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ASSOCIATION OF STRESS BIOMARKERS WITH ROAD TRAFFIC NOISE EXPOSURE AND RESIDENTIAL GREEN: INSIGHTS FROM THE RESTORE STUDY

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ABSTRACT

Chronic exposure to environmental noise, including from road traffic, may lead to physiological stress, which may in turn promote risk factors such as high blood pressure and lead to disease and even mortality. Residential green might mitigate such negative noise effects. However, knowledge about the effect chains of noise on stress and stress reduction in green spaces is still scarce. This study, therefore, investigated the association of chronic stress with road traffic noise exposure and residential green. Residents in the city of Zurich, Switzerland, who were exposed to different levels of road traffic noise and varying levels of access to green spaces in the vicinity of home, were visited. The participants filled in a questionnaire, hair samples were collected to measure the biomarkers cortisol and cortisone for chronic stress, and their residential environment was assessed with respect to day-evening-night-level (L_{den}) at home, normalized difference vegetation index (NDVI), and percentage of public green spaces, the latter two in a buffer of 300 m. The results did not show significant associations between stress biomarkers and noise exposure, but revealed a significant negative relationship between stress biomarkers and neighborhood green space exposure, underpinning the importance of the latter for public health.

Keywords: *road traffic noise, green space, stress, cortisol, cortisone, noise annoyance*

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1. INTRODUCTION

Urban areas are continuously growing, with 58% of the world population currently (as of 25 March 2025) living in urban areas [1]. Increasing mobility and infill development (densification) to limit urban expansion are at the expense of increased noise exposure of the residents and a decline in green spaces. In Europe, some 139 million people were estimated to be exposed to potentially harmful environmental noise (road, rail, air, industry) in the year 2017, exceeding 55 dB L_{den}, of whom 69% lived in urban areas [2].
Chronic exposure to environmental noise, including from road traffic, may trigger physiological stress responses, which may in turn lead to a wide range of risk factors such as high blood pressure, but also to disease and even mortality [3]. Adverse noise effects on health are mediated through the autonomic nervous system and the hypothalamic-pituitary-adrenal (HPA) axis [4]. Residential green might mitigate such negative noise effects including physiological stress [5], and therefore came increasingly into focus not only in research but also for city planners and authorities [6]. However, knowledge about the (causal) pathways between noise and stress, potentially mediated by

noise annoyance, and stress reduction in green spaces is still scarce. Some studies found an association of (rather high) noise exposure with physiological stress [7], while others did not [8], and similarly, whether annoyance acts as a mediator for stress [9] or not [10] remains disputed.
The objective of the current study therefore was to investigate the association of hair cortisol and cortisone as biomarkers for chronic stress with noise annoyance, road traffic noise exposure and residential green at home.

2. METHODS

A cross-sectional field study was conducted in the city of Zurich, Switzerland. The concept and methodology are detailed in the study protocol of [11], and summarized below.

2.1 Study design and population

Residents in the city of Zurich, who were exposed to varying levels of noise and access to public green spaces, filled in an online survey and were visited at home.
Stratification was done based on modelled road traffic noise exposure (either "low" [day-time level $L_{day} \leq 53$ dBA] or "high" [$L_{day} \geq 68$ dBA]) and access to green spaces ("Yes" [living in areas with a public green space within an Euclidean buffer of 300 m radius], "No"). Eligible residents (inclusion / exclusion criteria: see [11]) were contacted to complete an online survey (total of 1'129 responses; results reported elsewhere) and subsequently asked to participate in the visits at home, to which 235 participants volunteered (focus of this study).

2.2 Data collection

For this study, the following items were taken from the online survey: (i) road traffic noise annoyance (ICBEN 11-point scale), (ii) perceived stress in private life in the last four weeks (5-point numerical scale), gender and age.
During the visits, hair samples were collected to measure the concentrations of the stress biomarkers cortisol and its metabolite cortisone, using the method established in [12]. Cortisol reveals HPA axis activity over months and thus the cumulative impact of environmental exposures on stress physiology [13]. In the following, cortisol and cortisone are abbreviated as E (for "Compound E") and F (for "Compound F"), respectively [14].
The participants' exposure situation was assessed with respect to modelled road traffic noise L_{den} at the most exposed façade, normalized difference vegetation index (NDVI), and percentage of public green spaces (%GS), both in an Euclidean buffer with a radius of 300 m.

2.3 Statistical analysis

First, a correlation analysis (Spearman's ρ) was performed to study the relations between exposure (L_{den}, NDVI, %GS), noise annoyance, self-reported stress, and stress biomarkers. For the latter, E, F and their sum (E+F), were used, as the latter is more stable and shows less variability than the individual values.
Second, the association of the stress biomarkers (E, F, E+F) with exposure to L_{den}, green (NDVI or %GS), and noise annoyance as a mediator, was studied with multiple linear regression analysis, adjusting also for gender and age. For the analysis, the natural logarithm of the stress biomarkers was used to comply with the model assumption of normally distributed residuals. Tested effects were considered significant if the probability (p) of the observed results, or more extreme results, under the null hypothesis was ≤0.05.

3. RESULTS

3.1 Study sample

Of the 235 visits at home, 11 were excluded due to missing L_{den} or annoyance response data, resulting in a total of 224 participants (134 males, 90 females), covering an age range of 18–84 y (mean of 44.5 y).

3.2 Noise and green exposure data

The exposure data covered a wide range, with L_{den} of 30–75 dB (median 56 dB), NDVI of 0.18–0.73 (median 0.47) and %GS of 0–45.5% (median 3.3%). Correlation analysis (Table 1) revealed that – as expected – NDVI and %GS were positively correlated. Further, NDVI was negatively related with L_{den}, indicating that residential areas with increased road traffic noise tended to be less green and vice versa, but %GS and L_{den} were not related.

3.3 Annoyance and stress reactions

Correlation analysis (Table 1) revealed that noise annoyance was (weakly) positively related to perceived stress in private life. Further, it was positively correlated to L_{den} and negatively to NDVI, but not to %GS. Perceived stress was only (negatively) correlated to NDVI. As expected, the stress biomarkers E, F and E+F were highly correlated to each other. However, they were neither related to noise annoyance nor to perceived stress. F and E+F were (weakly) negatively correlated to %GS, but not to L_{den} or NDVI, while E did not show any link to these exposures. Except for the correlations between the stress biomarkers, however, scatter of the data was generally large.

Table 1. Correlation matrix (Spearman's ρ and p-value) for annoyance, perceived stress, stress biomarkers (cortisol E, cortisone F; sum E+F), and noise and green exposure. Significant ρ are marked in bold.

		Annoy	Stress	ln(E)	ln(F)	ln(E+F)	L_{den}	NDVI	%GS
Annoy	ρ		**0.19**	0.02	0.04	0.03	**0.57**	**-0.25**	-0.01
	p		<0.01	0.72	0.58	0.68	<0.001	<0.001	0.91
Stress	ρ			0.01	-0.01	0.00	0.08	**-0.15**	-0.07
	p			0.85	0.90	0.96	0.21	<0.05	0.31
ln(E)	ρ				**0.73**	**0.87**	0.05	0.02	-0.09
	p				<0.001	<0.001	0.44	0.79	0.17
ln(F)	ρ					**0.96**	0.04	0.01	**-0.19**
	p					<0.001	0.54	0.92	<0.01
ln(E+F)	ρ						0.05	0.00	**-0.17**
	p						0.43	0.98	<0.01
L_{den}	ρ							**-0.46**	0.02
	p							<0.001	0.72
NDVI	ρ								**0.44**
	p								<0.001
%GS	ρ								
	p								

Figures 1 and 2 show boxplots of the association of E+F with %GS and NDVI, respectively. In line with the correlation analysis, no association with NDVI is visible, whereas E+F tends to decrease with increasing %GS. While the scatter is large, outliers and extreme values (circles and stars in the boxplots) clearly decrease with increasing %GS. A (weak) trend of decreasing E+F with increasing %GS would also remain if the outliers were excluded.

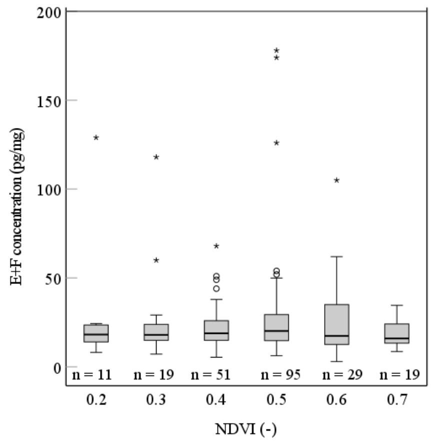

Figure 1. Boxplots of cortisol plus cortisone concentration (E+F) as a function of NDVI (classes in steps 0.1; n = number of observations per class).

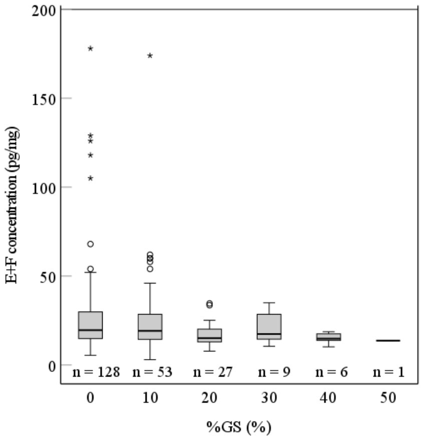

Figure 2. Boxplots of cortisol plus cortisone concentration (E+F) as a function of %GS (classes in steps of 10%, except class 0 with range of 0–4.9%; n = number of observations per class).

Multiple linear regression analysis confirmed these findings. The stress biomarkers ln(E), ln(F) and ln(E+F) were not significantly related with noise (p = 0.31–0.37), but ln(F) and ln(E+F) were negatively associated with %GS ($p < 0.05$). A mediating effect of annoyance – and thus an indirect pathway of noise – with the stress biomarkers could also not be confirmed.

4. DISCUSSION AND CONCLUSIONS

This study investigated the association of chronic stress with exposure to road traffic noise and residential green for residents in the city of Zurich, Switzerland. While no association with road traffic noise exposure was found, the stress biomarkers decreased, although weakly, with increasing available residential green spaces.

The missing link between physiological stress and noise exposure may be owed to limited co-factors in our analysis (see below) as we only considered age and gender. Previous research was inconsistent here: Some studies that included higher exposure reported a link (e.g., [7], 70–77 dBA L_{eq}), while others did not find an association despite high exposure (e.g., [8], 55–94 dBA). In contrast, the negative association of physiological stress with green spaces could be a sign for their beneficial effect [5]. Interestingly, only green spaces (%GS), but not vegetation in general (NDVI), were associated with stress reduction. This could suggest a physical activity pathway (green spaces promoting, e.g., sports), rather than an effect of visible green from home. The latter, in contrast, has often been reported for noise annoyance [15], and was also confirmed here (Table 1).

In interpreting the results, one should keep in mind that residual confounding might have been an issue for both the missing link with noise and the observed relation with green spaces, as (i) the study sample is rather limited (n = 224) and (ii) there are numerous factors related to stress and the two exposures. The latter might mask a possible link with noise, but also result in an overestimation of the "green space effect", e.g., as populations in urban areas with (many) green spaces are usually privileged. However, potential confounding would need further investigation.

In conclusion, our study provides some evidence that neighborhood public green spaces reduce chronic physiological stress and thus promote public health.

5. ACKNOWLEDGMENTS

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