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Annoyance to road traffic noise and residential green: a case study in the city of Zurich, Switzerland

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ABSTRACT

Urban areas are continuously growing in population and become denser in buildings to limit expansion of settlements. The latter often entails a loss of green spaces and increasing noise pollution, particularly from road traffic. Exposure to road traffic noise can lead to annoyance, which in turn may trigger stress-related diseases and negatively impact quality of life. Recently, green spaces in residential areas came into focus as a potential measure to reduce negative health impacts, including noise annoyance. Within the research project RESTORE (Restorative potential of green spaces in noise-polluted environments), an extended cross-sectional field study in the city of Zurich, is conducted to assess the relation between road traffic noise, residential greenery, noise annoyance, self-reported and physiological stress. Participants are selected from specific study sites within Zurich based on the areas' characteristics (noise exposure, residential green). In this contribution, we present first results on the association of noise annoyance with the exposure to road traffic noise and residential green.

Keywords: Noise annoyance, road traffic noise, green spaces, urban areas

INTRODUCTION

Urbanization has brought significant changes in our environment, including the loss of green spaces (GSs) and increasing levels of noise pollution. With the rapid expansion of urban areas, it is becoming increasingly challenging to limit the spread of settlements while preserving the natural environment. Transportation noise is the most widespread source of noise pollution that primarily impacts individuals residing in urban and semi-urban areas (1, 2). Noise pollution can lead to annoyance and stress-related diseases that negatively affect the quality of life (3). Literature has shown that GSs in urban areas are associated with a range of benefits for human health and well-being, including improved mental health, reduced stress, and increased physical activity (3-5). Moreover, GSs have been identified for their potential to reduce noise annoyance and its negative impacts on health (6, 7). Previous studies have shown that exposure to GSs can have a positive effect on mental and physical health outcomes, including stress reduction and increased physical activity (8, 9). However, the precise mechanisms by which GSs mitigate noise annoyance and stress-related diseases are not yet fully understood. It may be crucial to consider simultaneously individual, residence, and green space-related factors when examining the relationship between noise exposure and annoyance (10-12) in order to support effective interventions to promote human health and well-being in urban areas.

The research project RESTORE (Restorative potential of green spaces in noise-polluted environments) aims to address this knowledge gap. The main hypothesis of this study is that noise annoyance of people exposed to road traffic noise at home is associated with public GSs. Within RESTORE, an extended cross-sectional field study in the city of Zurich, is conducted to investigate the relationship between annoyance to road traffic noise, self-reported and physiological stress level and residential greenery. The field study focuses on specific study sites within Zurich that vary in their characteristics of noise exposure and residential greenery. The study comprises three waves of data collection of which the first two waves have been concluded and part of the data has been analyzed. The third wave of data collection is currently ongoing and will be completed by July 2023.

MATERIALS AND METHODS

Study Design

This study follows a cross-sectional study design approach, where data from participants are gathered at a single point in time. Given this study design, multiple predictors are investigated simultaneously, enabling the identification of potential confounding factors such as socioeconomic status or health-related behavior that might arise when addressing this topic (10, 13, 14). The data is collected through a large field survey conducted in the city across a sample of residents living in urban areas. The study is grounded in a classification stratification of residential areas accounting for their access to GSs and exposure to road traffic noise at home. The analysis presented here is based on data of the first two data collection waves. Details on the study design can be found in Dopico et al. (15).

Assessment of GSs and definition of study groups

For this analysis, exposure to road traffic noise during daytime and access to public GSs was spatially analyzed using Esri ArcGIS (version 10.8.1). The selection of GSs was done through a stratified sampling method using land-use classification data of the Federal Swiss Office of Topography (Swisstopo), which was the same data used in a previous study (7). Public GSs were considered accessible when lying within a circular Euclidean buffer with a radius of 300 m, centered around the buildings of the study participants, similar to previous studies (7, 9). Through this analysis, the buildings were categorized based on their proximity to GSs. Those with no GSs located within the 300 m circular buffer were classified as having no access to GSs. The study excluded GSs with restricted access or requiring payment (e.g., the zoo, golf fields). The remaining GSs were divided into large (≥ 10,000 m^2) and small (< 10,000 m^2) and loud and quiet (details next section and Dopico et al. (15)), resulting in a final dataset with four groups of GSs: loud and large (n=11), loud and small (n=12), quiet and large (n=18), and quiet and small (n=7). The study also analyzed vegetation around homes using the Normalized Difference Vegetation Index (NDVI) (16). Mean NDVI values for the months of April to October in the years 2019 to 2021 were used (data extracted from ESA (17)). Based on the combinations of different levels of noise exposure at home and access to GSs (see section *Exposure assessment*), the study design included up to seven study groups. For this paper, five study groups were created by pooling the study groups of large and small GSs (i.e., large quiet and small quiet, as well as large loud and small loud, were pooled). The five study groups were named LA (low noise exposure with access to large and quiet GSs), LNA (low noise exposure with no access to GSs), HAQu (high noise exposure with access to quiet GSs), HALo (high noise exposure with access to loud GS), and HNA (high noise exposure with no access to GS) (see table 1).

Table 1. Nomenclature used and their meaning for the study groups.

Study group abbreviation	Description
LA	Low noise exposure with access to large and quiet GSs
LNA	Low noise exposure with no access to GSs
HAQu	High noise exposure with access to quiet GSs
HALo	High noise exposure with access to loud GSs
HNA	High noise exposure with no access to GSs

Assessment of noise exposure

Road traffic noise exposure at the home addresses was assessed using the Swiss noise database sonBASE for the year 2015 to make an area selection (18). Daytime road traffic noise level L_{day} (in dBA), i.e., the 16-hour A-weighted equivalent continuous sound pressure level, from 6 a.m. to 10 p.m., was determined for the centroid coordinate point of each building. L_{day} was used to stratify the targeted population into either “high road traffic noise exposure” with L_{day} ≥ 68 dBA or “low road traffic noise exposure” with L_{day} ≤ 53 dBA. The former threshold is based on the work of Brink et al. (19) who found that 25% of the Swiss population is highly annoyed at this level. (Note that while these thresholds were originally defined for the L_{den} metric, the two metrics are similar in situations with dominating daytime traffic, as is the case in this study.) The lower road traffic noise threshold was derived based on the road traffic recommendations of the WHO (20). Additionally, since different noise sources may disparately impact health, residences that were exposed to aircraft noise L_{day} > 45 dBA and/or railway noise of L_{day} > 54 dBA were excluded from the study. Here, the same criterion as for the lower road traffic noise threshold applies, i.e., based on the recommendations of the WHO (20).

GSs were clustered based on road traffic noise exposure (using the L_{day}) in addition to size. L_{day} was considered appropriate for GSs as visitors mainly spend time in there during daytime. To account for the substantial variation in the road traffic noise levels within larger GSs, a GIS-based analysis was used to define quiet and loud GSs: A quiet GS has more than 50% of the area with L_{day} values below 45 dBA and a loud one has more than 50% of the area with L_{day} values above 58 dBA. The lower threshold was set according to recommendations for quiet urban areas in the literature (21-23), while the higher one was set to achieve a similar gap in noise exposure between quiet and loud GSs as between quiet and loud noise exposure situations at home. Field acoustic measurements were conducted in the selected GSs with one to six measurement locations per GS. The metrics obtained included short-term A-weighted equivalent continuous sound pressure level and psychoacoustic parameters. Two recordings were taken at each of the 78 measurement locations, in the morning and afternoon, to capture a range of noise exposure throughout the day. Recordings were taken mostly in September and October 2021, with some in Spring 2022. These measurements yield additional information beyond the calculations and can be used as additional predictor variables for annoyance and stress.

Outcome assessment

The primary outcome discussed in this paper is noise annoyance, which was measured using the numerical 11-point ICBEN scale (24).

Secondary variables included in this contribution are demographic and background information such as age (linear and quadratic term), gender, home ownership, satisfaction with their houses as well as education level. Participants were further asked about their noise sensitivity assessed with a 5-point numerical scale where 1 means "completely disagree" and 5 "fully agree" to the sentence "I am sensitive to noise" as well as with the 13-item NoiSeQ-R instrument (25). Both scales were used since the former was intended to be used in the regression model, while the later was used to classify participants into sensitive and non-sensitive groups (26). Participants with a 13-item NoiSeQ-R score of less than 1.77 (median of the study sample) were classified as non-sensitive group. Further, for the ongoing study additional key outcomes will be investigated, namely physiological stress and coping with stress. The former represents the activation of the autonomic nervous system through neural and hormonal reactions increasing cortisol levels (27-29). The latter corresponds to an emotional feeling caused by an unwanted event that can be assessed through a self-reported psychological assessment (30).

Participants

A total share of 9.2% from the total population of the city of Zurich represented the eligible participants by the time the study was designed (February 2021). The Resident's Office of the city selects addresses of participants from the official register data with a maximum of 20% of the total participants addresses provided for each study group and wave separately. In addition to the living area exposure condition (a stratify sample for noise exposure and GS accessibility), participants must be at least 18 years old.

Potential participants were selected from the stratified sample, and their residence addresses were used to invite them to take part in the field survey. Participants received an invitation letter with a website address as well as a QR code linked to the designed online questionnaire. The ethics committee of the Canton of Zurich approved this study, and all participants involved confirmed their consent for study participation.

Statistical analysis

In this paper, we present the results of the first two waves, with a sample size of 823 participants. Descriptive statistics were used to summarize participants' demographic characteristics and the distribution of noise annoyance scores. ANOVA and two-sample t-tests were used to examine differences in noise annoyance scores among different study groups, including noise sensitivity, satisfaction with house, home ownership, and education level.

Multivariate linear regression analysis was used to determine associations between noise annoyance and personal, residence, road traffic noise exposure and GSs related characteristics, as well as possible interactions. The regression estimates, confidence intervals (CI), t-values, and p-values were reported for each variable. Statistical significance was set at a probability of $p < 0.05$. All statistical analyses were performed using R software (version 4.2.2).

To assess the possibility of multicollinearity among the predictor variables, variance inflation factors (VIF) were utilized as described in Kutner et al. (31). As the model included categorical predictors with different levels, $GVIF^{1/(2\times df)}$ was calculated following the approach of Fox and Monette (32), where GVIF represents the generalized VIF of the variables. The quadratic term of age from this analysis was excluded. There was no evidence of multicollinearity in any of the predictors, as indicated by the $GVIF^{1/(2\times df)}$ values ranging from 1.02 to 1.15.

RESULTS

The current results reveal that participants with different residence and demographic characteristics were significantly associated with noise annoyance as shown in Table 2. Annoyance ratings were significantly different ($p < 0.001$) between the five study groups LA, LNA, HAQu, HALo and HNA (cf. Table 1), decreasing in the order HALo (4.56) ≈ HNA (4.25) > HAQu (3.47) > LNA (2.29) > LA (1.79). Annoyance ratings differed significantly between the age group categories 18-40, 41-65 and >65. House satisfaction was highly correlated with noise annoyance. Regarding home ownership, the owner group reported lower annoyance levels (2.77) than the tenant group (3.58); however, this result could be confounded by other factors, e.g., noise exposure. Lastly, annoyance was significantly different between groups of different education level, although no trend with increasing education is observable. Neither gender nor noise sensitivity were significantly related to annoyance. Further, a post-hoc test (Tukey's honestly significant difference) revealed significant differences for all study groups, except for LA-LNA ($p>0.5$), HNA-HAQu ($p>0.1$) and HNA-HALo ($p>0.8$).

Table 2. Noise annoyance (ICBEN 11-points scale) for participants with different demographic and background characteristics.

Variable	Category	Sample		ICBEN 11-pts scale		Analysis (p)
		N	% (variable)	Mean	sd	
Study group	LA	150	18.23	1.79	2.08	ANOVA (***)
	LNA	117	14.22	2.29	2.42	
	HAQu	199	24.18	3.47	3.07	
	HALo	253	30.74	4.56	30.5	
	HNA	104	12.64	4.25	3.03	
Age range	18-40	249	30.26	3.51	3.06	ANOVA (*)
	41-65	361	43.86	3.68	3.03	
	>65	213	22.88	2.91	2.85	
Gender	Female	425	51.64	3.50	3.03	Two-sample t-test (-)
	Male	398	48.36	3.36	2.98	
Noise sensitive	Non-sensitive	413	50.18	3.22	2.93	Two-sample t-test (-)
	Sensitive	400	48.60	3.62	3.05	
House satisfaction	Nothing	10	1.22	7	2.53	ANOVA (***)
	Little	23	2.79	5.21	3.46	
	Moderate	112	13.61	4.61	3.31	
	Considerably	296	35.97	3.84	2.84	
	Very much	382	45.64	2.57	2.72	
Home ownership	Owner	149	18.10	2.77	2.64	ANOVA (**)
	Tenant	674	81.90	3.58	3.06	
Highest education level	Elementary	17	2.07	3.76	3.11	ANOVA (*)
	Apprenticeship	183	22.24	2.96	2.99	
	Matura	67	8.14	2.92	3.01	
	University	556	67.56	3.64	2.99	

*** = p<0.001; ** = p<0.01; * = p<0.05; - = p>0.05

Table 3 presents the results of the multilinear regression analysis. The analysis revealed that participants living in high road traffic noise exposure areas are highly associated with the outcome, namely HAQu, HALo and HNA. In this model, the age shows a significant effect with the outcome as well as noise sensitivity. The noise annoyance significantly decreases with the absence of sound-insulating windows and with increasing house satisfaction as well as house-surrounding satisfaction. The frequency of the GSs visits reported a weak significant association with an increase in noise annoyance. No significant associations were found between noise annoyance and gender, the highest education level, hearing problems, home ownership, garden at home, and perception of enough GSs around home.

Table 3. Regression on road traffic noise annoyance score (ICBEN 11-points scale) for different personal, residence and green-related characteristics.

Variable	Category	Estimate	95% CI lower	95% CI upper	p-value
Intercept	-	5.251	1.88	8.62	**<0.01**
Study group	LA	0[a]	-	-	-
	LNA	0.050	-0.60	0.70	0.87
	HAQu	1.339	0.76	1.91	**<0.001**
	HALo	2.296	1.74	2.85	**<0.001**
	HNA	1.606	0.90	2.31	**<0.001**
Age	Age	0.081	0.02	0.15	**<0.05**
	Age^2	-0.001	0.00	0.00	**<0.01**
Gender	Male	0[a]	-	-	-
	Female	-0.048	-0.41	0.31	0.79
Highest education level	Elementary school	0[a]	-	-	-
	Apprenticeship	0.107	-1.22	1.43	0.87
	Matura	0.040	-1.38	1.46	0.95
	University	0.334	-0.97	1.63	0.61
Noise sensitivity	-	0.218	0.06	0.38	**<0.01**
Hearing problems	Yes (and wearing a device)	0.218	-0.74	1.18	0.65
	Yes (but without device)	0.043	-0.57	0.65	0.89
	No	0[a]	-	-	-
Home ownership	Owner	-0.021	-0.53	0.49	0.93
	Tenant	0[a]	-	-	-
sound-insulating windows	Yes	0.743	0.33	1.15	**<0.001**
	No	0[a]	-	-	-
	I do not know	0.648	0.16	1.14	**<0.01**
Garden at home	Yes	0.050	-0.34	0.44	0.8
	No	0[a]	-	-	-
House satisfaction	Nothing	0[a]	-	-	-
	Little	-1.874	-3.92	0.17	0.07
	Moderate	-1.615	-3.42	0.19	0.07
	Considerably	-2.024	-3.79	-0.25	**<0.05**
	Very much	-2.296	-4.08	-0.51	**<0.05**
Frequency visits GSs	Daily	0.916	-0.13	1.97	0.08
	Several times per week	0.778	0.04	1.52	**<0.05**
	Once per week	0.653	-0.13	1.44	0.1
	Several times per month	0.653	-0.14	1.45	0.1
	Once per month	0[a]	-	-	-
	Never	-0.484	-2.23	1.26	0.58
Perception of enough GSs around home	Yes	0.006	-0.37	0.39	0.97
	No	0[a]	-	-	-
House surrounding satisfaction	Nothing	0[a]	-	-	-
	Little	-3.168	-6.12	-0.21	**<0.05**
	Moderate	-3.107	-5.86	-0.35	**<0.05**
	Considerably	-4.135	-6.84	-1.43	**<0.01**
	Very much	-5.584	-8.29	-2.87	**<0.001**

[a] Reference level set to zero

High road traffic noise exposure, sound-insulating windows and house-surrounding satisfaction are highly associated with noise annoyance, whereas house satisfaction, frequency of the visits to GSs, noise sensitivity and age show a weaker association. Home ownership and highest education level present significant differences among their categories but do not seem to be significant predictors of noise annoyance in the regression model. There was no evidence indicating an effect of gender on the outcome.

DISCUSSION

The findings presented in this paper are based on the first two of three survey waves of a cross-sectional study, confirm our expectations that participants who are exposed to higher levels of road traffic noise are more annoyed. Further, our results also suggest that residential GSs may indeed have a positive moderating effect on the relationship between road traffic noise exposure and noise annoyance, as observed in previous studies (33, 34). Further, the association between age and noise annoyance suggests that as people get older, their level of noise annoyance tends to increase until they reach a certain age, at which point it starts to decrease again, as seen in previous studies (e.g., (35)). These findings are consistent with previous studies that have reported similar associations between noise exposure and annoyance while assessing health outcomes and including personal characteristics as in the project intended (e.g., (36, 37)). Finally, the study found that higher levels of house-surrounding satisfaction were associated with lower levels of noise annoyance, indicating that perceptions of the house-surrounding may mediate the extent to which noise is perceived as annoying, similar to the work of Okokon et al. (38).

Our study adds to the growing body of literature on the restorative potential of GSs in noise-polluted environments. Our findings extend these results by showing that residential GSs may mitigate negative health impacts of noise pollution as well as potentially serve as a protective factor against them.

It is important to note that no individual exposure was used in this study, only exposure in areas. A complete data set with the third wave will still be done including individual exposure data with the Lden metric as well as NDVI. Our future research will use more objective predictors of noise annoyance as well as outcomes, such as physiological stress by analyzing the levels of hair cortisol. The potential mediating role of noise annoyance and the moderating effect of GSs on the relationship between road traffic noise exposure and health outcomes will also be investigated in follow-up studies.

CONCLUSION

We conducted a cross-sectional field study in Zurich, Switzerland. The results of this contribution indicate that perceptions of the house-surrounding may moderate the extent to which noise is perceived as annoying. The findings further suggest that GSs may mitigate negative effects on the relationship between road traffic noise exposure and noise annoyance. Overall, our study underscores the importance of a comprehensive approach when it comes to plan and integrate the different dimensions of urban environments and the need to consider different factors, particularly in areas where GSs are scarce and noise pollution is prevalent.

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