Association between objectively-measured greenspace and noise annoyance: Noise reduction and perceived greenspace as putative mediators

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Summary
Urban vegetation may have the potential to buffer both sound wave propagation and the negative psychological reactions to residential noise (i.e., noise annoyance). In the present study, we aimed to examine the association between greenspace and combined noise annoyance due to different sources, and to determine to what extent the effect of objectively-measured greenspace was mediated by noise exposure and perceived greenspace in the neighborhood. We sampled 720 young adults (18 – 35 years) from the city of Plovdiv, Bulgaria. We collected data on greenspace in the neighborhood (derived using GIS and self-reports), noise exposure (calculated by a land use regression model), and mean of annoyances due to (1) transportation and (2) neighborhood noise sources in the living environment. Structural equation modelling was used to assess the association of greenspace with noise annoyance. Higher surrounding greenspace was associated with lower noise annoyance through two equally important indirect paths working in parallel: through lower noise exposure and through higher perceived greenspace. Interventions aimed at reducing noise annoyance may consider the potential of vegetation to reduce noise annoyance not only through acoustic mitigation of noise exposure, but also through psychological mechanisms.

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1. Introduction

Reduction of noise annoyance is one of the putative pathways linking greenspace to better health [1]. The mechanistic hypothesis for this indirect effect could be twofold. For one, vegetation can reduce noise level by physically disrupting sound waves propagation if it is on the path from the source to the receiver [2], or greener neighborhoods might simply have less artificial noise emitting sources and therefore be quieter [1]. In addition, there is literature indicating that perceived greenspace might reduce traffic-related annoyance via psychological mechanisms of stress reduction and increased perceived control over the acoustic environment [3, 4]. For instance, a meta-analysis found significantly lower odds of high noise annoyance in people who had a view of vegetation from their home [4]. However, most previous studies on psychological buffering of noise annoyance used either self-reported or objective measures of greenspace, and considered only noise annoyance due to a specific source [4]. Van Renterghem and Botteldooren's study was an exception because they examined the effect of both objectively-measured and self-reported green view from home on general and traffic noise annoyance [5]. Moreover, to our knowledge, there has been no comparison of the acoustic and psychological effects of greenspace on noise annoyance in the literature. Insight into that may provide useful information as to whether relying on objective measures in urban planning and forestry is sufficient to understand the person-environment interactions in the field of noise and health.

In the present study, we aimed to examine the association between greenspace and combined noise annoyance due to different sources, and to determine to what extent the effect of objectively-measured greenspace was mediated by noise exposure and perceived greenspace in the neighborhood.

2. Methods

2.1. Study design and sampling

Data were collected between October and November 2017 from the Medical University in Plovdiv located in the second largest city in Bulgaria. To be included in our study, students had to be aged 18 – 35 years (defining young adulthood) and resident in Plovdiv or the near provinces in Southern Bulgaria for the last six months. 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. In addition to questions on sociodemographic factors, and residential environment, participants were asked to report their current living address for subsequent assignment of geographic variables. The study design was approved by the Ethics Committee at the Medical University of Plovdiv [6]. 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 into geocodes manually 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. Hence, we analyzed a sample of 720 participants, the majority of whom (n = 642, 89.2%) lived in the city of Plovdiv (Figure 1). Geographic data management and calculations were carried out using ArcGIS 10.3-10.4 Geographical Information System (GIS) (ESRI, Redlands, CA, USA).

2.2. Greenspace

Normalized Difference Vegetation Index (NDVI; [7]) served as an objective measure 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 [8]. NDVI 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/). In line with previous studies [9], we removed all water pixels from the satellite images before NDVI assignment by using OSM water layer. NDVI was abstracted as mean value in a circular buffer of 300 m around the residence [6, 9].

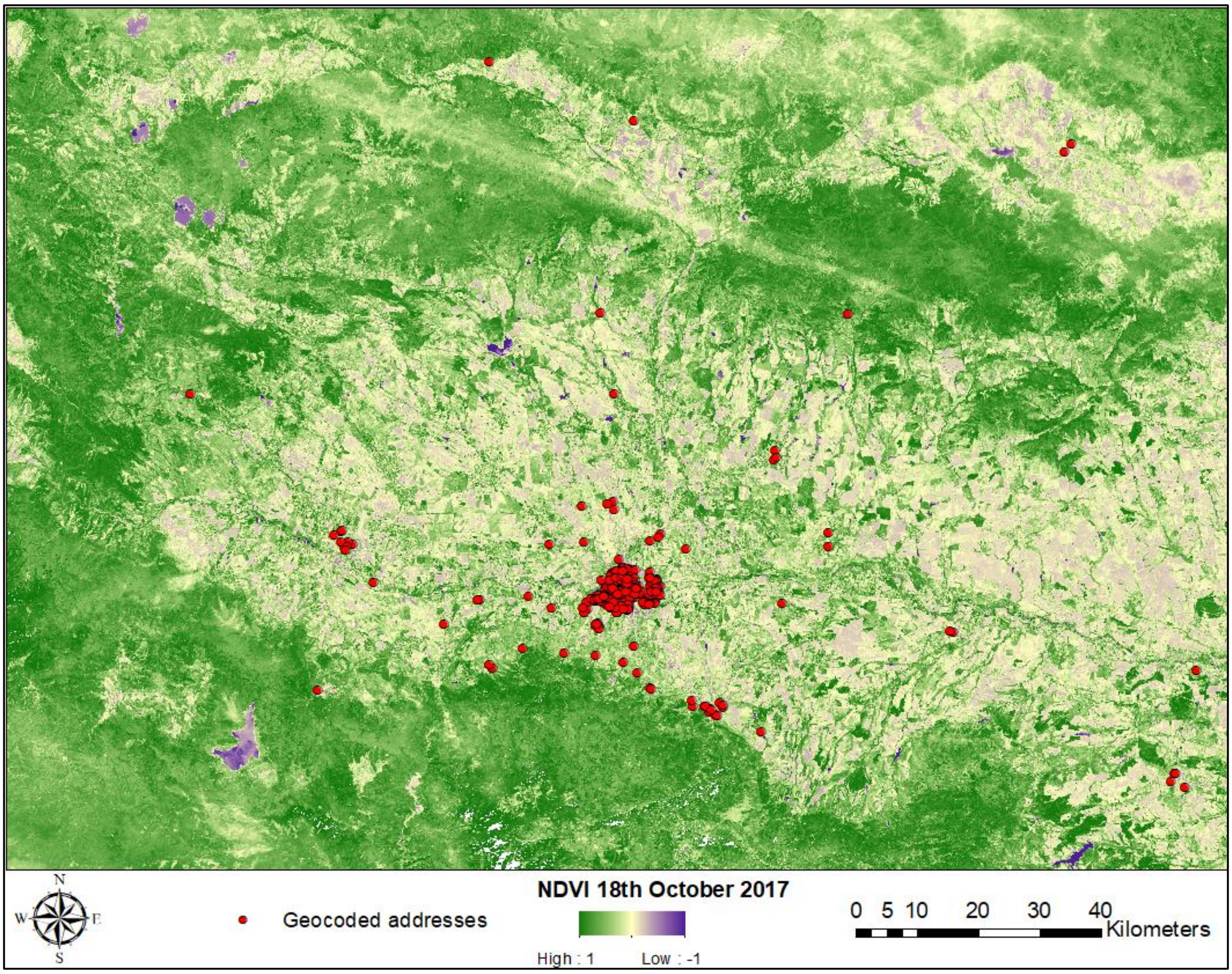

Figure 1. Map of residential addresses superimposed over Normalized Difference Vegetation Index (NDVI) geographic layer

Perceived neighborhood greenspace was measured with a scale developed for this study by averaging the scores on five items asking about different aspects of greenspace "exposure" (cf. [6]): (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 higher mean score indicating higher perceived greenspace in the living environment. Internal consistency of the scale is high (Cronbach's alpha = 0.81).

2.3. Noise exposure

An estimate of noise exposure was obtained by applying a land use regression (LUR) model to participant's residential address. The LUR was developed specifically for this study and is based on noise measurements carried out by the Regional Health Inspection at 45 locations in Plovdiv in 2016 (range: 62.4 – 73.5 dB(A)); measurements were conducted over the 12-hour period 07.00 – 19.00 hours (L_{day}) according ISO 1996-2:1987. Predictor variables derived with GIS were considered in the regression equation, following a supervised forward stepwise selection procedure previously described by Aguilera et al. [10]. The final LUR has an adjusted R^2 of 0.72 and leave-one-out cross validation R^2 of 0.65.

2.4. Noise annoyance

We combined individual annoyances from residential (i.e., both in the dwelling and the neighborhood) traffic noise and other neighborhood noise sources. The two 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") [11]: "How much does road traffic noise bother, disturb, or annoy you?"; and "How much does noise from neighbors/construction/recreational establishments bother, disturb, or annoy you?". The mean of responses served as a measure of noise annoyance in the living environment. The two items were correlated, r = 0.47 ($p < 0.001$).

2.5. Confounders

We gathered data on participants' age, sex, ethnicity, duration of residence, and average time spent at home/day. Additionally, we used a single item to assess perceived individual-level economic status. Population density in a 500-m buffer around the address was used as a proxy for urbanicity.

2.6. Statistical analysis

Most variables had less than 5% missing values, except 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, all missing data were replaced using the expectation maximization algorithm [12, 13].

For the analysis, we used structural equation modelling (SEM) to account for the theoretically-indicated associations between NDVI, perceived greenspace, L_{day}, and noise annoyance. 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) [14-16]. Guided by theory and bivariate correlations in the dataset, we specified confounding paths between control variables and key variables in the model. All aforementioned confounding variables were included in the model a priori.

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 [17]: non-significant χ^2 ($p > 0.05$), RMSEA (≤ 0.06, 90% CI ≤ 0.06), SRMSR (≤ 0.08), and CFI (≥ 0.95). Over 95% of the normalized residuals $\leq |2.58|$ were expected from a good-fitting model [14]. Modification indices and standardized residuals were inspected to improve model fit when suggested model re-specification was justified by scientific logic. Hence, post hoc re-specification was used to address only points of ill fit in the solution. Non-signficant confounding paths were removed. We specified user-defined estimands in order to estimate the specific indirect paths linking NDVI to noise annoyance. Results were considered statistically significant at the $p < 0.05$ level, and mediation was considered when the indirect path significantly exceeded zero, regardless of the significance of the total effect [18].

3. Results

Participants' characteristics are shown in Table 1. Inspection of Spearman correlation matrix showed that direction of correlations between NDVI, perceived greenspace, L_{day}, and noise annoyance was in line with theory (data not shown).

In SEM, taken together, the values for various fit indices were acceptable: χ^2 (19) = 60.62, $p < 0.001$, SRMSR = 0.05, RMSEA = 0.06 (90% CI: 0.04, 0.07), CFI = 0.94. (Figure 2) Higher NDVI $_{300\text{-m}}$ was associated with lower noise annoyance ($\beta = -0.22$; 95% CI: -0.34, -0.10). The direct effect was marginally significant ($\beta = -0.13$; 95% CI: -0.25, 0.0002). The two constituent indirect paths included (1) higher perceived greenspace ($\beta = -0.05$; 95% CI: -0.09, -0.02) and (2) lower L_{day} ($\beta = -0.05$, 95% CI: -0.09, -0.02). They were comparable in magnitude and accounted for around a half of the total indirect effect.

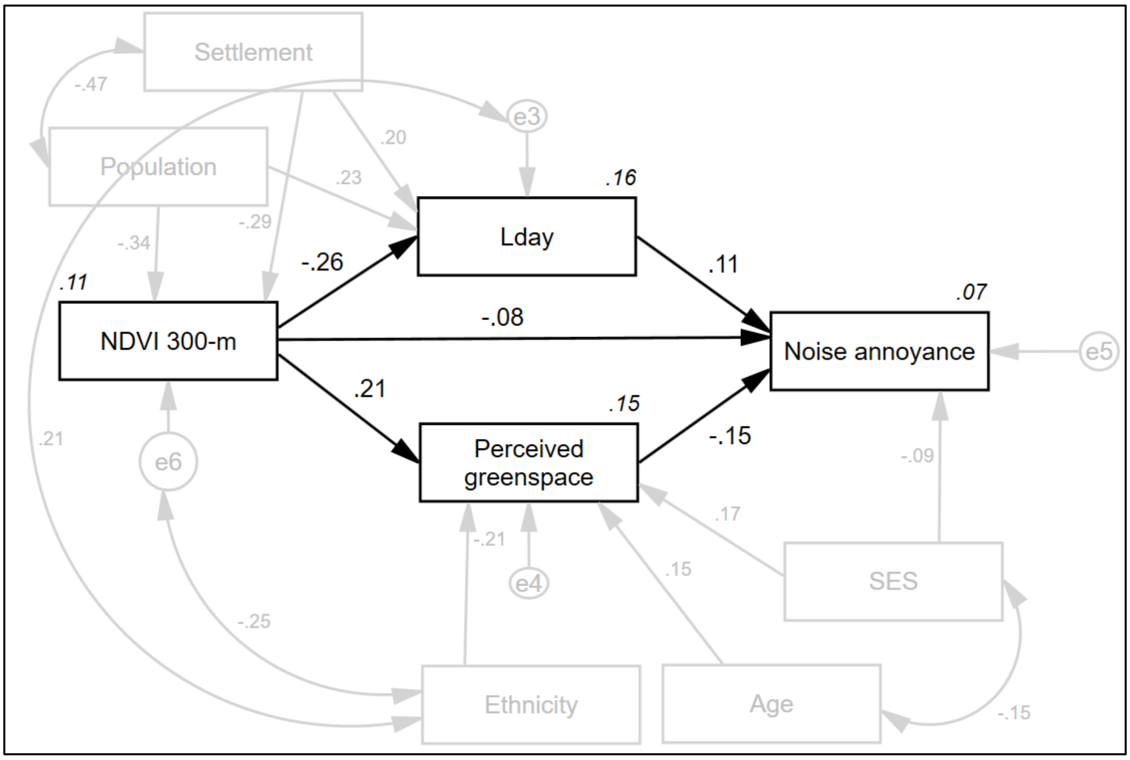

Figure 2. Structural equation model showing the estimated paths linking objective greenspace to noise annoyance Abbreviations: L_{day} – daytime road traffic noise level, NDVI – Normalized Difference Vegetation Index, SES – perceived economic status. Standardized regression weights are given for each path. Squared multiple correlations (R^2) are italicized. Control variables, covariances, and errors terms are shown in grey color to enhance readability.

Table I. Participant characteristics

Characteristic	*(N= 720)*
Male (n, %)	243 (33.8)
Age (median, IQR)	21.00 (3.0)
Bulgarian (n, %)	533 (74.0)
Economic status (mean, SD)	2.63 (1.2)
NDVI $_{300\text{-m}}$ (median, IQR)	0.41 (0.1)
Perceived greenspace (mean, SD)	2.98 (1.1)
L_{day}, dB(A) (mean, SD)	67.06 (1.7)
Noise annoyance (median, IQR)	1.50 (1.0)
Residence in Plovdiv (n, %)	642 (89.2)
Residence ≥ 5 years (n, %)	276 (38.3)
Time at home ≥ 8 hours (n, %)	394 (54.7)
Population (median, IQR)	9107.7 (3941.8)
Month: October (n, %)	328 (45.6)

Abbreviations: IQR – interquartile range, L_{day} – daytime road traffic noise level, NDVI – Normalized Difference Vegetation Index, SD – standard deviation.

4. Discussion

4.1. General findings

This study examined the association between greenspace "exposure" and noise annoyance in young adults. Overall, results indicated that higher surrounding greenspace in the living environment might have the capacity to mitigate noise annoyance due to traffic and other neighborhood sources. More specifically, greenspace operated through two indirect paths working in parallel: higher greenspace was associated with lower noise exposure, and in turn, with lower annoyance; it was also associated with higher perceived greenspace, and thus, with lower annoyance.

These findings are congruent with research indicating that various green structures can reduce noise level by blocking sound waves propagation [2]. Alternatively, greenspace may be spatially associated with lower noise level because it simply lacks artificial noise sources [1]. Our findings are also in line with studies indicating that the perception of living in a green environment (e.g., having a view of greenery from home) might relate to lower noise annoyance via stress reduction and increased perceived control over the acoustic environment [4]. That is, a person's feeling of being unable to escape and retaliate against the noise source might be suppressed by the knowledge that his/her neighborhood has quiet green spaces where he/she can find tranquility.

Interestingly, the effect of greenspace on noise annoyance was mostly indirect, where the two indirect pathways seemed to be equally important. Therefore, interventions aimed at reducing noise annoyance may consider the potential of vegetation to reduce noise annoyance not only through acoustic mitigation of noise exposure, but also through psychological mechanisms. In addition, our findings suggest that objective measures of greenspace have limited potential as predictors of noise annoyance, which is in line with previous reports on stronger associations observed for perceived greenspace [19]. Self-reports may better account for the actual interaction with greenspace and also tap mental representation of person's living environment, whereas geographic measures may be perceived as more useful by those involved with application (e.g., planners) [6].

4.2. Strengths and limitations

The present study has several important strengths. We collected data on both objective and perceived greenspace measures and used sophisticated statistical method to test a holistic mediation model. The high response rate (> 80%) is another strength. We focused on an understudied age group from South-East Europe. By focusing on students from one university, we reduced overdispersion in the data and also controlled for environmental influences (e.g., traffic noise, 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.

However, several limitations should be discussed. First, this study was of cross-sectional design. This precludes drawing causal inferences about associations. Also of note, cross-sectional tests of mediation might entail bias and produce overconfident results [20]. Recall bias cannot be ruled out either.

Including foreign students means that our sample was not representative of the general population of Plovdiv. However, 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.

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 mediation through L_{day}.

Finally, data were collected in October – November, when people spend less time outdoors than in summer.

Owing to these limitations, the associations we found are likely underestimated and lend further support to our hypothesis.

5. Conclusions

Greenspace in the living environment might have the capacity to mitigate noise annoyance through indirect paths working in parallel. Higher surrounding greenspace was associated with lower noise exposure, and in turn, with lower annoyance; it was also associated with higher perceived greenspace, and thus, with lower annoyance. Therefore, interventions aimed at reducing noise annoyance may consider the potential of vegetation to reduce noise annoyance not only through acoustic mitigation of noise exposure, but also through psychological mechanisms.

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Conflict of interests

We declare no actual or potential conflicts of interests. This study received no external funding.

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