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Multiple pathways link urban green- and bluespace to mental health in young adults

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Running title: Urban green/bluespace and mental health

Abstract

Background: A growing body of scientific literature indicates that urban green- and bluespace support mental health; however, little research has attempted to address the complexities in likely interrelations among the pathways through which benefits plausibly are realized.

Objectives: The present study examines how different plausible pathways between green/bluespace and mental health can work together. Both objective and perceived measures of green- and bluespace are used in these models.

Methods: We sampled 720 students from the city of Plovdiv, Bulgaria. Residential greenspace was measured in terms of the Normalized Difference Vegetation Index (NDVI), tree cover density, percentage of green areas, and Euclidean distance to the nearest green space. Bluespace was measured in terms of its presence in the neighborhood and the Euclidean distance to the nearest bluespace. Mental health was measured with the 12-item form of the General Health Questionnaire (GHQ-12). The following mediators were considered: perceived neighborhood green/bluespace, restorative quality of the neighborhood, social cohesion, physical activity, noise and air pollution, and environmental annoyance. Structural equation modelling techniques were used to analyze the data.

Results: Higher NDVI within a 300 m buffer around the residence was associated with better mental health through higher perceived greenspace; through higher perceived greenspace, leading to increased restorative quality, and subsequently to increased physical activity (i.e., serial mediation); through lower noise exposure, which in turn was associated with lower annoyance; and through higher perceived greenspace, which was associated with lower annoyance. Presence of bluespace within a 300 m buffer did not have a straightforward association with mental health owing to competitive indirect paths: one supporting mental health through higher perceived bluespace, restorative quality, and physical activity; and another engendering mental ill-health through higher noise exposure and annoyance.

Conclusions: We found evidence that having more greenspace near the residence supported mental health through several indirect pathways with serial components. Conversely, bluespace was not clearly associated with mental health.

Keywords: Air pollution; Annoyance; Greenness; Physical activity; Restoration; Social cohesion; Traffic noise; Water

1. Introduction

Approximately one billion people on a global scale meet the criteria for a common mental disorder (Steel et al., 2014), accounting for about one third of years lived with disability (Vigo et al., 2016). A growing body of scientific literature indicates that natural urban environments, such as green- and bluespace, might support mental health, but the evidence regarding how benefits are realized has significant gaps (Gascon et al., 2015; 2017).

Greenspace, a term encompassing both overall vegetation level and green spaces (e.g., parks, gardens) (Teylor and Hochuli, 2017), has been in the spotlight of environmental research longer than bluespace, so a conceptual framework about the mechanisms underlying its effect has been proposed and tested empirically. Putative pathways include mitigation of harmful exposures and annoyance caused by noise and air pollution; psychological restoration and stress reduction; and encouragement of health-enhancing behaviors, such as physical activity and social interactions (Hartig et al., 2014; Markevych et al., 2017; WHO, 2016). However, results have been mixed. For example, some studies observed significant mediation through social cohesion (e.g., Dadvand et al., 2016; de Vries et al., 2013; Maas et al., 2009; Sugiyama et al., 2008), but others have failed to identify such an indirect effect (e.g., Triguero-Mas et al., 2015; 2017). In other studies, stress reduction (Triguero-Mas et al., 2017) and mitigation of traffic emissions (Gascon et al., 2018) emerged as more important mediators than physical activity and social cohesion.

In recent years, the interest in bluespace as a protective factor in the urban environment has been gaining momentum (Grellier et al., 2017). Bluespace, defined as an accessible outdoor environment that prominently features water (after Grellier et al., 2017), is hypothesized to support mental health through many of the mediators proposed for greenspace. For example, areas with more bluespace might have fewer sources of noise and air pollution (cf. Markevych et al., 2017). Some types of bluespace might mask traffic noise perceptually or energetically with pleasant water sounds and reduce noise annoyance (cf. Li et al., 2012; Leung et al., 2014; Kang, 2012; Kang et al., 2016). Bluespace might also mitigate the heat island effect, reduce stress, and facilitate social contacts and physical activity (Grellier et al., 2017). However, few epidemiological studies have been able to quantify the effect of bluespace on mental health and well-being (Gascon et al., 2017). Some reported better mental health for participants living closer to bluespace (e.g., Brereton et al., 2008; MacKerron et al., 2013; White et al., 2013a; Völker et al., 2018) or in a neighborhood with more bluespace (e.g., Alcock et al., 2015; White et al., 2013b), but others did not find a significant association (e.g., Triguero-Mas et al., 2015; Gascon et al., 2018; Bezold et al., 2017). Moreover, studies that explicitly set out to investigate underpinning pathways have been scarce (e.g., Triguero-Mas et al., 2015; Gascon et al., 2018). Hence, the epidemiologic evidence on this subject remains thin. This holds especially for less affluent European countries and with regard to inland bluespace (Gascon et al., 2017).

The mixed findings referenced above could partially be due to the fact that the majority of previous studies were not specifically designed to collect comprehensive information on potential mediators and account for the possibility that mediating processes might be intertwined (Dzhambov et al., 2018). More specifically, green/bluespace might enhance neighborhood restorative quality, and thereby promote social contacts and outdoor physical activity, behaviors that commonly occur together in single episodes, and that in turn might relate to better mental health (Barton et al., 2016; Dzhambov et al., 2018). At the same time, by mitigating noise and air pollution, greenspace might reduce environmental annoyance, and thus increase restorative quality by making the residential environment more appealing settings for spending time outdoors (von Lindern et al., 2016). Other literature indicates that higher noise annoyance might harm mental health directly (van Kamp and

Davies, 2008) or indirectly through increasing interpersonal distance and inhibiting social cohesion in the neighborhood (Jones et al., 1981; Cohen and Spacapan, 1984; Dzhambov et al., 2017). Disregarding the possibility of such an interplay might entail spurious conclusions as to the importance of a particular pathway (Dzhambov et al., 2018) or even counterintuitive findings, such as neighborhood greenness being inversely related to physical activity (e.g., Gascon et al., 2018). In a previous study (Dzhambov et al., 2018), we addressed the issue by demonstrating that in single and parallel mediation models physical activity and social cohesion did not appear to mediate the effect of objectively-measured greenspace on mental health, but when neighborhood restorative quality was added to the model as their antecedent factor, those paths became significant. Nevertheless, more research is needed to replicate these findings for greenspace and to expand the model to incorporate bluespace. If multiple mediators can work together, an omnibus model encompassing several serial mediation components would be more comprehensive than a piece-wise estimation of each serial mediation path (cf. Dzhambov et al., 2018).

A related issue has to do with the fact that specific environmental measures might be relevant to different mediators (cf. Markevych et al., 2017). For example, the mere presence of vegetation in the living environment might be sufficient for reducing air pollution, but people's perceptions provide more useful information about their actual interaction with green/bluespace. Therefore, studies looking at the capacity of natural environments to support health should also consider perceptual measures in addition to the spatial ones (Markevych et al., 2017). For instance, perceived greenspace quality was found to partially mediate the effect of objective greenspace accessibility and usability on neighborhood satisfaction (Zhang et al., 2017), and self-reported time spent in greenspace mediated the effect of residential greenness on mental health (van den Berg et al., 2017). It follows that perceptual measures might be a link in the causal chain between green/bluespace and other mediators, such as neighborhood restorative quality or environmental annoyance.

The present study examines different plausible pathways linking green/bluespace to mental health, with a focus on how objective and perceived measures of green/bluespace fit a model in which multiple pathways are specified to work together. Uncovering these intricate mechanisms should help to advance epidemiological research in this area.

2. Methods

2.1. Study design and sampling

This study builds on previous research (Dzhambov et al., 2018) by extending it to a larger and more homogenous sample of young adults, which is an understudied group in the field (cf. Gascon et al. 2015; 2017). Data were collected between October and November 2017 from the Medical University in Plovdiv, the second largest city in Bulgaria. To be included in our study, students had to be aged 18 – 35 years (defining young adulthood; e.g., Petry, 2002) and resident in Plovdiv or the near provinces in Southern Bulgaria for the last six months. We used a convenience sample in order to achieve sufficient variability in the data. We targeted potential participants with different ethnic and cultural background, age, and program enrollment to ensure sufficient variation in the data. During a class/lecture, members of the research group advertised the study, informing the students about its general objectives, and asked them to complete a questionnaire. The study was presented as an omnibus survey on "neighborhood environment and quality of life". In addition to sociodemographic factors, residential environment, mental and general health, participants were asked to report their current living address, which was needed for subsequent assignment of geographic variables. Since a member of the research group was present, participants had the opportunity to give feedback and receive clarifications about each question. On average, completing the questionnaire took about 15 – 20 min. The study design was approved by the Ethics Committee at the Medical University of Plovdiv (Dzhambov et al., 2018). Participants signed informed consent forms. No incentives were offered.

Of the 1 000 students invited, 823 agreed to participate (82% response rate). Residential addresses were converted to geocodes manually by inspecting each address with the help of Google maps. Of the 788 participants left in the dataset after data cleaning, we were able to successfully geocode the residences of 720, because the others had provided vague description of their address or no address at all. The locations of the residents are shown in Figure 1. Instead of replacing missing data on geographic variables, participants who did not report their address were excluded, because they exhibited systemic differences compared with the rest: they were somewhat younger, reported less neighborhood green/bluespace, as well as lower restorative quality in their neighborhood; they were also more likely to be female and less likely to be long-term residents (> 10 years) (data not shown). Hence, we analyzed a sample of 720 participants, the majority of whom (n = 642, 89.2%) lived in the city of Plovdiv. Geographic data management and calculations were carried out using ArcGIS 10.3-10.4 Geographical Information System (GIS) (ESRI, Redlands, CA, USA).

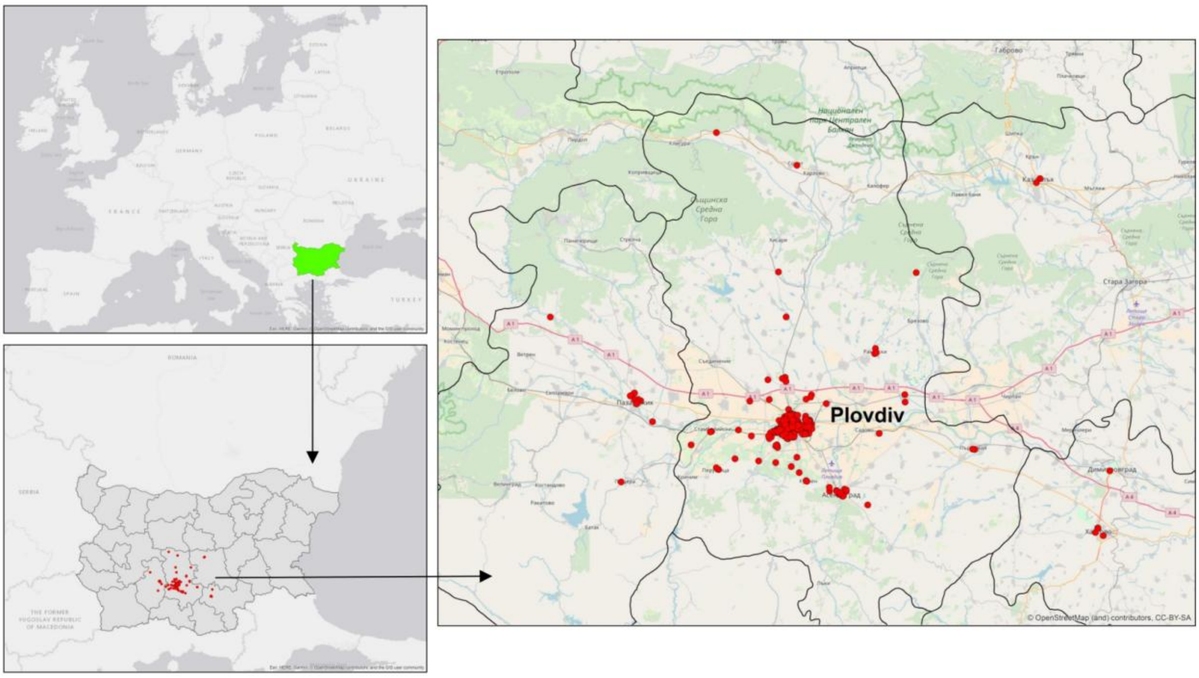

Figure 1. Location of the study area

2.2. Greenspace

The choice of greenspace measures was based on the presumption that different measures represent different aspects of interaction with greenspace, and thereby are relevant to different mediators (Markevych et al., 2017). We collected data on greenness surrounding the residence, proportion of green space near the residence, and distance to the nearest structured urban green space from the residence. Surrounding greenness quantifies overall neighborhood vegetation level, which may be important for reduction of air pollution or noise, without accounting for its type or whether it is publicly accessible. The other two measures are proxies for availability of structured green spaces – one focuses on their amount, and the other on their proximity, both of which may be relevant for the social functions of green spaces (Markevych et al., 2017). Treating these as separate measures is empirically justified in that the correlations between them in the study area are not strong (Dzhambov et al., 2018).

Normalized Difference Vegetation Index (NDVI; Tucker, 1979) and tree cover density served as measures of surrounding greenness. NDVI is commonly used as a proxy for overall vegetation level and ranges from -1 to +1, where positive values closer to 1 indicate high greenness (Gascon et al., 2016). It was calculated based on the difference of surface reflectance in two vegetation-informative wavelengths – visible red and near infrared light. For these calculations, we used two cloud-free Landsat 8 Operational Land Imager satellite images at a resolution of 30 m x 30 m, obtained on 18th of October 2017 (https://earthexplorer.usgs.gov/). As a sensitivity analysis, we derived NDVI from six Sentinel 2 MultiSpectral Instrument satellite images with a higher resolution for needed bands (10 m x 10 m), obtained on 16th and 18th of October 2017 (https://scihub.copernicus.eu/). In line with previous studies that treated the effect of green- and bluespace separately (Gascon et al., 2018), we removed all water pixels from the satellite images before NDVI assignment by using the Open Street Maps (OSM) water layer. (See Supplementary Figure S1 for a map of residential addresses superimposed over the NDVI layer.)

Percentage of tree cover density was calculated based on the Tree Cover Density 2012 map developed by the European Environmental Agency at a resolution of 20 m x 20 m (http://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/view).

Percentage of green areas was calculated based on the Urban Atlas 2012 (https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012). The types of green areas considered were “Complex and mixed cultivation patterns”, “Forests”, “Green urban areas”, “Herbaceous vegetation associations”, “Pastures”, “Permanent crops” and “Sports and leisure facilities”. For residential sites not covered by Urban Atlas (n = 17), we used the corresponding layer in OSM (http://download.geofabrik.de/europe.html). Mean NDVI and tree cover density, and percentage of green areas were abstracted in circular buffers of 100 m, 300 m, and 500 m around the residence (Dzhambov et al., 2018; Gascon et al., 2018).

Euclidean distance to the edge of the nearest structured urban green space was calculated based on the OSM data. The definition of an “urban green space” included the following land use types: “Park”, “Allotment”, and “Recreation ground”.

2.3. Bluespace

Measures for bluespace do not exactly correspond to those for greenspace because of different expectations regarding mechanisms of effect and the slight amount of bluespace in Plovdiv. Following previous studies (cf. Gascon et al., 2017), we determined participants’ exposure to bluespace based on its presence versus absence in circular buffers of 100 m, 300 m, and 500 m, and the Euclidean distance to the bluespace nearest to the residence. For these calculations, we extracted data on all types of water bodies and wetlands from Urban Atlas 2012 (https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012). One artificial city lake was manually added to the water layer. OSM data were used for residential sites outside the coverage of the Urban Atlas layer. Since the provinces where the study took place are land-locked, only freshwater was considered. (See Supplementary Figure S1 for a map of residential addresses superimposed over the bluespace layer.)

2.4. General mental health

Mental health in the past month was measured with the Bulgarian translation (Georgieva, 2010; Mutafova and Maleshkov, 2001) of the 12-item form of the General Health Questionnaire (GHQ-12), a measure of common minor psychiatric morbidity (i.e., depression, anxiety) (Goldberg and Blackwell, 1970). The GHQ-12 is one of the most commonly used mental health inventories in green/bluespace research (Gascon et al., 2015; 2017). Each item is scored from 0 to 3, with a higher summary score indicating worse mental health (Cronbach's alpha = 0.87). The GHQ-12 was included in the analyses as a continuous variable to increase the statistical power.

2.5. Potential mediators

Candidate mediators were selected based on expert recommendations (Hartig et al., 2014; Markevych et al., 2017) and empirical research illustrating how they might work together (Dzhambov et al., 2018). The following putative mediators were considered: perceived neighborhood green- and bluespace, restorative quality of the living environment, neighborhood social cohesion, commuting/leisure time physical activity, residential noise and air pollution, and annoyance from environmental pollution. In the questionnaire, "neighborhood" was defined as the area within a 10-15-minutes walking distance around the residential address. All self-report measures referred to the last month.

Perceived neighborhood greenspace was measured with a scale developed for this study that included five items about different aspects of greenspace "exposure" (cf. Dzhambov et al., 2018): (1) perceived neighborhood greenness, (2) visible greenery from home, (3) accessibility to the nearest structured green space, (4) time spent in greenspace, and (5) quality of greenspace. Each item was measured on a 6-point scale, with a higher score indicating higher perceived greenspace in the living environment. The score used in analyses was the average of the responses across the five items**.** Internal consistency of the scale is high (Cronbach's alpha = 0.81). Another scale, representing aspects of bluespace exposure potentially relevant to mental health (cf. Gascon et al., 2017), was constructed from five analogous items. A higher mean score indicates higher perceived bluespace. Cronbach's alpha for this scale is 0.84. (See Supplementary Section S1 for the items included in these scales.)

Perceived restorative quality of the living environment was assessed with items from the Perceived Restorativeness Scale (PRS) (Hartig et al., 1997a; 1997b), originally intended to enable researchers to study the contributions of the components of restorative experience described in Attention Restoration Theory (Kaplan, 1995; Kaplan and Kaplan, 1989). The instructions in our questionnaire were adapted to refer to the neighborhood environment (Dzhambov et al., 2018). Consistent with previous studies with the PRS (Dahlkvist et al., 2016; von Lindern et al., 2016; Dzhambov et al., 2018), only the "Being away" and "Fascination" subscales were used. These subscales capture experiences of psychological distance and positive engagement with the environment. Following Lindal and Hartig (2013; 2015), we used single items to reduce questionnaire length and response burden: "*My neighborhood has places where the time spent gives me a break from my day-to-day routine and where I can get away from the things that usually demand my attention.*" and "*My neighborhood has places that are fascinating and where my attention is drawn to many interesting things.*", respectively. Agreement with each statement was measured on an 11-point scale. After examining the correlation between the two items ($r = 0.71$), we decided to use their mean to avoid collinearity (cf. von Lindern et al., 2016; Dzhambov et al., 2018). A higher mean value for the two items indicates higher restorative quality of participant's residential environment.

To measure perceived neighborhood social cohesion, we used three items elicited from the brief form of the Perceived Neighborhood Social Cohesion questionnaire (PNSC-BF) (Dupuis et al., 2017, 2016), which was previously translated to Bulgarian (Dzhambov et al., 2018). To reduce questionnaire length, the items pertinent to the subscales "Trust in people", "Attachment to neighborhood", and "Tolerance and respect" were combined into a single statement: "*Most people in my neighborhood can be trusted; they wouldn't take advantage of* *me; and, if I were in trouble, they would come to my aid.*", "*Most people in my neighborhood are friendly; they are concerned with the interests of others, and help each other.*", and "*People in my neighborhood respect each other and accept others who are not like them.*", respectively. Responses were made on a 7-point scale. A higher mean score indicates higher perceived neighborhood social cohesion. Cronbach's alpha for our three-item scale is 0.88.

Participants' physical activity energy expenditure was measured with a reliable and reasonably valid self-report tool, the Short Questionnaire to Assess Health-Enhancing Physical Activity (SQUASH) (Wendel-Vos et al., 2003; Campbell et al., 2016). The questions asked about different types of physical activity performed during an average week in the past month, and about the number of days/week, time/day, and effort they took. As described by Campbell et al. (2016), we assigned metabolic equivalent of task (MET) values to each activity according to its intensity (3 METs for "light", 5.2 METs for "moderate", and METs 6.5 for "intense"), and computed total daily physical activity energy expenditure. For these calculations, we also used data on participants' self-reported body weight. For the present study, we only consider commuting/leisure time walking and bicycling, because gardening activities are not common among young Bulgarians, household and university/work activities were unlikely to be associated with neighborhood greenspace, and most leisure time sports activities took place at University campus or indoors. That was confirmed by a preliminary inspection of the dataset.

An estimate of noise exposure (L_{day}; daytime road traffic noise level) was obtained by applying a land use regression (LUR, R^2 adjusted = 0.72) model to participant's residential address. The LUR was developed specifically for this study. The LUR is based on noise measurements carried out in Plovdiv in 2016 (range: 62.4 – 73.5 dB(A)) (SPECTRI, 2017) and predictor variables derived with the help of GIS (cf. Aguilera et al., 2015). (See Supplementary Section S2 for details regarding model development.)

Nitrogen dioxide (NO_2) was calculated as a proxy for residential air pollution. Briefly, we used a global LUR model for NO_2 with an adjusted R^2 of 0.52 and a root-mean-square error of 4.8 ppb (9.02 $\mu g/m^3$) for the European region (observed range 0 – 47 ppb (0 – 88.36 $\mu g/m^3$)) (Larkin et al., 2017). The model was constructed using data from air quality monitoring stations, which were predicted from satellite-based NO_2 and other commonly used geographic variables related to air pollution (Larkin et al., 2017). Predicted L_{day} and NO_2 values outside the observed range of the measurements used to construct the respective LURs ($n \approx 1\%$), were recoded to the closest observed value.

Like von Lindern et al. (2016), we combined traffic noise, other noise sources, air pollution, and vibration in our measure of environmental annoyance experienced in the residential context (i.e., both in the dwelling and the neighborhood). The four items we used mimic the phrasing and response options of the 5-point verbal International Commission on Biological Effects of Noise annoyance scale ("0 = Not at all", "1 = Slightly", "2 = Moderately", "3 = Very", and to "4 = Extremely") (Fields et al., 2001): "*How much does road traffic noise bother, disturb, or annoy you?*"; "*How much does noise from neighbors/construction/recreational establishments bother, disturb, or annoy you?*"; "*How much does air pollution bother, disturb, or annoy you?*"; "*How much does vibration from different sources (e.g., street traffic, construction work, neighbors, loud music) bother, disturb, or annoy you?*". The mean of responses served as the score for analysis. In order to give noise annoyance equal weight to air pollution and vibration annoyances, we calculated the mean of the four items by the formula: ((traffic noise annoyance + residential noise annoyance)/2 + air pollution annoyance + vibration annoyance)/3. Cronbach's alpha for the whole scale is 0.81. A higher mean score indicates higher environmental annoyance in the participant's home and its surroundings.

2.6. Confounders

We gathered data on participants' age, gender, ethnicity, duration of residence, and average time spent at home/day. Additionally, we used single items to assess recently experienced stressful life events ("*Have you lately experienced a stressful life event, such as death/illness of a relative, separation from a loved one, being fired?*"; "yes"/"no") and perceived individual-level economic status ("*Having in mind your monthly income, how easy is it for you to "make ends meet", meet your expenses without depriving yourself?*"; "0 = Very difficult" to "5 = Very easy"). Population density (total number of people) in a 500-m buffer around the address was calculated based on the 2011 Census population grid (1 km x 1 km) (http://www.nsi.bg/en/content/12309/population-grid-1-sqkm-census-2011).

2.7. Statistical analysis

Most self-reported variables had less than 5% missing values, except physical activity which had 13.9% missing. Participants had complete data on all geographic variables, except on L_{day} (11.3% missing), because the LUR was only applied to address points in Plovdiv where its validity was confirmed. Due to the reasonably low proportion of missing data, values were imputed using the expectation maximization algorithm (Dempster et al., 1977; Pigott, 2001), which facilitated subsequent mediation analysis. All variables included in the multivariate analysis models were also included in the imputation procedure. To improve the prediction of missing values, several auxiliary variables were included in the imputation procedure only (perceived noise and air pollution in the neighborhood, perceived neighborhood economic status, residential satisfaction, stress, sleep disturbance, university faculty, smoking, alcohol consumption, and self-rated health).

Some mediators deviated from the normal distribution. Most of them were not transformed, because parametric tests are fairly robust against violations of the normal distribution assumption (cf. Schmider et al., 2010; Blanca et al., 2017). Nevertheless, physical activity was cube root-transformed to achieve closer-to-normal distribution before including it in the models, because it was grossly right-skewed, and we did not want to reduce the sample size by discarding cases with zero values (cf. van den Berg et al., 2017). Because the rating scale data for the mediators and GHQ-12 yielded summary scores with more than five distinct values, those variables were treated as continuous in our analyses (Norman, 2010; Rhemtulla et al., 2012).

Next, we tested single mediation models linking green/bluespace to GHQ-12. In addition to being treated as mediators, perceived green/bluespace were also tested as the initial variables in the causal chain on par with objective measures. We used bootstrapping (5000 samples) implemented in the PROCESS v. 2.16 macro for SPSS (pre-specified Model 4) to obtain bias-corrected 95% CIs of indirect paths (Hayes, 2013). All control variables were included in the model *a priori* based on previous knowledge: age, gender, ethnicity (Bulgarian/other), individual-level economic status (continuous), duration of residence (< 5/≥ 5 years), time spent at home/day (< 8/≥ 8 hours), stressful life events (no/yes), population (continuous), settlement (Plovdiv/other), and month of data collection (October/November).

We ran stratified sensitivity analysis to test for effect modification by sex, age, ethnicity, duration of residence, time spent at home/day, and stressful life events. Interactions between putative modifiers and key measures of green/bluespace (NDVI and presence of bluespace in the 300-m buffer, perceived green- and bluespace) were formally examined using Wald's test (at the relaxed $p < 0.1$ level), which was the main criterion for the presence of moderation. As another sensitivity analysis, we used Sentinel 2-NDVI instead of Landsat 8-NDVI to check whether single mediation results would change.

Finally, we used structural equation modelling (SEM) techniques to assess the theoretically-indicated interplay between factors specified in Figure 2. Small's test of multivariate normality showed the assumption of multivariate normality to be violated, and we used a maximum likelihood minimization function with bootstrap-generated confidence intervals and standard errors for all regression paths (5000 samples) (Brown, 2006; Kelley, 2005; Haukoos and Lewis, 2005). Based on results of single mediation models, NDVI $_{300\text{-m}}$ (per one interquartile range increase) and presence of bluespace in the 300-m buffer were selected as objective measures of green/bluespace. Guided by theory and bivariate correlations in the dataset, we specified confounding paths between control variables and key variables in the model. Error terms of NDVI $_{300\text{-m}}$ and bluespace $_{300\text{-m}}$; L_{day} and NO_2; perceived green/bluespace; and settlement and population were *a priori* allowed to be correlated. Goodness of fit was evaluated by using the chi-squared test, standardized root mean square residual (SRMSR), root mean square error of approximation (RMSEA), and comparative fit index (CFI), according to suggestions for acceptable model fit provided in Hu and Bentler (1999): non-significant χ^2 ($p > 0.05$), RMSEA (≤ 0.06, 90% CI ≤ 0.06), SRMSR (≤ 0.08), and CFI (≥ 0.95). These multiple indices were used because they provided a more conservative and reliable evaluation of the solution. Standardized residuals and modification indices were inspected to identify localized points of ill fit in the initial solution, after which the model was re-specified *a posteriori*. Modification indices and standardized residuals were inspected to improve model fit when suggested model re-specification was justified by scientific logic. Over 95% of the normalized residuals ≤ |2.58| were expected from a good-fitting model (Brown, 2006).

Associations were considered statistically significant at the $p < 0.05$ level, and mediation was taken as indicated when the indirect path significantly exceeded zero, regardless of the significance of the total effect (Zhao et al. 2010). Marginally significant ($p < 0.1$) indirect paths are discussed only as suggestive evidence of mediation.

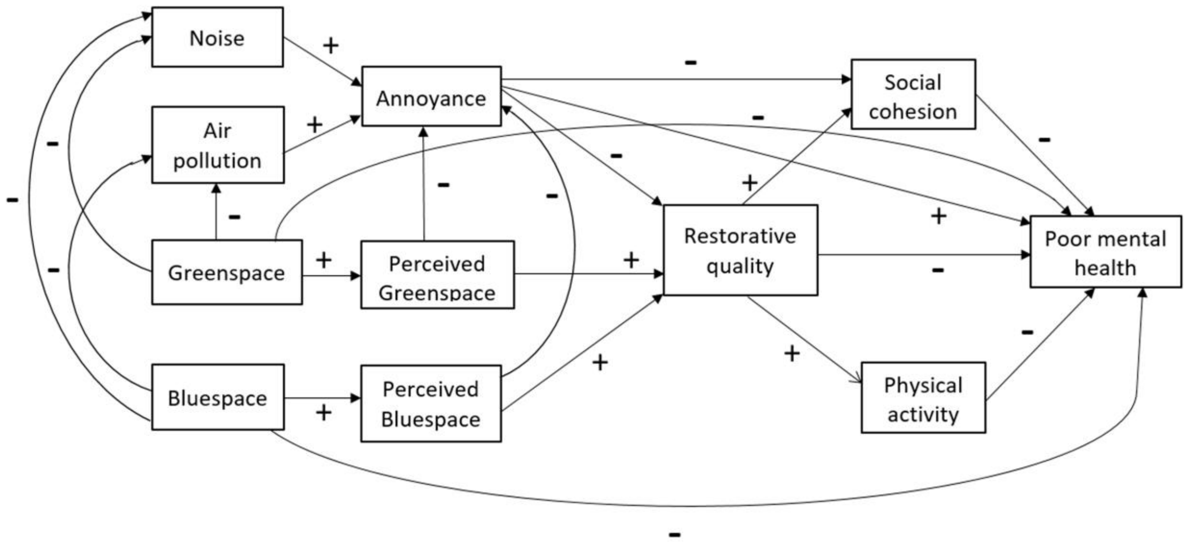

Figure 2. Conceptual diagram showing theoretically-indicated pathways linking green- and bluespace to poor mental health

3. Results

3.1. Characteristics of the sample

Participants' median age was 21 years, 34% were men, and most were Bulgarians (74%) (Table 1). The directions of correlations between exposure variables, mediators, and GHQ-12 were in line with theory (Supplementary Table S1). Perceived greenspace was the strongest correlate of GHQ-12 (r_s = -0.31, p < 0.01); the correlation of GHQ-12 with NDVI $_{100\text{-m}}$ was weaker but significant (r_s = -0.19, p < 0.01). GHQ-12 was not associated with any of the bluespace measures. The association between objective and perceived greenspace measures was strongest for the 100-m buffer of NDVI (r_s = 0.29, p < 0.01), and distance to bluespace was significantly associated with perceived bluespace (r_s = -0.31, p < 0.01).

Table 1. Participant characteristics

Characteristic	(N= 720)
Sociodemographic factors	
Male (n, %)	243 (33.8)
Age (median, IQR)	21.00 (3.00)
Bulgarian (n, %)	533 (74.0)
Economic status (mean, SD)	2.63 (1.20)
Green/bluespace	
Landsat NDVI $_{100\text{-m}}$ (median, IQR)	0.40 (0.14)
Landsat NDVI $_{300\text{-m}}$ (median, IQR)	0.41 (0.11)
Landsat NDVI $_{500\text{-m}}$ (median, IQR)	0.41 (0.07)
Sentinel NDVI $_{100\text{-m}}$ (median, IQR)	0.35 (0.12)
Sentinel NDVI $_{300\text{-m}}$ (median, IQR)	0.36 (0.11)
Sentinel NDVI $_{500\text{-m}}$ (median, IQR)	0.36 (0.06)
Tree cover density $_{100\text{-m}}$, % (median, IQR)	4.52 (6.04)
Tree cover density $_{300\text{-m}}$, % (median, IQR)	5.12 (6.02)
Tree cover density $_{500\text{-m}}$, % (median, IQR)	6.36 (4.84)
Land use greenspace $_{100\text{-m}}$, % (median, IQR)	0.00 (0.34)
Land use greenspace $_{300\text{-m}}$, % (median, IQR)	6.70 (18.50)
Land use greenspace $_{500\text{-m}}$, % (median, IQR)	11.79 (15.64)
Distance to green space, m (median, IQR)	160.72 (268.12)
Distance to bluespace, m (median, IQR)	1489.46 (1143.26)
Bluespace presence $_{100\text{-m}}$ (n, %)	3 (0.4)
Bluespace presence $_{300\text{-m}}$ (n, %)	35 (4.9)
Bluespace presence $_{500\text{-m}}$ (n, %)	68 (9.4)
Mental health	
GHQ-12 (mean, SD)	11.04 (6.08)
Candidate mediators	
Perceived greenspace (mean, SD)	2.98 (1.10)
Perceived bluespace (median, IQR)	1 (1.60)
Restorative quality (median, IQR)	3.50 (3.00)
Social cohesion (mean, SD)	2.89 (1.39)
Physical activity, EE* (median, IQR)	130.00 (266.57)
L_{day}, dB(A) (mean, SD)	67.06 (1.73)
NO_2, µg/m^3 (mean, SD)	15.18 (3.03)
Environmental annoyance (mean, SD)	1.61 (0.89)
Other covariates	
Stressful life event (n, %)	258 (35.8)
Residence in Plovdiv (n, %)	642 (89.2)
Duration of residence ≥ 5 years (n, %)	276 (38.3)

Time spent at home/day ≥ 8 hours (n, %)	394 (54.7)
Population $_{500\text{-m}}$ (median, IQR)	9107.70 (3941.80)
Month: October (n, %)	328 (45.6)

Abbreviations: EE – energy expenditure, GHQ-12 – General Health Questionnaire-12, IQR – interquartile range, L_{day} – daytime road traffic noise level, NDVI – Normalized Difference Vegetation Index, NO_2 – nitrogen dioxide, SD – standard deviation. All continuous variables are positively coded (i.e., higher values on the variable indicate higher values on the respective factor, except for GHQ, where higher values indicate worse mental health). [*]Before cube root-transformation.

3.2. Main analysis

Supplementary Table S2 shows results (total effects and the coefficients for the indirect effects) of single mediation models linking green/bluespace to GHQ-12. NDVI $_{300\text{-m}}$ was the only objective greenspace measure that had a significant and negative total effect on GHQ-12. That association was mediated by perceived greenspace and environmental annoyance. Perceived greenspace acted as a single mediator for most objective measures, except land use greenspace in the 500-m buffer and distance to green space. Results for the other candidate mediators were inconsistent across buffer sizes of tree cover density and land use greenspace. Perceived greenspace was related to lower GHQ-12, with physical activity and annoyance acting as single mediators.

None of the objective measures of bluespace was associated with GHQ-12, and only the total effect of bluespace $_{300\text{-m}}$ was in the expected direction. However, we observed a significant mediation through restorative quality for all measures, except presence of bluespace in the 100-m buffer. Social cohesion acted as a mediator in the 300-m buffer. Perceived bluespace was not directly associated with GHQ-12, but restorative quality, social cohesion, and physical activity worked as single mediators.

The initial SEM had a poor fit to the data: χ^2 (148) = 670.957, $p < 0.001$, SRMSR = 0.072, RMSEA = 0.070 (90% CI: 0.065, 0.076), CFI = 0.762. Inspection of standardized residuals and modification indices indicated some localized points of ill fit in the solution. Hence, we re-specified the model by drawing covariance links, which reflected plausible correlations between participants' characteristics without implying a causal relationship (e.g., foreign students were more likely to live in Plovdiv, have shorter duration of residence, and spend more time at home). We also added two direct regression paths that were also plausible (i.e., from perceived greenspace to social cohesion and GHQ-12). (See Supplementary Figure S2 for the initial and final model.) Thus, we obtained a reasonably well-fitting final model: $\chi^2_{(133)}$ = 228.913, $p < 0.001$, SRMSR = 0.037, RMSEA = 0.032 (90% CI: 0.025, 0.039), CFI = 0.956. (Figure 3) The correlation matrix from this solution is given in Supplementary Table S3.

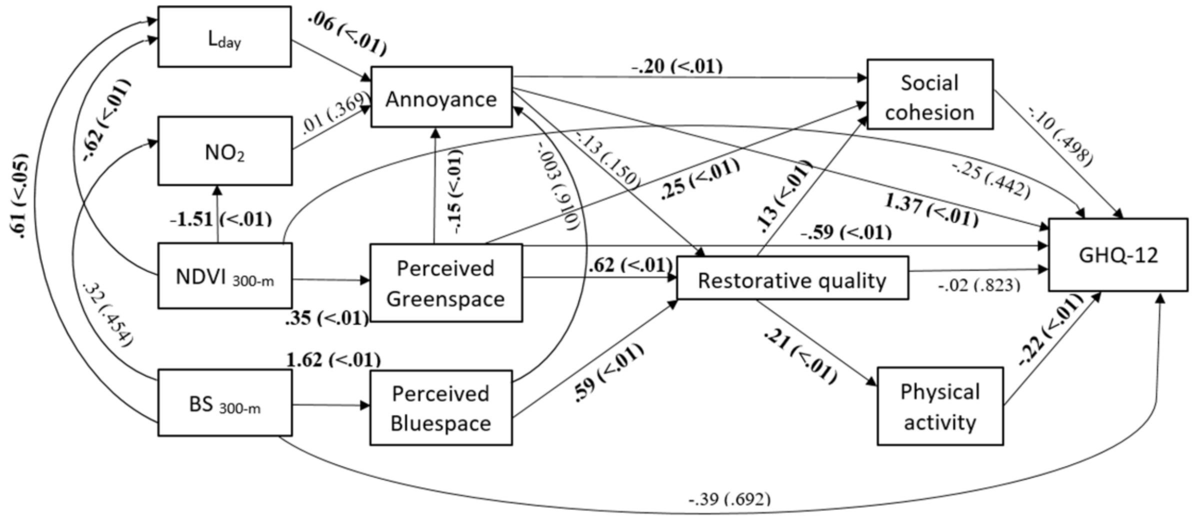

Figure 3. Structural equation model showing the estimated paths linking green- and bluespace to mediators and poor mental health (GHQ-12)

Abbreviations: BS – bluespace, GHQ-12 – General Health Questionnaire-12, L_{day} – daytime road traffic noise level, NO_2 – nitrogen dioxide. Unstandardized regression weights with their significance level (in parenthesis) are given for each path. Bold coefficients are statistically significant. Higher GHQ-12 score is indicative of poorer mental health. Control variables, covariances, and errors terms are not displayed to enhance readability.

Table 2 shows estimated total, direct, and indirect effects in the structural model. The total effect of NDVI $_{300\text{-m}}$ on GHQ-12 was significant and fully mediated by several serial mediation components. More specifically, NDVI $_{300\text{-m}}$ was associated with lower L_{day}, which in turn was associated with lower environmental annoyance, and in turn with better mental health (path 1); another pathway operated through increased perceived greenspace, which in turn was associated with decreased annoyance, and in turn with better mental health (path 7); higher perceived greenspace was also related to higher restorative quality, and through it to higher physical activity, and in turn to better mental health (path 11); simultaneously, perceived greenspace worked as a single mediator leading to better mental health (path 15). Two marginally significant ($p < 0.1$) serial mediation paths involved annoyance acting as a constraint on restoration, and thus, decreasing physical activity (paths 3 and 9). Using alternative buffers for NDVI did not materially change the indirect effect coefficients (data not shown; available on request from the authors), but for two exceptions: NDVI had no total effect on GHQ-12 in the 100-m (β = -0.350; -0.904, 0.215; p = 0.227) and 500-m (β = -0.256; -0.802, 0.248; p = 0.311) buffers.

Total effect of presence of bluespace in the 300-m buffer was non-significant. However, bluespace was indirectly associated with better mental health through perceived bluespace, which related to higher restorative quality, and in turn to higher physical activity (path 18). However, bluespace was also associated with poorer mental health through higher L_{day}, and in turn higher annoyance (path 23). A marginally significant path involved higher L_{day} leading to higher annoyance, in turn to lower restorative quality, and in turn to reduced physical activity (path 26).

Table 2. Total, direct, and indirect effects linking green/bluespace to poor mental health (GHQ-12) in the structural equation model

	β unstandardized (95% CI)	**p-value**
NDVI 300-m		
Total effect	**-0.624 (-1.276, -0.008)***	**0.049**
Direct effect	-0.250 (-0.928, 0.406)	0.442
Total indirect effect	**-0.375 (-0.589, -0.213)***	**< 0.001**
Specific indirect paths through:		
(1) L_{day} → EA → GHQ-12	**-0.049 (-0.109, -0.014)***	**0.003**
(2) L_{day} → EA → RQ → SC → GHQ-12	-0.0001 (-0.001, 0.0001)	0.230
(3) L_{day} → EA → RQ → PA → GHQ-12	-0.0002 (-0.001, 0.00001)	0.059
(4) NO_2 → EA → GHQ-12	-0.023 (-0.077, 0.026)	0.353
(5) NO_2 → EA → RQ → SC → GHQ-12	-0.00003 (-0.001, 0.00003)	0.240
(6) NO_2 → EA → RQ → PA → GHQ-12	-0.0001 (-0.001, 0.0001)	0.189
(7) Perceived GS → EA → GHQ-12	**-0.071 (-0.137, -0.033)***	**< 0.001**
(8) Perceived GS → EA → RQ → SC → GHQ-12	-0.0001 (-0.001, 0.0001)	0.250
(9) Perceived GS → EA → RQ → PA → GHQ-12	-0.0003 (-0.001, 0.00001)	0.060
(10) Perceived GS → RQ → SC → GHQ-12	-0.003 (-0.013, 0.005)	0.409
(11) Perceived GS → RQ → PA → GHQ-12	**-0.010 (-0.022, -0.003)***	**0.002**
(12) L_{day} → EA → SC → GHQ-12	-0.001 (-0.004, 0.001)	0.320
(13) NO_2 → EA → SC → GHQ-12	-0.0003 (-0.004, 0.0005)	0.316
(14) Perceived GS → EA → SC → GHQ-12	-0.001 (-0.006, 0.002)	0.364
(15) Perceived GS → GHQ-12	**-0.203 (-0.395, -0.066)***	**0.004**
(16) Perceived GS → SC → GHQ-12	-0.008 (-0.038, 0.016)	0.436
Presence of bluespace 300-m		
Total effect	-0.421 (-2.239, 1.591)	0.683
Direct effect	-0.394 (-2.250, 1.165)	0.693
Total indirect effect	-0.026 (-0.286, 0.196)	0.816
Specific indirect paths through:		
(17) Perceived BS → RQ → SC → GHQ-12	-0.012 (-0.057, 0.024)	0.448
(18) Perceived BS → RQ → PA → GHQ-12	**-0.043 (-0.096, -0.014)***	**0.002**
(19) Perceived BS → EA → GHQ-12	-0.006 (-0.145, 0.121)	0.904
(20) Perceived BS → EA → RQ → SC → GHQ-12	-0.00001 (-0.001, 0.0002)	0.653
(21) Perceived BS → EA → RQ → PA → GHQ-12	-0.00002 (-0.001, 0.001)	0.736
(22) Perceived BS → EA → SC → GHQ-12	-0.0001 (-0.005, 0.003)	0.760
(23) L_{day} → EA → GHQ-12	**0.049 (0.004, 0.146)***	**0.028**
(24) L_{day} → EA → SC → GHQ-12	0.001 (-0.001, 0.006)	0.244
(25) L_{day} → EA → RQ → SC → GHQ-12	0.0001 (-0.00004, 0.001)	0.189
(26) L_{day} → EA → RQ → PA → GHQ-12	0.0002 (-0.000001, 0.001)	0.051
(27) L_{day} → EA → RQ → GHQ-12	0.0001 (-0.001, 0.002)	0.472
(28) NO_2 → EA → GHQ-12	0.005 (-0.007, 0.057)	0.301
(29) NO_2 → EA → SC → GHQ-12	0.0001 (-0.0001, 0.003)	0.242
(30) NO_2 → EA → RQ → SC → GHQ-12	0.00001 (-0.000004, 0.0004)	0.190
(31) NO_2 → EA → RQ → PA → GHQ-12	0.00002 (-0.00001, 0.0005)	0.177
(32) NO_2 → EA → RQ → GHQ-12	0.00001 (-0.00004, 0.001)	0.333

Abbreviations: EA – environmental annoyance, GHQ-12 – General Health Questionnaire-12, GS – greenspace, L_{day} – daytime road traffic noise level, NDVI – Landsat-derived Normalized Difference Vegetation Index, NO_2 – nitrogen dioxide, PA – physical activity, RQ – restorative quality, SC – social cohesion. Coefficients for NDVI are rescaled to an interquartile range increment. *Coefficient is statistically significant at $p < 0.05$.

3.3. Sensitivity analyses

Supplementary Table S4 shows stratified total effects of green/bluespace. The association of NDVI $_{300\text{-m}}$ with better mental health was more pronounced in non-Bulgarians, whereas the association of perceived greenspace with better mental health was more pronounced in participants over 21 years. Presence of bluespace within the 300-m buffer, which was not associated with GHQ-12 in the main analysis, here was associated with lower GHQ-12 in men, participants over 21 years of age, non-Bulgarians, and those with less than 5 years of residence duration. There was an association for perceived bluespace only in men.

There was no materially important change in the magnitude of coefficients for the indirect effects in single mediation models when Sentinel-NDVI was used instead of Landsat-NDVI, and the total effect coefficients for NDVI $_{300\text{-m}}$ and NDVI $_{500\text{-m}}$ turned borderline significant ($p = 0.054$). (See Supplementary Table S5)

4. Discussion

4.1. Overall findings

This study examined associations between different green/bluespace measures, potential mediators, and mental health in a sample of Bulgarian young adults. We found evidence that increased greenspace was associated with better mental health through several indirect pathways. The pathways through perceived greenspace and environmental annoyance were driving the indirect effect. Conversely, bluespace was not clearly associated with mental health owing to indirect paths working competitively in opposite directions.

4.2. Greenspace

Tests of the single mediation models indicated that perceived greenspace acted as a single mediator for most objective measures, which is consistent with the idea that self-reports may give a better account of individual's cognitive representation of their living environment than objective measures (Dzhambov et al., 2018). In broader outline, our results also concur with reports of Zhang et al. (2017) and van den Berg et al. (2017) that perceived measures of interaction with greenspace were significant mediators leading to neighborhood satisfaction and mental health. In the model with multiple indirect paths, perceived greenspace also worked as a single mediator and explained the highest proportion (around one third) of the total effect of surrounding greenness on mental health. Since perceived greenspace is not expected to improve health *per se*, these results suggest that there might be additional mediators on the pathway from perceived greenspace to GHQ-12 or that the measures we used did not adequately represent the respective constructs.

This study corroborates findings of Dzhambov et al. (2018) that restorative quality and physical activity, two mediators non-significant in the single mediation models for NDVI $_{300\text{-m}}$, operated as serial mediators. That is, higher surrounding greenness was associated with higher perceived greenspace, which in turn was related to higher restorative quality, and through it to higher physical activity, and thus, to better mental health. These results further illustrate that incorrect specification of orthogonal pathways in single or parallel mediation model could explain the null (de Vries et al., 2013; Triguero-Mas et al., 2015; Dadvand et al.,

2016) and sometimes negative (Gacon et al., 2018) indirect effect through physical activity in previous research.

Social cohesion was not an important mediator in the present study. Its association with green/bluespace and mental health was in the expected direction though. In single mediation models, it significantly mediated the effect of some measures (tree cover density $_{500\text{-m}}$, land use greenspace $_{100\text{-m}}$, presence of bluespace $_{300\text{-m}}$, and perceived bluespace), but in the full model none of the paths including it reached significance. This result corroborates findings of a null (e.g., Triguero-Mas et al., 2015; 2017) or weak (e.g., Gascon et al., 2018) indirect path through social cohesion, but stands in contrast to those of other research (Sugiyama et al., 2008; Maas et al., 2009; de Vries et al., 2013; Dadvand et al., 2016), including a previous study in Plovdiv (Dzhambov et al., 2018), where restorative quality and social cohesion worked as serial mediators linking NDVI to mental health. Possible reasons for these discrepancies could be the reduced number of social cohesion items we used, age of our participants, or adjustment for other factors that might have attenuated its association with mental health.

As in other studies (Gascon et al., 2018; Dzhambov et al., 2018), another pathway linking surrounding greenness to mental health involved mitigation of noise exposure. The role of noise in our study was revealed in the full model, in which surrounding greenness was associated with lower L_{day}, which in turn was associated with lower annoyance, and so with better mental health. The reasons for this effect could be twofold: for one, vegetation can reduce noise exposure if it is on the path of sound waves (Van Renterghem et al. 2015); also, greener neighborhoods might simply have less artificial noise emitting sources and therefore be quieter (Markevych et al. 2017).

In contrast with Gascon et al. (2018), in our study, NO_2 did not act as a mediator (either single or serial), whereas in theirs, it explained 4% and 30% of the total effects on depression of NDVI $_{300\text{-m}}$ and access to major green spaces within 300-m, respectively. This could have multiple explanations, such as lower model performance of the global LUR we used to calculate NO_2 (R^2 = 0.52 vs. 0.75), differences in definition of poor mental health (GHQ-12 vs. self-reported doctor diagnosis), and participants' age (18 – 35 vs. 44 – 74 years). A previous study in Plovdiv did not indicate single mediation through fine particulate matter (Dzhambov et al., 2018).

Unlike findings of previous studies (Zijlema et al., 2017; Dzhambov et al., 2018), annoyance acted as a single mediator for several measures of greenspace. The fact that we used a more comprehensive measure of environmental annoyance (i.e., traffic/neighborhood noise, air pollution, vibration) may contribute to the contrasting findings. SEM showed that surrounding greenness was related to lower annoyance through higher perceived greenspace, and in turn to better mental health. That is consistent with the literature indicating that perceived greenspace might enable residents to develop a sense of control over the acoustic environment, because they know that there is a refuge from traffic noise exposure in the neighborhood and do not feel helpless (Riedel et al., 2018). Also, noise annoyance and perceived air pollution might mediate the effect of self-reported greenspace on GHQ-12 (Dzhambov et al., 2018). Two marginally significant paths suggested that by reducing annoyance, which might act as a constraint on restoration (von Lindern et al., 2016), surrounding greenness encouraged physical activity, and thus improved mental health. However, in our model, perceived greenspace was essentially treated as a confounder of the relationship between annoyance and restorative quality, possibly weakening the annoyance-restorative quality link. Also, unlike von Lindern et al. (2016), we considered noise annoyance due to different neighborhood sources, not just to traffic.

4.3. Bluespace

The null total effect of bluespace in our study corroborates findings of some other authors (e.g., Triguero-Mas et al., 2015; Bezold et al., 2017; Gascon et al., 2018); however, authors of these studies did not proceed with tests of hypotheses of indirect effects to explore the possible reasons for their findings (e.g., Triguero-Mas et al., 2015; Gascon et al., 2018), hence we can make no comparison. Noteworthy, current view on mediation analysis imposes no requirement that there be evidence of a total effect of exposure on outcome (Zhao et al., 2010; Hayes, 2013). A total effect may be negligible if, as illustrated in the present study, indirect paths work competitively in opposite directions and conceal a direct effect. There might also be unmeasured mediators on the pathway between exposure and outcome.

Perceived bluespace did not act as a single mediator for objective bluespace, but in single mediation models, it was indirectly linked to better mental health through restorative quality, social cohesion, and physical activity. On the other hand, restorative experiences in relation to bluespace emerged as an important mediator. Restorative quality worked as a single mediator for almost all bluespace measures. Although it has not been explicitly tested as a mediator in previous studies of bluespace and health, our findings are in line with empirical reports that scenes containing water have high restorative potential (White et al., 2010) and that visits to coastal natural area support restoration (White et al., 2013c). Furthermore, SEM indicated that living within 300-m of bluespace was associated with better mental health indirectly through higher perceived bluespace, which in turn related to higher restorative quality, then to higher physical activity, and so to mental health.

Our rationale for testing noise and air pollution as mediators for bluespace was that, similarly to greenspace, more bluespace in a residential area might correlate with less sources of noise and air pollution. Strikingly, having a bluespace within a neighborhood of 300-m was associated with higher noise exposure, which in turn related to higher annoyance, and thus, to poorer mental health. This illustrates how indirect paths might work competitively in opposite directions and mislead researchers to infer a null effect. One possible reason for these findings could be the urban fabric of the study area: the major water body that most participants had an access to is the Maritza River, which flows through a densely populated part of Plovdiv where traffic congestion is high.

Environmental annoyance *per se* was not a mediator for bluespace. To our knowledge, this is the first time the associations between bluespace and vibration and air pollution annoyances were tested, so we cannot compare our findings with those of others. As for noise annoyance, it should be noted that masking of unwanted sounds is greater when the masker and the noise signal are the same frequency (cf. Van Renterghem, in press). However, our participants had the opportunity to interact only with small water bodies, which generate mid-to-high frequency sounds, whereas traffic noise emissions are dominated by mid and low frequencies (Galbrun and Ali, 2013). Also, on days with little wind, still water bodies may allow for sound propagation to a greater degree than intervening vegetation. In addition, in SEM, adjusting for greenspace could have attenuated the effect of perceived bluespace.

4.4. Strengths and limitations

The present study has several important strengths. It was specifically designed to address the research question at hand, rather than making use of already available data. That enabled us to collect data on multiple green/bluespace measures not covered in secondary studies relying solely on geographic measures, and to use sophisticated statistical methods to test a holistic mediation model, which was previously recommended in order to take better account of different mechanisms supporting mental health (Markevych et al., 2017; Dzhambov et al., 2018). Also, we had a high response rate (> 80%) compared with other, population-based studies (e.g., PHENOTYPE; van den Berg et al., 2017).

We focused on an understudied age group from South-East Europe, which is an underrepresented region in the pertinent literature (cf. Gascon et al., 2015; 2017). By focusing on students from one university, we reduced overdispersion in the data. Importantly, we could also control for environmental influences (e.g., traffic emissions, greenness) on campus, where students spend most of their time when not in their neighborhood. At the same time, our sample was diverse in terms of residential settings and individual characteristics, ensuring sufficient variability in the data, including participants with a different ethnic and racial background. Notably, questionnaires were filled in the presence of a member of the research group, which allowed participants to ask questions, increased the quality of their responses, and resulted in high overall response rate, and little missing data. The present study adds to the scarce evidence concerning the benefits of fresh water bodies (cf. Gascon et al., 2017).

However, several limitations should be discussed. First, this study was cross-sectional like most studies in the field (Gascon et al., 2015; 2017). This precludes drawing causal inferences about some associations. The associations between mediators and mental health may go both ways: for instance, longitudinal analyses have already indicated persistent, positive, and bidirectional associations between mental health and physical activity and social rhythm/social capital (Steinmo et al., 2014; Yu et al., 2015; Cai et al., 2017). Also of note, cross-sectional tests of mediation might entail bias and produce overconfident results (Maxwell et al., 2011). Recall bias cannot be ruled out. We intend to follow a subgroup of participants in order to test our findings.

Students were considered an important group because they typically are young adults, a group on which there is almost no previous research (Gascon et al., 2015; 2017). The student occupation is of itself interesting. Being a student is commonly experienced as highly stressful. Chronic stress is likely to increase the risk of some underlying disorder, and the GHQ screens for this risk with items that tap chronic stress. However, the non-random sampling and purposeful inclusion of foreign students means that our sample was not representative of all young people in Plovdiv. That does not necessarily have an effect on the internal validity of our study, because we controlled for a wide range of sociodemographic and residential factors.

We used validated measures to assess green/bluespace and mediators, but those might not have adequately captured the respective constructs. For example, to reduce questionnaire length and response burden, we used a reduced number of items from the PRS and PNSC-BF to describe restorative quality and social cohesion.

We only considered residential green/bluespace, and although we controlled for green/bluespace on university campus, we could not account for exposures while commuting or during time spent outside the study area, as with recreational visits to distant parks. Static environmental exposure assessments disregard how ordinary life can extend beyond participants' neighborhood in ways that become meaningful over time (Helbich, 2017). In that some movement outside of the neighborhood compensates for a lack of green/bluespace within it (Sijtsma et al., 2012), our estimates of the associations between mental health and green/bluespace within the neighborhood are likely to be conservative. Modern Global Positioning System (GPS) technology is making its way into green- and bluespace research as a more precise way to assess location-specific physical activity (e.g., Triguero-Mas et al., 2017). Unfortunately, it was not feasible to use this approach to constantly monitor participants for a whole month.

It is likely that we have overestimated noise exposure at addresses located on minor roads and in smaller settlements, owing to the limited observed range of measurements used to construct the LUR. Even though that is expected to have attenuated the association between L_{day} and annoyance, we detected significant serial mediation through those mediators. NO_2 data were not of the best quality either (i.e., the LUR model was global, not developed specifically for our study area, and it was based on data from relatively few monitoring stations in Bulgaria.).

Finally, data were collected in October – November, when people spend less time outdoors and vegetation contrasts are lower than in summer. By adjusting for month, we controlled for monthly variation in average temperatures; the weather in the study area was warmer in 2017 than typical for that time of the year, plus most questions referred to the past month when people were even more likely to spend time outdoors.

Given these limitations, we suspect that the associations we found are more likely to have been underestimated than overestimated.

5. Conclusion

The present study provides a picture of how objective and perceived measures of green- and bluespace relate to mental health through a complex set of pathways. Rather than having a simple, direct effect, higher surrounding greenness can be beneficial for mental health through multiple indirect effects. Firstly, it was associated with higher perceived greenspace, which in turn was related to better mental health both directly and indirectly through increased restorative quality of the living environment, and subsequently, through increased physical activity. Secondly, it was associated with lower noise exposure, which in turn was associated with lower environmental annoyance. Finally, another pathway involved higher perceived greenspace, which was associated with lower annoyance. Bluespace also did not have a straightforward association with mental health. The complexity in part owed to indirect paths working competitively in opposite directions: one supporting mental health through higher perceived bluespace, restorative quality, and physical activity; and another, related to mental ill-health through higher noise exposure and environmental annoyance.

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Competing financial interests

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References

Aguilera I, Foraster M, Basagaña X, Corradi E, Deltell A, Morelli X, Phuleria HC, Ragettli MS, Rivera M, Thomasson A, Slama R, Künzli N. 2015. Application of land use regression modelling to assess the spatial distribution of road traffic noise in three European cities. J Expo Sci Environ Epidemiol. 25(1):97-105.

Alcock I, White MP, Lovell R, Higgins SL, Osborne NJ, Husk K, Wheeler BW. 2015. What accounts for Englands green and pleasant land'? A panel data analysis of mental health and land cover types in rural England. Landsc Urban Plan 142:38–46.

Barton J, Bragg R, Wood C, Pretty J. 2016. Green Exercise: Linking Nature, Health and Well-being. Routledge.

Bezold CP, Banay RF, Coull BA, Hart JE, James P, Kubzansky LD, Missmer SA, Laden F. 2018. The Association Between Natural Environments and Depressive Symptoms in Adolescents Living in the United States. J Adolesc Health. 62(4):488-495.

Blanca MJ, Alarcón R, Arnau J, Bono R, Bendayan R. 2017. Non-normal data: Is ANOVA still a valid option? Psicothema 29(4):552-557.

Brereton F, Clinch JP, Ferreira S. 2008. Happiness, geography and the environment. Ecol Econ 65:386–396.

Brown T. 2006. Confirmatory factor analysis for applied research. New York, NY: Guilford Press.

Cai D, Zhu M, Lin M, Zhang XC, Margraf J. 2017. The Bidirectional Relationship between Positive Mental Health and Social Rhythm in College Students: A Three-Year Longitudinal Study. Front Psychol. 8: 1119. doi: 10.3389/fpsyg.2017.01119. eCollection 2017.

Campbell N, Gaston A, Gray C, Rush E, Maddison R, Prapavessis H. 2016. The Short Questionnaire to Assess Health-Enhancing (SQUASH) Physical Activity in Adolescents: A Validation Using Doubly Labeled Water. J Phys Act Health 13:154-158.

Cohen S, Spacapan S. 1984. The social psychology of noise. In: Jones DM, Chapman AJ. (Eds.), Noise and Society. Chichester: John Wiley & Sons, pp. 221-245.

Dadvand P, Bartoll X, Basagaña X, Dalmau-Bueno A, Martinez D, Ambros A, et al. 2016. Green spaces and General Health: Roles of mental health status, social support, and physical activity. Environ Int 91:161-167.

Dahlkvist E, Hartig T, Nilsson A, Högberg H, Skovdahl K, Engström M. 2016. Garden greenery and the health of older people in residential care facilities: A multi-level cross-sectional study. J Adv Nurs 72:2065-2076.

de Vries S, van Dillen SME, Groenewegen PP, Spreeuwenberg P. 2013. Streetscape greenery and health: stress, social cohesion and physical activity as mediators. Soc Sci Med 94:26–33.

Dempster AP, Laird NM, Rubin DB. 1977. Maximum likelihood estimation from incomplete data via the EM algorithm (with discussion). J Royal Stat Assoc B39:1-38.

Dupuis M, Baggio S, Gmel G. 2017. Validation of a brief form of the Perceived Neighborhood Social Cohesion questionnaire. J Health Psychol 22:218-227.

Dupuis M, Studer J, Henchoz Y, Deline S, Baggio S, N'Goran A, Mohler-Kuo M, Gmel G. 2016. Validation of French and German versions of a Perceived Neighborhood Social Cohesion Questionnaire among young Swiss males, and its relationship with substance use. J Health Psychol 21:171-182.

Dzhambov A, Hartig T, Markevych I, Tilov B, Dimitrova D. 2018. Urban residential greenspace and mental health in youth: Different approaches to testing multiple pathways yield different conclusions. Environ Res 160:47-59.

Dzhambov A, Tilov B, Markevych I, Dimitrova D. 2017. Residential road traffic noise and general mental health in youth: The role of noise annoyance, neighborhood restorative quality, physical activity, and social cohesion as potential mediators. Environ Int 109:1-9.

Fields JM, De Jong RG, Gjestland T, Flindell IH, Job RFS, Kurra S, et al. 2001. Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation. J Sound Vib 242:641–679.

Galbrun L, Ali TT. 2013. Acoustical and perceptual assessment of water sounds and their use over road traffic noise. J Acoust Soc Am 133(1):227-37.

Gascon M, Cirach M, Martínez D, Dadvand P, Valentín A, Plasència A, Nieuwenhuijsen MJ. 2016. Normalized difference vegetation index (NDVI) as a marker of surrounding greenness in epidemiological studies: The case of Barcelona city. Urban For Urban Gree 19:88–94.

Gascon M, Sánchez-Benavides G, Dadvand P, Martínez D, Gramunt N, Gotsens X, Cirach M, Vert C, Molinuevo JL, Crous-Bou M, Nieuwenhuijsen M. 2018. Long-term exposure to residential green and blue spaces and anxiety and depression in adults: a cross-sectional study. Environ Res 162:231-239.

Gascon M, Zijlema W, Vert C, White MP, Nieuwenhuijsen MJ. 2017. Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies. Int J Hyg Environ Health 220(8):1207-1221.

Gascon M, Triguero-Mas M, Martínez D, Dadvand P, Forns J, Plasència A, Nieuwenhuijsen MJ. 2015. Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. Int J Environ Res Public Health 12:4354-4379.

Georgieva EK. 2010. Exploring elements of quality of life in patients with cardiovascular disease [in Bulgarian]. [PhD thesis]. Sofia: Medical University of Sofia.

Goldberg DP, Blackwell B. 1970. Psychiatric illness in general practice: A detailed study using a new method of case identification. BMJ 1:439-443.

Grellier J, White MP, Albin M, Bell S, Elliott LR, Gascón M, Gualdi S, Mancini L, Nieuwenhuijsen MJ, Sarigiannis DA, van den Bosch M, Wolf T, Wuijts S, Fleming LE. 2017. BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and well-being from Europe's blue spaces. BMJ Open 7:e016188. doi: 10.1136/bmjopen-2017-016188

Hartig T, Kaiser FG, Bowler PA. 1997a. Further development of a measure of perceived environmental restorativeness. In: Working Paper No. 5. Institute for Housing and Urban Research, Uppsala University, Gävle, Sweden.

Hartig T, Korpela K, Evans GW, Garling T. 1997b. A measure of restorative quality in environments. Scand. Hous Plann Res 14:175–194.

Hartig T, Mitchell R, de Vries S, Frumkin H. 2014. Nature and Health. Annu Rev Public Health 35: 207–228.

Haukoos JS, Lewis RJ. 2005. Advanced statistics: bootstrapping confidence intervals for statistics with "difficult" distributions. Acad Emerg Med 12(4):360-5.

Hayes A. 2013. Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. New York: Guilford Press.

Helbich M. 2018. Toward dynamic urban environmental exposure assessments in mental health research. Environ Res. 161:129-135.

Hu LT, Bentler PM. 1999. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. Struct. Equ. Modeling 6:1-55.

Jones DM, Chapman AJ, Auburn TC. 1981. Noise in the environment: a social perspective. J Appl Psychol 1:43–59.

Kang J. 2012. On the diversity of urban waterscape. Proceedings of the Acoustics 2012 Conference. Nantes.

Kang J, Aletta F, Gjestland TT, Brown LA, Botteldooren D, Schulte-Fortkamp B, Lercher P, van Kamp I, Genuit K, Fiebig A, Coelho JLB, Maffei L, Lavia L. 2016. Ten questions on the soundscapes of the built environment. Build Environ 108:284–294.

Kaplan R, Kaplan S, 1989. The Experience of Nature: Y Psychological Perspective. Cambridge University Press, New York.

Kaplan S, 1995. The restorative benefits of nature: towards an integrative framework. J Environ Psychol 15:169–182.

Kelley K. 2005. The Effects of Nonnormal Distributions on Confidence Intervals Around the Standardized Mean Difference: Bootstrap and Parametric Confidence Intervals. Educ Psychol Meas 65(1):51–69.

Larkin A, Geddes JA, Martin RV, Xiao Q, Liu Y, Marshall JD, Brauer M, Hystad P. 2017. Global Land Use Regression Model for Nitrogen Dioxide Air Pollution. Environ Sci Technol 51(12):6957-6964.

Leung TM, Chau CK, Tang SK, Pun LSC. 2014. On the study of effects of views to water spaces on noise annoyance perceptions at home. Melbourne, Internoise.

Li HN, Chau CK, Tse MS, Tang SK. 2012. On the study of the effects of sea views, greenery views and personal characteristics on noise annoyance perception at homes. J Acoust Soc Am 131(3):2131–2140.

Lindal PJ, Hartig T. 2013. Architectural variation, building height, and the restorative quality of urban residential streetscapes. JEnviron Psychol 33:26-36.

Lindal PJ, Hartig T. 2015. Effects of urban street vegetation on judgments of restoration likelihood. Urban For Urban Gree 14(2):200-9.

Maas J, Dillen SME van, Verheij RA, Groenewegen PP. 2009. Social contacts as a possible mechanism behind the relation between green space and health. Health Place 15:586-595.

MacKerron G, Mourato S. 2013. Happiness is greater in natural environments. Glob Environ Chang 23:992–1000.

Markevych I, Schoierer J, Hartig T, Chudnovsky A, Hystad P, Dzhambov AM, de Vries S, Triguero-Mas M, Brauer M, Nieuwenhuijsen MJ, Lupp G, Richardson EA, Astell-Burt T, Dimitrova D, Feng X, Sadeh M, Standl M, Heinrich J, Fuertes E. 2017. Exploring pathways linking greenspace to health: Theoretical and methodological guidance. Environ. Res. 158:301-317.

Maxwell SE, Cole DA, Mitchell MA. 2011. Bias in cross-sectional analyses of longitudinal mediation: partial and complete mediation under an autoregressive model. Multivariate Behav Res 46:816-841.

Mutafova M, Maleshkov Ch. 2001. Expected life-expectancy in good health [in Bulgarian]. Sofia: Heron Press.

Norman, G., 2010. Likert scales, levels of measurement and the "laws" of statistics. Adv Health Sci Educ Theory Pract. 15, (5), 625-632.

Petry NM. 2002. A comparison of young, middle-aged, and older adult treatment-seeking pathological gamblers. Gerontologist 42(1):92-9.

Pigott TD. 2001. A review of methods for missing data. Educ Res Eval 7(4):353-83.

Rhemtulla M, Brosseau-Liard PÉ, Savalei V. 2012. When can categorical variables be treated as continuous? A comparison of robust continuous and categorical SEM estimation methods under suboptimal conditions. Psychol. Methods. 17(3): 354-373.

Riedel N, Köckler H, Scheiner J, van Kamp I, Erbel R, Loerbroks A, Claßen T, Bolte G. 2018. Home as a Place of Noise Control for the Elderly? A Cross-Sectional Study on Potential Mediating Effects and Associations between Road Traffic Noise Exposure, Access to a Quiet Side, Dwelling-Related Green and Noise Annoyance. International Journal of Environmental Research and Public Health. 15(5):1036.

Schmider E, Ziegler M, Danay E, Beyer L, Bühner M. 2010. Is it really robust? Reinvestigating the robustness of ANOVA against violations of the normal distribution assumption. Meth Eur J Res Meth Behav Soc Sci 6(4):147-51.

Sijtsma FJ, de Vries S, van Hinsberg A, Diederiks J. 2012. Does 'grey' urban living lead to more 'green' holiday nights? A Netherlands Case Study. Landscape and Urban Planning. 105(3):250-257.

SPECTRI. 2017. Development of an updated strategic noise maps of Plovdiv agglomeration [Report].

Steel Z, Marnane C, Iranpour C, Chey T, Jackson JW, Patel V, Silove D. 2014. The global prevalence of common mental disorders: a systematic review and meta-analysis 1980-2013. Int J Epidemiol 43(2):476-93.

Steinmo S, Hagger-Johnson G, Shahab L. 2014. Bidirectional association between mental health and physical activity in older adults: Whitehall II prospective cohort study. Prev Med 66:74-9.

Sugiyama T, Leslie E, Giles-Corti B, Owen N. 2008. Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? J Epidemiol Community Health 62:e9.

Teylor L, Hochuli DF. 2017. Defining greenspace: multiple uses across multiple disciplines. Landsc. Urban Plan. 158, 25–38.

Triguero-Mas M, Donaire-Gonzalez D, Seto E, Valentín A, Martínez D, Smith G, Hurst G, Carrasco-Turigas G, Masterson D, van den Berg M, Ambròs A, Martínez-Íñiguez T, Dedele A, Ellis N, Grazulevicius T, Voorsmit M, Cirach M, Cirac-Claveras J, Swart W, Clasquin E, Ruijsbroek A, Maas J, Jerret M, Gražulevičienė R, Kruize H, Gidlow CJ, Nieuwenhuijsen MJ. 2017. Natural outdoor environments and mental health: Stress as a possible mechanism. Environ Res 159:629-638.

Triguero-Mas M, Dadvand P, Cirach M, Martínez D, Medina A, Mompart A, Basagaña X, Gražulevičienė R, Nieuwenhuijsen MJ. 2015. Natural outdoor environments and mental and physical health: relationships and mechanisms. Environ Int 77:35–41.

Tucker CJ. 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. Remote Sens Environ 8:127-150.

van den Berg M, van Poppel M, Graham S, Triguero-Mas M, Andrusaityte S, van Kamp I, van Mechelen W, Gidlow C, Gražulevičiene R, Nieuwenhuijsen MJ, Kruize H, Maas J. 2017. Does time spent on visits to green space mediate the associations between the level of residential greenness and mental health? Urban For Urban Gree 25:94–102.

van den Berg MM, van Poppel M, van Kamp I, Ruijsbroek A, Triguero-Mas M, Gidlow C, Nieuwenhuijsen MJ, Gražulevičiene R, van Mechelen W, Kruize H, Maas J. 2017. Do Physical Activity, Social Cohesion, and Loneliness Mediate the Association Between Time Spent Visiting Green Space and Mental Health? Environ Behav https://doi.org/10.1177/0013916517738563

van Kamp I, Davies H. 2008. Environmental noise and mental health: Five year review and future directions. In Proceedings of the 9th International Congress on Noise as a Public Health Problem.

Van Renterghem T, Forssén J, Attenborough K, Jean P, Defrance J, Hornikx M, Kang J. 2015. Using natural means to reduce surface transport noise during propagation outdoors. Appl Acoust 92:86–101.

Van Renterghem T. in press. Towards explaining the positive effect of vegetation on the perception of environmental noise. Urban Forestry & Urban Greening. https://doi.org/10.1016/j.ufug.2018.03.007

Vigo D, Thornicroft G, Atun R. 2016. Estimating the true global burden of mental illness. Lancet Psychiatry 3(2):171-8.

Völker S, Heiler A, Pollmann T, Claßen T, Hornberg C, Kistemann T. 2018. Do perceived walking distance to and use of urban blue spaces affect self-reported physical and mental health? Urban For Urban Gree 29:1–9.

von Lindern E, Hartig T, Lercher P. 2016. Traffic-related exposures, constrained restoration, and health in the residential context. Health Place 39:92-100.

Wendel-Vos GCW, Schuit AJ, Saris WHM, Kromhout D. 2003. Reproducibility and relative validity of the Short Questionnaire to Assess Health-enhancing physical activity. J Clin Epidemiol 56:1163-1169.

White M, Smith A, Humphryes K, Pahl S, Snelling D, Depledge M. 2010. Blue space: the importance of water for preference, affect, and restorativeness ratings of natural and built scenes. J Environ Psychol 30:482–93.

White MP, Alcock I, Wheeler BW, Depledge MH. 2013a. Would you be happier living in a greener urban area?: A fixed-effects analysis of panel data. Psychol Sci 24, 920–928.

White MP, Alcock I, Wheeler BW, Depledge MH. 2013b. Coastal proximity, health and well-being: results from a longitudinal panel survey. Health Place 23:97–103.

White MP, Pahl S, Ashbullby K, Herbert S, Depledge MH. 2013c. Feelings of restoration from recent nature visits. J Environ Psychol 35:40–51.

WHO 2016. Urban green spaces and health. Copenhagen: WHO Regional Office for Europe.

Yu G, Sessions JG, Fu Y, Wall M. 2015. A multilevel cross-lagged structural equation analysis for reciprocal relationship between social capital and health. Soc Sci Med 142:1-8.

Zhang Y, Van den Berg AE, Van Dijk T, Weitkamp G. 2017. Quality over Quantity: Contribution of Urban Green Space to Neighborhood Satisfaction. Int J Environ Res Public Health, 14:535.

Zhao X, Lynch JG, Chen Q. 2010. Reconsidering Baron and Kenny: Myths and truths about mediation analysis. J Consum Res 37(2):197-206.

Zijlema WL, Triguero-Mas M, Smith G, Cirach M, Martinez D, Dadvand P, Gascon M, Jones M, Gidlow C, Hurst G, Masterson D, Ellis N, van den Berg M, Maas J, van Kamp I, van den Hazel P, Kruize H, Nieuwenhuijsen MJ, Julvez J. 2017. The relationship between natural outdoor environments and cognitive functioning and its mediators. Environ Res 155:268-275.