Road Traffic Noise and Sleep Disturbances in an Urban Population: Cross-sectional Study

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Aim To explore the relationship between sleep disturbances caused by traffic noise and relevant personality traits, such as extroversion-introversion, neuroticism, and subjective noise sensitivity.

Methods A cross-sectional study was carried out from January to April 2005 in a central municipality of Belgrade, the capital of Serbia and Montenegro. Noise measurements were performed at 12 measurement sites three times at daytime and twice at night. On the basis of noise measurement results, three streets with the highest and three streets with the lowest values of equivalent sound pressure level (Leq) were chosen to represent noisy (>65 dB(A)) and quiet (<55dB(A)) areas, respectively. The respondents from both areas were asked to fill out the questionnaire on noise-related health problems. The final sample consisted of 310 respondents, 192 from noisy area and 118 from quiet area.

Results Respondents from noisy area reported having significantly more difficulties with falling asleep, being woken up by noise at night more often, and having more difficulties with falling back to sleep. They also complained of poorer sleep quality and tiredness after sleep and they slept by an open window in summer less often. Noise annoyance, subjective noise sensitivity, and neuroticism were significantly correlated with difficulties with falling asleep, time needed to fall asleep, poorer sleep quality, tiredness after sleep, and use of sleeping pills. After adjustment for potential modifying personality traits including subjective noise sensitivity, neuroticism, and extroversion, residence in noisy area was shown to be a significant predictor for difficulties with falling asleep (odds ratio [OR], 2.71; 95% confidence interval [CI], 1.27-5.80), difficulties with falling back to sleep (OR, 1.87; 1.02-3.40), waking up at night (OR, 2.60; 1.49-4.52), sleeping by closed windows (OR, 13.51; 5.84-31.25), having poor sleep quality (OR, 2.99; 1.13-7.89), and feeling tired after sleep (OR, 2.50; 1.11-5.63).

Conclusion Urban population living in noisy area was at higher risk for sleep disturbances than population living in the quiet area. Furthermore, sleep disturbances were significantly and positively related to personality traits of neuroticism, subjective noise sensitivity, and noise annoyance.

Noise is one of the major environmental hazards of the modern world, originating from a wide variety of sources, including traffic (air, road, or rail), industrial facilities, or social activities. About 40% of the population in the European Union are exposed to road traffic noise with an equivalent sound pressure level (Leq) exceeding 55 dB(A) at daytime, whereas 20% are exposed to levels above 65 dB(A). Noise pollution is a major public health problem in developing countries as well. It is caused mainly by road traffic; the 24-hour Leq can reach even 75-80 dB(A) along the main roads. More than 30% of Europeans are exposed to Leq exceeding 55 dB(A) at night, which may cause sleep disturbances (1). Systematic noise measurements in Serbia were performed in four cities with a population over 250 000. The results of follow-up measurements in Belgrade over 30 years showed that outdoor noise levels exceeded the allowed limits on 23 out of 27 measuring sites for 11-16 dB during day and 10-14 dB during night (2).

In contrast to some other environmental problems, noise pollution continues to increase, followed by an increasing number of complaints from the exposed residents. The adverse health effects of community noise pose a serious public health problem. They include hearing impairment, interference with speech communication, disturbance of rest and sleep, psychological and performance effects, effects on one's behavior, and subjective annoyance and interference with intended activities. Furthermore, noise has socio-cultural, esthetic, and economic effects. The estimated social costs for all noise nuisances are around 2.1% of the gross national product in industrialized countries, with about 0.2% attributable to productivity losses and 1.9% to decreases in property values (3).

Healthy sleep is a prerequisite for good physiological and mental functioning. However, disturbed sleep includes biological responses that may have numerous adverse effects on health and well-being, from difficulties with falling asleep, alterations of sleep stages, and awakenings to increased blood pressure and cardiac arrhythmia (4). The pathophysiological basis for a noise-sleep relation may be the stimulation of hypothalamus-pituitary-adrenal axis, adrenal medulla, and sympathetic nervous system with a subsequent release of "stress hormones," ie, adrenaline, noradrenaline, and cortisone (5). These biological responses might have long-term health implications including chronic fatigue syndrome, lower work productivity, increased proneness to accidents, and disturbances of blood pressure and coronary circulation.

Substantial individual differences in neuroendocrine, immune, and behavioral responses to noise indicate that the level of noise itself may not be of primary importance. A close relation between arousal level and personality traits, such as introversion, neuroticism, and subjective noise sensitivity, can explain these differences (6,7). However, it is still unclear how important these personality characteristics are for the occurrence of sleep disturbances.

The aim of this study was to explore the relationship between extroversion-introversion, neuroticism, and subjective noise sensitivity as personality traits and sleep disturbances caused by traffic noise. We expected personalities characterized by higher levels of introversion, neuroticism, and subjective noise sensitivity to be more prone to noise-disturbed sleep.

Participants and methods

A cross-sectional questionnaire study was carried out from January to April 2005 in a central municipality of Belgrade. The municipality is characterized by homogeneous social structure and living conditions of the residents.

Noise measurement

For noise measurements, a Noise Level Analyzer type 4426 (Brüel & Kjær, Nærum, Denmark) was used. Three measurements were performed at daytime (between 9 and 10:30 AM, 2 and 3:30 PM, and 6 and 7:30 PM) and two at night (between midnight and 1:30 AM, and 3:30 and 5:00 AM). Equivalent noise levels (Leq) were automatically calculated as continuous steady noise levels that would have the same total A-weighted acoustic energy like the real fluctuating noise measured over the same period. This approach to noise measurement has been adopted by the International Standard Organization for the measurement of community noise (ISO 1982) (8). Other two noise parameters, L1 and L99, were instrumentally calculated as noise levels that had been exceeded for 1% and 99% during the measurement period, respectively. Each measurement lasted 15 minutes and sampling speed was 10 samples per second, which resulted in a total of 9,000 samples. The obtained values of noise levels were free-field, with facade reflex included. Light and heavy vehicles were counted per hour at each measurement site. The measurements were performed at two sites in each of the six streets. Overall, there was a total of 10 measurements per street.

Three streets with the highest and three streets with the lowest Leq values were chosen to represent noisy and quiet areas, respectively. According to the criteria of Organization for Economic Cooperation and Development (9), noisy area belonged to "black acoustic zone" (above 65 dB(A) Leq), whereas quiet area belonged to "white acoustic zone" (below 55 dB(A) Leq).

Participants

The questionnaires were distributed to all apartment residents in the area through their mail boxes. The number of distributed questionnaires corresponded with the number of dwellers in each apartment. Adults were asked to fill out the questionnaires by the next day, when these were collected. To be enrolled in the study, the residents had to live at the present address for longer than 10 years and have their bedroom windows facing the street. Long-term exposure to noise is considered to be of public health importance for sleep disturbances as one might expect the noise sensitive minority to move away from noisy area in the first few years of dwelling. The exclusion criteria were the presence of chronic diseases that might cause sleep disturbances and hearing loss. Out of 403 questionnaires distributed, 339 were filled out, giving the response rate of 77%. Twenty-nine subjects were excluded because they did not meet the inclusion criteria. The final sample consisted of 310 respondents, 192 exposed to 24h-equivalent noise level above 65 dB(A) and 118 exposed to 24h-equivalent noise level below 55 dB(A).

Questionnaires

The questionnaire was anonymous. The first part of the questionnaire gathered information on demographic characteristics (age, sex, employment, and period of residence), apartment size, and number of dwellers in an apartment. The second part contained questions on sleep disturbances and inquired about average duration of night sleep (hours); difficulty falling asleep initially (1 to 4 scale: not at all, mostly not, mostly yes, or very much); difficulty falling back to sleep after waking up at night (yes or no); time needed to fall asleep (1 to 4 scale: <15 minutes, 15-30 minutes, 30-60 minutes, or >60 minutes); sleeping by an open window (yes or no); waking up at night (yes or no) and reasons for waking up; subjective quality of sleep (1-5 scale: very bad, bad, variable, good, or excellent); tiredness after sleep (1-5 scale: very tired, tired, variable, alert, or very alert); and use of sleeping pills (1-4 scale: every day, several times a week, several times a month, or seldom or never). These questions have been commonly used in international studies on noise and sleep (10).

Subjective noise sensitivity was measured by Weinstein's Noise Sensitivity Scale (11), which consists of 21 statements with degrees of agreement from 0 to 5; higher scores on the 0 to 5 scale indicate higher sensitivity to noise. Noise annoyance was assessed on a numeric scale from 0 to 10 (12). Personality traits of extroversion-introversion and neuroticism were measured by Eysenck Personality Questionnaire (13). The questionnaire consists of 65 questions with binary answers. Twenty-four questions refer to extroverted or introverted behavioral tendencies, such as liveliness, sociability, or talkativeness; 24 questions refer to neurotic tendencies in one's behavior, such as worrying, irritation, or anxiety; and 17 questions are aimed at assessing respondent's honesty in answering. Each answer was given 0 or 1 point on the scales of extroversion, neuroticism, and dishonesty. The answers were considered reliable if the sum of points on the dishonesty scale was <8.

Statistical analysis

Numeric variables were presented as mean± standard deviation (SD), and categorical variables as percentages (relative numbers). The differences between respondents living in noisy and quiet area were tested by Student's *t* test for variables with normal distribution, or by Mann-Whitney U-test for parametric heterogeneous data. The differences in the frequencies of variables were estimated by χ^2 test. The relationship between the variables was tested with Spearman's correlation test. Binary logistic regression was used to calculate adjusted odds ratios for the occurrence of sleep disturbances in noisy residential area. Odds ratios were adjusted for age, sex, subjective noise sensitivity, neuroticism, and extroversion.

For the purpose of this analysis, sleep disturbance parameters were reclassified in the following way. For difficulties falling asleep and going back to sleep after waking up, the answer "yes" included "mainly yes" and "very much", and the answer "no" included "not at all" and "mainly not." For time needed to fall asleep, the answers were dichotomized into "<15 minutes" and ">15 minutes." For subjective quality of sleep, the answer "bad" included "very bad" and "bad," and the answer "good" included "good" and "excellent." For feeling tired after waking up, "tired" included "very tired" and "tired", and "alert" included "alert" and "very alert." The answer "often" to consumption of sleeping pills included "every day" and "several times a week", and "seldom" included "several times a month" and "seldom or never."

STATISTICA software was used for all data analyses (Version 6, StatSoft Inc., Tulsa, OK, USA).

Results

The traffic noise levels and average number of vehicles were significantly higher in the noisy area than in the quiet one (Table 1). No significant differences between the respondents from the noisy and quiet areas were observed except that apartment size per dweller was larger in the noisy area (Table 2).

Table 1. Noise measurements and vehicle counting in investigated areas of Belgrade*

	Area (mean±SD)†			
	noisy (>65 dB(A))		quiet (<55 dB(A))	
Parameters	day‡	night§	day	night
Noise [dB(A)]:				
Leq	77.2 ± 4.6	69.8 ± 3.8	51.5 ± 2.9	38.5 ± 2.3
L1	91.8 ± 6.2	85.7 ± 4.7	72.5 ± 5.1	51.0 ± 3.7
L99	54.3 ± 3.3	48.4 ± 4.1	34.7 ± 2.4	30.6 ± 2.0
No. of heavy vehicles per hour	126 ± 19	21 ± 5	3 ± 2	1 ± 1
No. of light vehicles per hour	1744 ± 66	391 ± 22	28 ± 9	4 ± 2

*Abbreviations: dB(A) – noise levels on a decibel scale using frequency-dependent weighting, average Leq values were calculated for measurement periods; Leq – continuous noise level that has the same total A-weighted acoustic energy as the fluctuating noise measured over the same period; L1 – noise level exceeded for 1% of the measurement period; L99 – noise level exceeded for 99% of the measurement period.

†All differences between the noisy and quiet areas were statistically significant, *P*<0.001; Student's *t* test (noise parameters) or Mann-Whitney's U-test (No. of vehicles).

‡Between 6 AM and 10 PM.

§Between 10 PM and 6 AM.

Respondents from noisy area had significantly more difficulties falling asleep, more often reported waking up at night, and had more difficulties in falling back to sleep (Table 3). They also had significantly poorer sleep quality and more often complained about tiredness after sleep. When asked to specify the causes of sleep disturbances, 48.7% of the respondents from noisy area listed traffic noise, as opposed to only 12.9% of respondents from quiet area ($\chi^2 = 12.014$; $P<0.001$). Noise was the most important cause of awakenings for 44.4% of respondents from noisy area, compared with 6.1% respondents from quiet area ($\chi^2 = 22.570$; $P<0.001$). Considering the fact that respondents in noisy area significantly less often slept by open windows in the summer ($P<0.001$), noise was estimated to be the main cause (83.5%). No significant differences were observed between the respondents according to the residence area in the average duration of night sleep, time needed to fall asleep, and use of sleeping pills.

Correlation analysis showed that noise annoyance was significantly related to all sleep quality parameters except for average duration of night sleep and the use of sleeping pills (Table 4). Subjective noise sensitivity was significantly correlated with difficulties falling asleep, time needed to fall asleep, tiredness after sleep, and use of sleeping pills. Respondents with higher sensitivity to noise had significantly poorer sleep quality. Respondents with higher level of neuroticism had poorer quality of sleep, but had no decrease in the average duration of night sleep. Extroversion was not significantly related to noise-relat-

Table 2. General characteristics of the studied population sample by residential area

	Area*		
General characteristics	noisy	quiet	*P*
No. of residents	192	118	
Age (mean±SD, y)	43.5 ± 14.2	41.6 ± 15.1	0.409†
Men (%)	35.4	39.8	0.435‡
Education (%):			
high school	46.6	47.8	0.200‡
college degree	20.4	16.2	
university degree	33.0	35.9	
Type of work (%):			
physical	30.4	36.4	0.435‡
intellectual	69.6	63.6	
Employment rate (%)	53.7	55.7	0.744‡
Apartment size (m^2/person, mean±SD)	23.7 ± 11.2	20.0 ± 9.1	0.003†
Floor (mean±SD)	1.9 ± 1.1	2.2 ± 1.5	0.808§
Years of residence (mean±SD)	19.7 ± 13.4	17.8 ± 13.1	0.119†
Noise sensitivity score (mean±SD)	85.5 ± 17.1	83.2 ± 15.8	0.232†

*Noisy area >65 dB(A); quiet area <55 dB(A).
†Student's *t* test for independent variables.
‡χ^2 test.
§Mann-Whitney's U-test.

Table 3. Parameters of sleep disturbance of the population by residential area

	Area*		
Sleep disturbance parameters	noisy	quiet	*P*
Duration of night sleep (h)	6.9 ± 1.2	7.2 ± 2.0	0.100†
Difficulty with falling asleep (grade, mean±SD)	2.1 ± 0.8	1.9 ± 0.7	0.023‡
Time needed to fall asleep (grade, mean±SD)	1.9 ± 0.9	1.8 ± 0.9	0.892‡
Sleeping by open window (%)	52.6	93.7	<0.001§
Waking up at night (%)	60.1	38.8	<0.001§
Difficulty in falling back to sleep (%)	35.7	23.2	0.024§
Sleep quality (grade, mean±SD)	3.4 ± 0.9	3.6 ± 0.9	0.015‡
Tiredness after sleep (grade, mean±SD)	2.9 ± 0.8	2.6 ± 0.8	0.005‡
Use of sleeping pills (grade, mean±SD)	1.2 ± 0.7	1.2 ± 0.6	0.963‡

*Noisy area >65 dB(A); quiet area <55 dB(A).
†Student's *t* test.
‡Mann-Whitney's U-test.
§χ^2 test.

Table 4. Spearman correlation coefficients between sleep quality parameters and personality traits of 192 respondents in the noisy area

	Personality traits*			
Sleep disturbance parameters	noise annoyance	subjective noise sensitivity	neuroticism	extroversion
Duration of night sleep (h)	-0.106	-0.047	0.071	0.057
Difficulty in falling asleep (grade)	0.382§	0.373§	0.294§	-0.039
Time needed to fall asleep (grade)	0.341§	0.226‡	0.226‡	-0.014
Sleep quality (grade)	-0.262§	-0.276§	-0.332§	0.129
Tiredness after sleep (grade)	0.276§	0.186†	0.315§	-0.147†
Use of sleeping pills (grade)	0.120	0.218‡	0.260§	-0.083

*Personality traits were defined as follows: noise annoyance – subjective reaction toward specific noise or noisy environment; subjective noise sensitivity – factor underlying attitudes toward noise in general; neuroticism – tendency to react with feelings of anxiety, anger and inferiority; extroversion – personality type more open to experiences and social contacts.
†$P<0.05$.
‡$P<0.01$.
§$P<0.001$.

ed sleep disturbances, except for negative correlation with tiredness after sleep.

After adjustment for personality traits including subjective noise sensitivity, neuroticism, and extroversion, residence in noisy area was identified as important predictor for the occurrence of difficulties with falling asleep ($P = 0.010$), difficulties with falling back to sleep ($P = 0.041$), being woken up at night by noise ($P<0.001$), and sleeping by closed windows ($P<0.001$). Living in the noisy area increased the risk of complaints of poor sleep quality ($P = 0.027$) and tiredness after sleep ($P = 0.027$) (Table 5).

Table 5. Occurrence of sleep disturbances in relation to noisy vs quiet area of Belgrade

Sleep disturbances	OR (95% CI)*
Difficulty in falling asleep	2.7 (1.3-5.8)
Time needed to fall asleep	1.1 (0.7-1.8)
Sleeping by closed window	13.5 (5.8-31.3)
Waking up at night	2.6 (1.5-4.5)
Difficulty in falling back to sleep	1.9 (1.0-3.4)
Poor quality of sleep	3.0 (1.1-7.9)
Tiredness after sleep	2.5 (1.1-5.6)
Use of sleeping pills	1.2 (0.3-4.6)

*Adjusted odds ratios (OR) and 95% confidence intervals (CI), adjusted for age, sex, subjective noise sensitivity, neuroticism, and extroversion.

Discussion

Our study showed that sleep disturbances were significantly more pronounced in urban population of Belgrade exposed to traffic noise above 65 dB(A) Leq than in respondents living in a quiet area. Personality traits of neuroticism, extroversion, and subjective noise sensitivity and noise annoyance had a significant modifying effect on this relationship.

There are two commonly used methodological approaches in studies on noise and sleep disturbances: laboratory experiments and field research. The advantage of field research originates from the fact that noise is a ubiquitous environmental hazard making the exploration of noise effects in an everyday-life setting possible. The main disadvantages of this method are that noise is commonly measured outdoors only, making it difficult to assess the sound pressure level of the noise to which the residents were actually exposed and the fact that noise-induced sleep disturbances are subjectively evaluated. On the other hand, laboratory experiments allow both the strict control of sound pressure level of a stimulus and the objective evaluation of noise-induced sleep disturbances by electroencephalography (EEG) and polysomnography (PSG). This method, however, represents an unusual situation for the respondents. In two large meta-analyses on noise-induced sleep disturbances, these methods showed large discrepancies in analyzed parameters. Thus, respondents were more likely to be awakened from sleep in a laboratory setting than at home at the same sound pressure level (14,15).

Our study included several possible influencing factors, such as age, sex, education, type of work, employment status, what floor the apartment is on, period of residence, and subjective noise sensitivity (3). High level of noise annoyance found among respondents from the noisy area might be an underlying factor in sleep disturbances, as well as other psychological and behavioral effects of noise. One of the factors we were not able to control for was air pollution, especially the concentrations of carbon monoxide and tetraethyl gas (use of lead-free gas is not mandatory in Serbia). Nevertheless, concentrations of air pollutants are considerably lower in Belgrade than in other European cities with similar traffic intensity (2).

A significant relationship was found between noise levels and difficulties with falling asleep, although there were no differences in time needed to fall asleep between respondents from noisy and those from quiet area. These findings could be a consequence of adjustment to noise at night, considering long-term residence at the measurement locations. Previous studies frequently reported increased time needed to fall asleep in noisy environment, assessing that time either by delayed second phase of sleep on EEG or by subjective estimation (16). Laboratory EEG studies showed that traffic noise of 55 dB(A) caused significant prolongation of the time needed to fall asleep and the impairment of subjective sleep quality in comparison with control nights when noise level was below 32 dB(A) (17). Respondents exposed to recorded traffic noise of up to 60 dB reported the elongation of this time for 14 to 22 minutes (18,19). Similar findings were observed among children – when noise level was lowered for 11 dB, children needed 11 minutes less to fall asleep (20). Longitudinal studies conducted among urban residents of Gothenburg who were exposed to daytime traffic noise higher than 71.8 Leq dB(A) also showed more difficulties with falling asleep, poorer sleep quality, and higher level of tiredness after sleep, than did control population exposed to daytime noise level under 56 Leq dB(A) (21,22).

Our study confirms the results of previous investigations on effects of noise on waking up at night. Field research in the center of Valencia showed that 49% of the residents would wake up frequently at night due to traffic noise (16). In laboratory setting, waking up at night caused by recorded traffic noise level of 75.6 dB(A) was more frequent than during control nights without noise disturbance (23). The noise level itself and number of noisy events are thought to influence the occurrence of waking. This was proven in laboratory settings when noise level was higher than 60 dB(A) (24).

Poorer sleep quality and tiredness after sleep, which are important late effects of noise, have been reported previously (22,25). They can be explained by the changes in sleep stages, such as shortening of deep sleep and rapid eye movement (REM) phase and increased superficial sleep and awake state (23,26). Poorer sleep quality and irritated state in the morning were observed in residents exposed to traffic noise or low frequency noise (27).

Closing bedroom windows at night is one of the behavioral patterns indicative of the disturbing effects of noise (28). Our results showed that residents of noisy area slept less frequently by an open window during summer and reported noise to be the main reason for this behavior. Another behavioral pattern is use of sleeping pills. The lack of differences between the residents from noisy and quiet areas in this study implicates that this behavior might be influenced mainly by personality traits, such as neuroticism. Highly significant correlation coefficient between neuroticism and use of sleeping pills in our study supports this assumption. On the other hand, the time of day when residents are exposed to noise could even be more important than the level of noise itself. A large study in the surrounding area of Amsterdam airport showed that only the exposure to aircraft noise during the late evening was associated with the intake of non-prescribed sleep medication or sedatives (29).

The strongest relationship between noise effects on sleep quality and personality traits was observed for subjective noise sensitivity and neuroticism. Correlation analysis revealed that noise annoyance and subjective noise sensitivity among noisy area respondents significantly influenced sleep quality. These results confirm previously reported correlation between subjective noise sensitivity and time needed to fall asleep, number of awakenings, and feeling of tiredness after sleep among urban population exposed to noise at night (22,30). People considered to be more vulnerable to noise are those who perceive it difficult and stressing to accomplish their current plans and goals in different areas of life, whether it is work, studies, personal economy, marital relations, or something else (31). Therefore, personality traits such as noise sensitivity should be considered as possible predictors of sleep disturbances induced by community noise (11).

Another important factor influencing the effects of noise could be the habituation. Although some investigators claim there is no habituation of sleep to road traffic noise (19), recent studies have provided some evidence that it exists. However, habituation could be observed when subjective sleep parameters were taken into account, but polygraph sleep parameters of EEG reactions showed little or no evidence (32).

Deleterious effects of community noise on sleep quality are of great importance for complete rest and psychosomatic health. Early indicator of poor acoustic characteristics of the environment for sleep quality is the reaction of vulnerable categories of the population, such as children under 6 years of age, people with neurotic tendencies, and elderly people. Deleterious sleep environment might be one of the causes of psychosocial and behavioral problems among school children (33).

Considering noise to be great environmental problem, a multi-pronged approach combining natural and social sciences, politics, law enforcement, and noise abatement measures might be a promising public health strategy (34). Preventive measures should be directed at decreasing nighttime Leq level to 30 dB(A) or lower and maximum level to 45 dB(A) or lower.

In conclusion, our study showed that the population living in urban area where traffic noise level is above 65 dB(A) Leq was at a significantly higher risk of the occurrence of sleep disturbances than it was population living in a quiet area. We found that these sleep disturbances were significantly and positively related to neuroticism and subjective noise sensitivity. Therefore, we suggest that assessment of personality traits by standardized and possibly concise questionnaires be included into research methodology of effects of noise on sleep.

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