.1
Derelict/vacant	Vacant land	4.0	0.4	627.8	13.8	4.4	1.0	136.5	2.9
Street greenery	Street trees and green features					135.1	32.5		
	Subtotal	*1065.3*		*4527.4*		*415.8*		*4777.2*	
Non-urban NOE									
	Woodland/forests	0.0	0.0	1862.0	10.4	859.6	16.3	1344.7	100.0
	Rural and agricultural land	0.0	0.0	16077.1	89.6	4430.4	83.7	0.0	0.0
	Country parks	1696.3	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	Subtotal	*1696.3*		*17939.1*		*5290.0*		*1344.7*	
Total urban & non-urban NOE		***2761.6***	***27.0***	***22466.5***	***73.8***	***5705.8***	***71.6***	***6121.9***	***39.2***

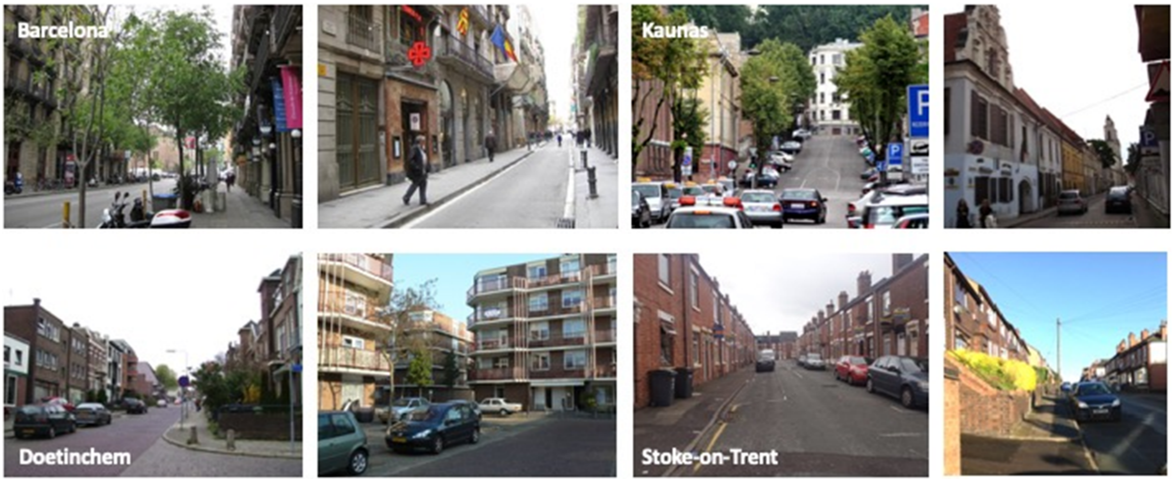

Fig. 1. Streetscapes from study cities.

surveys (i.e. they only answered some questions), and these participants were excluded from analyses. We ran models on all completed (scheduled and unscheduled) EMAs, and separately on scheduled EMAs only.

2.3. Measures

2.3.1. Contact with NOE

Our independent variables were two binary variables representing exposure versus non-exposure to NOE 10 and 30 min prior to participants' answering an EMA survey (within 50 m of participants' locations during those 10 or 30 min). We used these exposure timeframes based on previous studies, which have found mood to be affected 10 min (Brown et al., 2013; Focht, 2009), or 30 min after NOE exposure (Gidlow et al., 2016; Triguero-Mas et al., 2017b).

We obtained participants' locations using the GPS and network signal from smartphones. We obtained location of NOE from different data sources depending on study city. In Barcelona, Stoke-on-Trent and Kaunas, we used the Urban Atlas 2006 dataset. Urban Atlas provides land use and land cover data at 0.25 ha resolution derived from high-resolution satellite imagery from 2006 for 305 urban areas. In Doetinchem, we used an adapted version of the Top10NL 2006 dataset (The Netherlands' Cadastre, 2006) which is a Dutch topographical basemap built from aerial photographs, field surveys and other administrative data. Urban Atlas and Top10NL had resolution 0.25 ha. For points that fell outside of city limits, we used the CORINE Land Cover 2006 (CLC2006) dataset with 100 m spatial resolution.

We then assigned exposure versus non-exposure to NOE (within 50 m of participant location). This assignment was based on information about median distance between coordinates acquired with smartphones and with GPS trackers begin 24 m overall (Donaire-Gonzalez et al., 2016). We coded each participant's location as being within 50 m of NOE (value of 1), or not (value of 0).

2.3.2. Mood outcomes

We used EMA to assess mood through a questionnaire that was an adaptation of items used by Dunton et al. (2009) to assess mood and tiredness/fatigue from the Restorative Outcome scale (Korpela and Ylén, 2009). We used six questions: "Just before the beep…(i) how happy were you feeling?, (ii) how stressed were you feeling?, (iii) how tense or anxious were you feeling?, (iv) how tired were you feeling?, (v) how restored and relaxed were you feeling?, (vi) how alert were you feeling?" Each question had five possible answers: not at all, a little, moderately, quite a bit, and extremely. We recategorised the possible answers to ensure that the final categories were meaningful (i.e. making sure there were no categories with no observations or very low frequencies). From this data, we created a negative affect (NA) measure by averaging the scores for each of the following items: stressed, anxious, and tired (Chronbach's $\alpha = 0.69$). Given the distribution of answers, we grouped answers in to two categories (1) Not at all, (2) moderately, quite a bit or extremely. A high NA score indicated some negative affect. We created a positive affect (PA) measure using the items: happy and restored/relaxed (Chronbach's $\alpha = 0.67$). We grouped answers in to three categories (1) Not at all, or a little, (2) moderately, and (3) quite a bit or extremely. A high PA score indicated high positive affect.

2.3.3. Covariates

We recorded information for each participant, including city of residence, age, gender, and education level in a face-to-face survey prior to the beginning of the study period. We also collected information on mental health status and included it as a covariate because it could affect both NOE contact, and baseline mood. We used the Mental Health Inventory (MHI-5) subscale from the SF-36 health questionnaire (Fone et al., 2007). The MHI-5 scores were transformed into a scale from 0 to 100, with higher scores indicating good mental health. We squared this variable due to left skew. We also recorded day of the week, and included weekday versus weekend status as a covariate because contact with NOE might differ due to predominant working schedules. In

Table 2
Participants sampling strategy.

	Invited n	Willing to participate n (% of invited)	Participated n	Finally included in the analyses
Barcelona	1044	379 (36%)	109	94
Stoke-on-Trent	5858	271 (26%)	99	93
From the original sample	*1044*	*164 (17%)*	*49*	*48*
Further approaches	*4814*	*107 (2%)*	*50*	*45*
Doetinchem	861	224 (26%)	111	77
Kaunas	997	280 (28%)	112	104
Total	**8760**	**1154 (13%)**	**431**	**368**

addition, obtained information on residential neighbourhood SES from locally-derived datasets in each city. Mental health data was missing for 8 of the 368 participants. We created three classes for age based on the distribution, including (1) 18–39, (2) 40–59, and (3) 60–79. We classified education level and neighbourhood SES as (1) low, (2) medium, and (3) high using tertiles of country-specific distributions.

We estimated residential NOE exposure using the Normalized Difference Vegetation Index (NDVI). The NDVI provides a measure of vegetation density at 30 m spatial resolution based on satellite imagery. NDVI values range from −1 to +1, and values closer to +1 indicate a higher density of healthy vegetation (Weier and Herring, 2000). We calculated the mean NDVI score within a 300 m buffer surrounding participants' homes. Residential NDVI values were included as covariates in regression models because they might affect baseline mood. We also calculated the percent of study time that participants spent in NOE, which could affect response via overall dose.

2.4. Statistical analyses

We calculated descriptive statistics using cross-tabulations and tests for normality and correlation among covariates. Additionally, we checked for collinearity among the predictor variables. We found that percent of study time spent in NOE to be collinear with our primary independent variables of interest – presence/absence of NOE within 10 and 30 min of EMA survey – with polychoric correlation (rho = 0.67, $p < 0.000$). Therefore, we dropped the percent of time spent in NOE variable from regression analyses. We then estimated random-effects ordered logistic regression models for both positive and negative affect outcomes with robust standard errors clustered at the participant level. The units of observation were EMA surveys completed by each participant (i). Each regression model (see Eq. (1)) included a mood outcome (positive or negative affect) Y_i; a binary indicator of presence versus absence of NOE within the 10 or 30 min prior to each EMA GS_i; home city fixed-effects C_i; a binary indicator of weekday versus weekend W_i; a indicator hour of the day (in four classes: 0–6 h, 7–12 h, 13–18 h and 19–24 h) H_i; a binary indicator of EMA survey type (scheduled or unscheduled) T_i; a measure of percent NOE, assessed from NDVI data, at each participant's residential location $NDVI_i$; a series of independent demographic covariates (sex, age, education level, neighbourhood SES and mental health status) X_i; participant-level random effects, ν_i; and a residual error, ε_i. The primary coefficient of interest is $\beta_1$for variable GS_i, indicating association between NOE exposure and mood.

$$Y_i = \beta_0 + \beta_1 GS_i + \beta_2 C_i + \beta_3 W_i + \beta_4 H_i + \beta_5 T_i + \beta_6 NDVI_i + \sum_{k=1}^{5} \beta_k X_i + \nu_i + \varepsilon_i \quad (1)$$

As a sensitivity analysis, we ran models on scheduled EMA surveys

Table 3
Participant and exposure characteristics.

	Total	Barcelona	Stoke-on-Trent	Doetinchem	Kaunas
Observations (subjects)	**2614 (368)**	**638 (94)**	**565 (93)**	**349 (77)**	**1062 (104)**
Sociodemographic characteristics					
Gender, females (n (%))	192 (52%)	44 (46%)	51 (54%)	43 (55%)	54 (51%)
Age (median, IQR)	51 (33,60)	38.5 (27, 51)	41 (33, 62)	57 (49, 65)	54 (34, 62)
Neighbourhood SES (n (%))					
Low	105 (29%)	34 (36%)	24 (26%)	21 (27%)	26 (25%)
Medium	124 (34%)	34 (36%)	32 (34%)	25 (32%)	33 (32%)
High	131 (36%)	26 (28%)	34 (37%)	31 (40%)	40 (38%)
Education (n (%))					
Low	15 (4%)	13 (14%)	1 (1%)	0 (0%)	1 (0%)
Medium	133 (36%)	30 (32%)	45 (48%)	36 (47%)	22 (21%)
High	211 (57%)	51 (54%)	43 (46%)	41 (53%)	76 (73%)
Mental Health Status, median (sd)	54.0 (10.2)	51.5 (10.5)	54.0 (10.4)	54.0 (9.3)	54.0 (10.3)
EMA survey type (observations (subjects))					
Unscheduled	1301 (1 6 0)	170 (17)	300 (47)	152 (31)	679 (62)
Scheduled	1313 (2 0 8)	468 (74)	265 (46)	197 (46)	383 (42)
Day of the week (n (%))					
Weekday	1870 (72%)	472 (74%)	393 (70%)	255 (73%)	750 (71%)
Weekend day	744 (28%)	166 (26%)	172 (30%)	94 (27%)	312 (29%)
Day of the study (n (%))					
1	723 (28%)	192 (30%)	174 (31%)	134 (38%)	223 (21%)
2	578 (22%)	168 (26%)	135 (24%)	87 (25%)	188 (18%)
3	486 (19%)	131 (21%)	105 (19%)	63 (18%)	187 (18%)
4	380 (15%)	75 (12%)	83 (15%)	33 (9%)	189 (18%)
5	263 (10%)	39 (6%)	46 (8%)	17 (5%)	161 (15%)
6	176 (7%)	29 (5%)	22 (3%)	15 (4%)	110 (10%)
7	8 (0%)	4 (1%)	0 (0%)	0 (0%)	4 (0%)
Mood (n (%))					
Positive affect index					
1. "Not at all" to less than "moderately"	865 (33%)	236 (37%)	222 (39%)	56 (16%)	351 (33%)
2. Moderately	511 (20%)	137 (21%)	91 (16%)	53 (15%)	230 (22%)
3. More than "Moderately" to "Extremely"	1238 (47%)	265 (42%)	252 (45%)	240 (69%)	481 (45%)
Negative affect index					
1. Not at all	1110 (42%)	360 (56%)	210 (37%)	176 (50%)	364 (34%)
2. More than "Not at all	1504 (58%)	278 (44%)	355 (63%)	173 (50%)	698 (66%)
Environment					
Percent of participant time spent in NOE (mean (sd))	25.6 (34.0)	7.1 (11.5)	29.9 (37.0)	54.1 (40.3)	24.9 (32.1)
Residential mean NDVI within 300 m (mean (sd))	0.44 (0.16)	0.44 (0.16)	0.21 (0.10)	0.48 (0.09)	0.56 (0.09)
Presence of NOE within 10 min of EMA survey (n (%))					
Yes	76 (30%)	58 (9%)	180 (32%)	191 (55%)	357 (34%)
No	1828 (70%)	580 (91%)	385 (68%)	158 (45%)	705 (66%)
Presence of NOE within 30 min of EMA survey (n (%))					
Yes	910 (35%)	79 (12%)	216 (38%)	200 (57%)	415 (39%)
No	1704 (65%)	559 (88%)	349 (62%)	149 (43%)	647 (61%)

only. In addition, we tested interaction terms (10-minute responses) by city, sex, age (ages 18–39, 40–59, and 60–79), education (low, medium and high), neighbourhood SES (low, medium, and high), mean NDVI values within 300 m of residences (low and high categories defined as below and above median value, respectively), and mental health status (poor and good categories defined as below and above median value, respectively). We found statistically significant estimates for interaction terms for city, sex, age, mean NDVI levels and mental health status, and therefore stratified models using these variables. P-values of less than 0.05 indicated significant effect. We present regression coefficients as odds ratios (OR), which represent association between positive affect or negative affect and NOE exposure for NOE-exposed versus unexposed. We performed all analyses using Stata 15 software (StataCorp, 2017).

3. Results

Our sample was distributed by sex and neighbourhood SES nearly homogenously across the four cities (see Table 3). Most of our participants were highly educated (especially in Lithuania). Participants had a median age of 51 years. Barcelona participants were the youngest (median: 39 years old), and Doetinchem participants were the oldest (median: 57 years old). Baseline mental health status was a median of 54, on a scale of 0–100.

Approximately half of our EMA surveys (n = 1313) were answered at scheduled times, and half (n = 1301) at unscheduled times. Unscheduled EMAs included answers from 56 surveys completed when mobile phones were operating with low battery power, all occurring in Barcelona (data not shown).

From the 2965 EMAs, 2614 were answered completely (12% of the EMAs were missed or incomplete). Participants completed an overall average of 4.1 EMA surveys (min: 1, max: 21, sd: 3.6) (see Table S1). However, the number of EMA surveys answered per day was more distributed throughout the 7-day study period in Lithuania, where at the beginning of the sampling period some participants started EMA surveys manually (see Table 3).

On weekdays, participants completed an average of 3.7 EMAs, approximately 72% of surveys, and on weekend days they completed an average of 5.3 EMAs, approximately 28% of surveys. The frequency of survey completion was highest on day one, and decreased steadily over the 7-day study period, with very few (in some cases none) surveys completed on day seven (see Table 3). Participants completed 30% of EMA surveys within 10 min, and 35% within 30 min of spending time in natural outdoor environments. Approximately 67% of surveys indicated a moderate or higher level of positive affect (i.e. a high positive mood status), and 58% indicated some negative affect.

Average residential mean NDVI within 300 m of participants' residential locations was 0.44, and median value was 0.50 across the total sample. The average ranged from 0.21 (Stoke-on-Trent) to 0.56 (Kaunas). The percent of time that participants spent within NOE on average was 25.6%. This value ranged from 7.1% in Barcelona to 54.1% in Doetinchem. Looking at the total sample, women spent an average of 27.8% of their time in NOE, and men spent 25.0%. Percent of time spent in NOE was lower for participants living in low SES neighborhoods, but also did not vary significantly (average percent for low SES: 23.4%; medium SES: 24.0%; high SES: 27.6%).

Regression estimates of the associations between mood and presence of NOE within the previous 10 min of answering an EMA, adjusted for home city, day of the week, hour of the day, EMA survey type, residential NOE exposure (NDVI), and sex, age, education level, mental health status and neighbourhood SES, are shown in Table 4. When considering scheduled and unscheduled surveys, overall there was a positive relationship between positive affect and NOE exposure (OR: 1.39, 95% CI: 1.06, 1.81). According to stratified models, positive statistically significant relationships were only found in Stoke-on-Trent (OR: 2.65, 95% CI: 1.46, 4.85), exclusively for men (OR: 1.54, 95% CI: 1.06, 2.25), solely for those aged 40–59 years (OR: 1.62, 95% CI: 1.07, 2.48), and for participants residing in high NDVI areas (OR: 1.41; 95% CI: 1.01, 1.97).

When considering scheduled surveys only, we found the same direction of association for the all the analyses with the exception of Doetinchem, Kaunas, Women and people aged 60–79 years. These results were not statistically significant, except in Stoke-on-Trent (OR: 3.93, 95% CI: 1.49, 10.35).

When considering scheduled and unscheduled surveys, overall there was a non-significant negative association between negative affect and NOE exposure within 10 min of EMA surveys. However, when stratifying, we found a statistically significant negative relationship between negative affect and NOE exposure in Stoke-on-Trent (OR: 0.36, 95% CI: 0.17, 0.78), solely for men (OR: 0.61, 95% CI: 0.40, 0.92), and exclusively for those aged 18–39 years (OR: 0.54, 95% CI: 0.31, 0.93). In general, we found the same directions of association when considering scheduled surveys only, despite no statistical significance.

Fewer associations were statistically significant for NOE contact 30-minutes prior to answering EMAs than 10-minutes prior (Table 5). However, nearly all relationships maintained the same direction of association. When analyzing scheduled and unscheduled EMAs, statistically significant associations were found between positive affect and NOE exposure overall, for men, or for those aged 60–79 years. For scheduled and unscheduled EMAs, statistically significant associations were found between negative affect and NOE exposure for Stoke-on-Trent inhabitants and men. No statistically significant associations were found for scheduled EMAs only.

Table 4
Random-effects ordered logistic regression estimates (odds ratio; OR) of positive and negative affect associated with time spent in NOE within the last 10 min for all EMAs and, separately for scheduled EMAs only, with pooled data, and stratified by city, sex, age, and residential NDVI values.

	Positive affect		Negative affect	
	OR	95% CI	OR	95% CI
Scheduled and unscheduled				
All Cities	1.39*	(1.06, 1.81)	0.80	(0.58, 1.10)
Barcelona	1.19	(0.57, 2.47)	0.79	(0.34, 1.85)
Stoke-on-Trent	2.65**	(1.46, 4.85)	0.36*	(0.17, 0.78)
Doetinchem	0.76	(0.38, 1.53)	1.63	(0.71, 3.74)
Kaunas	1.25	(0.88, 1.78)	0.97	(0.62, 1.53)
Men	1.54*	(1.06, 2.25)	0.61*	(0.40, 0.92)
Women	1.21	(0.82, 1.78)	1.19	(0.72, 1.98)
Ages 18–39	1.18	(0.72, 1.93)	0.54*	(0.31, 0.93)
Ages 40–59	1.62*	(1.07, 2.48)	0.88	(0.56, 1.39)
Ages 60–79	1.47	(0.91, 2.36)	1.17	(0.55, 2.53)
Low NDVI	1.49	(0.91, 2.11)	0.72	(0.42, 1.23)
High NDVI	1.41*	(1.01, 1.97)	0.87	(0.58, 1.31)
Poor mental health	1.22	(0.86, 1.73)	0.82	(0.48, 1.38)
Good mental health	1.43	(1.00, 2.04)	0.93	(0.64, 1.36)
Scheduled only				
All Cities	1.22	(0.78, 1.92)	0.92	(0.57, 1.46)
Barcelona	1.19	(0.57, 2.47)	0.79	(0.34, 1.85)
Stoke-on-Trent	3.93**	(1.49, 10.35)	0.29	(0.06, 1.32)
Doetinchem	1.23	(0.49, 3.11)	1.28	(0.50, 3.26)
Kaunas	0.71	(0.34, 1.50)	1.63	(0.64, 4.17)
Men	1.64	(0.90, 2.98)	0.78	(0.43, 1.40)
Women	0.91	(0.46, 1.80)	1.05	(0.47, 2.34)
Ages 18–39	1.25	(0.62, 2.53)	0.63	(0.28, 1.40)
Ages 40–59	1.35	(0.60, 3.05)	1.03	(0.57, 1.85)
Ages 60–79	0.82	(0.33, 2.05)	2.52	(0.51, 12.62)
Low NDVI	1.15	(0.63, 2.11)	0.77	(0.38, 1.57)
High NDVI	1.31	(0.69, 2.50)	1.03	(0.53, 2.01)
Poor mental health	1.21	(0.73, 2.00)	0.82	(0.43, 1.58)
Good mental health	1.19	(0.67, 2.10)	1.30	(0.76, 2.25)

***$p < 0.001$.
* $p < 0.05$.
** $p < 0.01$.

Table 5
Random-effects ordered logistic regression estimates (odds ratio; OR) of positive and negative affect associated with time spent in NOE within the last 30 min for all EMAs and, separately for scheduled EMAs only, with pooled data, and stratified by city, sex, age, and residential NDVI values.

	Positive affect		Negative affect	
	OR	95% CI	OR	95% CI
Scheduled and unscheduled				
All Cities	1.33*	(1.03, 1.70)	0.87	(0.64, 1.19)
Barcelona	1.41	(0.79, 2.53)	1.02	(0.49, 2.11)
Stoke-on-Trent	1.83	(1.06, 3.17)	0.38**	(0.20, 0.77)
Doetinchem	0.69	(0.37, 1.30)	1.38	(0.60, 3.21)
Kaunas	1.25	(0.87, 1.81)	1.10	(0.69, 1.75)
Men	1.69**	(1.19, 2.39)	0.60**	(0.41, 0.86)
Women	1.00	(0.71, 1.41)	1.48	(0.88, 2.47)
Ages 18–39	1.22	(0.79, 1.89)	0.62	(0.37, 1.06)
Ages 40–59	1.33	(0.90, 1.98)	1.08	(0.70, 1.68)
Ages 60–79	1.71*	(1.06, 2.76)	0.87	(0.42, 1.78)
Low NDVI	1.33	(0.93, 1.91)	0.87	(0.53, 1.42)
High NDVI	1.34	(0.95, 1.89)	0.89	(0.59, 1.34)
Poor mental health	1.09	(0.75, 1.56)	0.95	(0.55, 1.65)
Good mental health	1.03	(0.59, 1.81)	0.93	(0.47, 1.84)
Scheduled only				
All Cities	1.21	(0.81, 1.79)	1.06	(0.70, 1.60)
Barcelona	1.23	(0.60, 2.52)	1.31	(0.60, 2.86)
Stoke-on-Trent	2.03	(0.85, 4.83)	0.37	(0.12, 1.19)
Doetinchem	1.00	(0.43, 2.32)	1.19	(0.47, 3.01)
Kaunas	0.88	(0.43, 1.79)	2.17	(0.95, 4.98)
Men	1.66	(1.01, 2.75)	0.85	(0.50, 1.42)
Women	0.90	(0.50, 1.63)	1.32	(0.66, 2.66)
Ages 18–39	1.17	(0.63, 2.18)	0.75	(0.37, 1.52)
Ages 40–59	1.19	(0.59, 2.39)	1.26	(0.74, 2.14)
Ages 60–79	1.37	(0.59, 3.13)	1.84	(0.60, 5.69)
Low NDVI	1.21	(0.69, 2.10)	1.06	(0.57, 1.97)
High NDVI	1.25	(0.72, 2.18)	1.06	(0.60, 1.88)
Poor mental health	1.41	(0.96, 2.07)	0.87	(0.58, 1.31)
Good mental health	1.12	(0.59, 2.09)	1.17	(0.64, 2.15)

***$p < 0.001$.
* $p < 0.05$.
** $p < 0.01$.

4. Discussion

This study found, in general, a relationship between mood and exposure to NOEs in four mid-sized European cities. The results of this study indicate that the associations differ by population subgroup. Specifically, in subgroup analyses, the associations remained significant for men. The relationships we found by city, age subgroups, and residential NDVI exposure were not consistent for the different outcomes and exposures evaluated. Moreover, the associations were stronger and more consistent for positive affect and after 10 min of exposure to NOEs and in general were weaker and less consistent for negative affect and after 30 min of exposure.

Our study responds to calls for more nuanced, multi-dimensional measures of nature exposure in relationship to health outcomes (Cox et al., 2017; Kondo et al., 2015; Shanahan et al., 2015). There is a need for more advanced metrics of the physical parameters of natural environments, in addition to more advanced measures of exposure that reflect time-activity patterns. Our study advances previous studies by controlling for traditional residential greenness and measuring mood response based on physical proximity to urban NOE (rather than proximity to residential address). We found more statistically significant associations between mood and NOE within 10 min of exposure, compared to within 30 min of exposure. This could indicate that the positive association between NOE exposure and mood (or negative association with negative affect) is short-term, and therefore that the immediacy of nature dose matters for affective responses.

Our results suggest that exposure to NOE has a significant association with affect (positive association with positive affect and negative association with negative affect) mostly in the northern European city of Stoke-on-Trent. However, a prior analysis of data collected from the same study participants found the most significant relationship between NOE contact and mental health (measured as self-reported psychological well-being, sleep quality, vitality and somatisation) in Doetinchem (Triguero-Mas et al., 2017a). This could indicate that mood and other mental health indicators respond to environmental factors in different ways. The majority of NOE in Stoke-on-Trent is in protected, rural or agricultural areas outside of residential built areas, and the city has less green civic space, natural trails or pathways, and streetside landscape than other study cities. Our findings could indicate that residents whose environment is less green experience greater positive mood response once immersed.

This finding could also reveal differential effect of NOE exposure on mood by cultural context. For example, Dadvand et al. (2014b) investigated the association between NOE exposure and birth weight in a UK birth cohort, and found an interaction between surrounding greenness and ethnicity, which resulted in a positive association between birth weight and NOE for British participants, but not for Pakistani British participants. The mechanisms here are unknown, however emerging research has found that different cultural groups may report affect differently based on a normative “ideal affect” (Tsai et al., 2006).

While there are few existing studies that test for differences in effect by sex, our study adds to findings of positive association between NOE exposure and health for men, rather than women (Björk et al., 2008; Dadvand et al., 2016; Richardson and Mitchell, 2010; Triguero-Mas et al., 2017a). This finding corresponds to those found in a previous analysis of the association between objective NOE contact and mental health with the same study participants (Triguero-Mas et al., 2017a). As Richardson and Mitchell (2010) suggested, these differences by gender could be because women worry about their personal safety more than men. This disparity could prevent women from visiting remote NOE (that can potentially affect mood the most) (Richardson and Mitchell, 2010).

We found a statistically significant association between NOE exposure at 10 min and positive affect only for middle age participants (aged 40–59) and a negative statistically significant association between NOE exposure at 10 min and negative affect only for young participants (aged 18–39). NOE exposure 30 min prior to answering the survey was statistically significantly associated with positive affect only for older participants (aged 60–79). Our study adds to the existing heterogeneity of results by age group. To our knowledge, only five studies have investigated heterogeneity of effect by age for the association between NOE and health (Björk et al., 2008; Dadvand et al., 2016; de Vries et al., 2003; Maas et al., 2009; Triguero-Mas et al., 2017a; van den Berg et al., 2016). Among these studies, two found no differences by age group (Björk et al., 2008; van den Berg et al., 2016). de Vries et al. (2003) reported that living in a neighbourhood with a higher percentage of green space was strongly associated with self-reported health symptoms for participants older than 65 years of age. Dadvand et al. (2016) found a stronger association between residential exposure to surrounding greenness and self-perceived general health for those older than 65 years, but when considering access to green spaces they found a stronger relationship for those younger than 65 years. Maas et al. (2009) found stronger associations between surrounding greenness and several morbidity indicators for people between 46 and 65 years old. A previous study of the same participants included in the present study found that the associations between NOE contact and several indicators of mental health were stronger for younger participants (Triguero-Mas et al., 2017a). The heterogeneity in the results by age may indicate that other factors could be involved in the age effects, as previous studies have suggested (see Astell-Burt et al. (2014) for how age effects vary by sex and Maas et al. (2006) for how age effects are modified by level of urbanity).

There are a number of limitations that should be mentioned. The study cities and neighborhood sampling units were not based on representative sample, and samples were not population weighted. This could limit the external validity of our findings. In addition, more than half of participants were female, and the ratio of low to high education levels varied across cities. However, we adjusted for these factors in our regression analyses. Regarding our outcome measures, the Chronbach's alpha measure for positive and negative mood outcomes was low, which could influence internal consistency, and likely bias our results toward the null. However, we elected to use this scale, as opposed to some more commonly used measures because of its relatively small size (number of questions), in order to reduce participation burden and thereby increase participation and compliance.

In addition, not all EMA surveys were answered as designed (exactly on random schedule). Sensitivity analyses on only complete and randomly-scheduled EMA survey data confirmed the positive, though not statistically significant, association for positive affect. The statistically significant positive association between positive affect and NOE exposure is stronger with unscheduled EMAs. These EMAs could be biased by manual entries in which the participant's awareness of their exposure to nearby NOE triggered a manual EMA survey. Further, due to the dynamic structure of our EMA data, more advanced modeling techniques such as dynamic structure equation modeling could be more beneficial than our approach.

Our study did not take in to account level of physical activity, or social interactions during momentary assessments. Previous studies have found that momentary contact with nature or outdoors increases physical activity, and physical activity has been shown to have a positive effect on mood based on these momentary assessments (Dunton et al., 2012; Liao et al., 2015). Likewise, positive or negative social interactions during or just prior to the assessment could influence participants' moods. We were also not able to determine whether participants were indoors or outdoors during EMA surveys or during the exposure window, and this should information should be collected in future studies. Residual confounding of other urban factors such as air pollution, over-crowding or neighbourhood deprivation could also have affected our data.

Due to additional data limitations, we were not able to assess the characteristics of NOEs that participants travelled through. NDVI or similar data can give only a course-scale estimate of the presence of NOE. As cities begin to collect and share more complete spatial administrative records on parks and NOE (e.g. tree inventories or LIDAR), we will be able to improve our estimates of exposure.

While Ecological Momentary Assessment reduces risk of recall bias associated with traditional retrospective surveys, it is still a subjective assessment of mood. Other technologies are developing to capture more objective preferential responses to environments, for instance the use of ambulatory eye trackers (e.g. eye-tracking via the Glass device). However, rather than treat exposure as a general characteristic of place of residence, our use of EMA allowed us to assess participants' real-time mood responses to environments as they progressed through their daily routines.

The application of EMA methods in nature exposure research is relatively new. Expanding upon the "stimuli-emotional response" model many experimental studies employ, the use of EMA allowed for a more accurate picture of an individual's *mood,* capturing a longer-lasting generalised state. This study uniquely determined how momentary mood improves as a result of nature exposures including intentional nature visits as well as residential, commute-based, and nature in and around one's destinations. This approach and these results suggest a way to think beyond the 'far away nature' vs. 'local nature' dichotomy, and instead consider the effects of multiple types of nature, every day, and *any time of day*.

Our findings support increasing evidence of positive association between psychological and mental health and exposure to natural outdoor environments, especially among urban populations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2019.105237.

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