Original Article

Nighttime Road-Traffic Noise and Arterial Hypertension in an Urban Population

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Commonly used daytime measurements in previous investigations on community noise and arterial hypertension (AH) may be a source of exposure bias, as urban residents spend most of their daytime hours out of the home on workdays. For this reason, we focused on the relation of nighttime noise and AH. A cross-sectional study was performed on a sample of 2,503 (995 men and 1,508 women) adult residents of a downtown Belgrade municipality. The inclusion criteria were a period of residence longer than 10 years and a bedroom oriented toward the street. The exclusion criteria were a high level of noise annoyance at work and diseases related to AH. Noise measurements were performed in all 70 streets of the municipality. The streets were grouped into noisy areas (equivalent noise level [L_{eq}]>45 dB(A)) and quiet areas ($L_{eq} \leq 45$ dB(A)). The residents were interviewed in regard to antihypertensive therapy. Subjects who responded that they had not received such therapy were contacted for blood pressure measurements with mercury sphygmomanometer. Possible confounding factors: family history of AH, age, body mass index, smoking habits, physical activity and alcohol consumption were controlled for. The proportions of men with AH in the noisy and quiet areas were 23.6% and 17.5%, respectively. The adjusted odds ratio (OR) for AH was 1.58; the 95% confidence interval (CI) ranged from 1.03–2.42; and the probability value was 0.038, when men living in quiet streets were taken as a reference category. This relation was statistically insignificant for women: adjusted OR: 0.90; 95% CI: 0.59–1.38; *p*: 0.644. This cross-sectional study showed that nighttime urban road-traffic noise might be related to occurrence of AH in men. (*Hypertens Res* 2008; 31: 775–781)

***Key Words*: noise, blood pressure, hypertension, urban population, adults**

Introduction

Large cities in both developed and developing countries face similar challenges in coping with the problem of noise pollution. It has been estimated that every fifth EU citizen lives in a so-called “black acoustic zone” with an equivalent noise level (L_{eq}) over 65 dB(A), which is considered to produce strong acoustical stress (*1*). Furthermore, every third EU citizen may suffer from sleep disturbances due to exposure to nighttime L_{eq} over 55 dB(A) (*2*). Systematic noise monitoring performed on 25 measuring points in Belgrade in the last 30 years indicates that noise limits have been constantly exceeded by 11–16 dB in the daytime and 10–14 dB at night (*3*). Extremely high levels of traffic noise, from 90–100 dB(A), in Asian megalopolises such as Calcutta and Bangkok are the outcome of the dominant use of outdated two-stroke diesel engines and motorcycles (*4*). Consequently, urban populations in such cities usually rate road-traffic noise as a major environmental problem, together with water and air pollution.

Arterial hypertension is one of the major risk factors for

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early death in urban populations, due to its association with coronary heart disease and stroke (*5*). The relation between noise exposure and arterial hypertension has been studied intensively since the 1980s. The suggested pathogenic concept linking noise with arterial hypertension is based on a general stress-reaction model (*6*). Noise activates the hypothalamic-pituitary-adrenal axis and sympathetic nervous system and induces reticular formation, leading to an increase in the circulatory stress hormones adrenaline, nor-adrenaline and cortisol, which play a major role in blood pressure regulation (*7*, *8*). Some laboratory findings suggest that there are sex-related differences in hormonal reactions to noise. Male adults exposed to a noise level of 75 dB(A) showed significant increase of heart rate and blood pressure, whereas no significant effects were observed among females (*9*, *10*). The results of an earlier population study performed in an urban area near Belgrade support these findings. In men highly annoyed by noise, the prevalence of arterial hypertension was significantly higher compared to residents with low noise annoyance. This relation was not significant in women (*11*).

So far, investigations have provided conflicting results regarding the relationship between road-traffic noise and arterial hypertension (*12*). One of the possible reasons for the discrepancy in results may be the different noise measurement methods used. The commonly used daytime measurements in residential areas may be a source of exposure bias. In fact, on workdays people spend most of their daytime hours out of the home. For this reason, nighttime noise measurements might alleviate any exposure bias problem.

The aim of this study was to investigate the relation between nighttime urban traffic noise and the prevalence of arterial hypertension in an urban adult population. We hypothesized that the prevalence of arterial hypertension would be higher in noisy areas with nighttime L_{eq} exceeding 45 dB(A), an adopted outdoor limit in residential areas, compared to areas with nighttime $L_{eq} \leq 45$ dB(A). We considered that it would be important for the cost-benefit analysis of road-traffic noise countermeasures to estimate the relationship between exceeded noise limits and the prevalence of arterial hypertension in an exposed population. Another hypothesis was that the relation between urban noise and arterial hypertension would be stronger in men than in women.

Methods

Noise Measurements

Noise measurements were performed in the middle of all 70 streets of a downtown Belgrade municipality during April–October 2004. A Brüel & Kjær 4426 Noise Level Analyzer (Brüel & Kjær, Nærum, Denmark) was used according to the recommendations of the International Standard Organization for the measurement of community noise (ISO 1982) (*13*). L_{eq} were measured over two night intervals: between 10 and 12 PM and between midnight and 1:30 AM. The time interval of each measurement was 15 min, and the speed of sampling was 10/s, with 9,000 samples collected per measurement at one site. From the two obtained L_{eq}, we calculated a composite nighttime L_{eq} for each street using the following formula:

$$L_{eq} = 10 \log_{10} \left(\sum_{i=1}^{n} t_i 10^{L_i/10}\right) \text{dB(A)},$$

where t_i is a part of the total measuring time in which a constant noise level L_i was detected. As we had two equal nighttime measuring intervals, t_i was 0.5 for each of them. The residents were divided into two categories according to nighttime traffic noise exposure: those living in quiet areas ($L_{eq} \leq 45$ dB(A)) and those living in noisy areas ($L_{eq} > 45$ dB(A)). This cut-off point was used because it is a nighttime outdoor limit in Serbia and in most of the European countries. Traffic density at each measuring site was estimated by counting light and heavy vehicles per hour.

Questionnaire

The questionnaire was anonymous and consisted of three segments. The first part comprised general socio-demographic data: age, sex, education, employment, period of residence, daily time spent in the apartment, apartment size, number of dwellers, and orientation of the bedroom(s) (toward the street or not).

The second part included noise-related questions. A five-point verbal annoyance scale (0, not at all; 1, slightly; 2, moderately; 3, very; and 4, extremely annoyed) and an eleven-point numeric annoyance scale (graded from 0 [not at all annoyed] to 10 [extremely annoyed]) were used according to the recommendations for shared annoyance questions in noise annoyance surveys from the International Commission on the Biological Effects of Noise (*14*). Subjective noise sensitivity was measured with Weinstein's Noise Sensitivity Scale (*15*). In previous studies on noise and arterial hypertension, both the noise level and noise annoyance rating were used as independent variables (*12*). However, we consider the noise level to be the more reliable and more important independent variable from a public health point of view. The intrapersonal and interpersonal variability of noise annoyance might be too large for this parameter to serve as a reliable independent variable. However, noise annoyance should always be controlled as a possible confounding factor, due to its usually close relation to noise exposure level. In order to exclude possible occupational noise exposure, a four-point graded scale on noise exposure at work was used (0, "There is no noise at all"; 1, "Yes, noise is present, but it does not annoy me"; 2, "Yes, noise is present, and it annoys me"; and 3, "Yes, noise is present, and it imperils my hearing").

The third segment consisted of questions on antihypertensive therapy and possible confounding factors, such as family history of arterial hypertension, body weight and height, smoking habits, physical activity, and alcohol consumption, graded on a six-point scale (0: never; 1: several times a year;

2: 1–3 times a month; 3: 1–3 times a week; 4: 4–6 times a week; and 5: every day). There were also questions concerning medically confirmed diseases related to arterial hypertension: diabetes mellitus, renal diseases, aortal coarctation, Cushing's Syndrome, hyperthyreosis, pheochromocytoma, primary aldosteronism, acromegaly and hyperparathyroidism.

Study Sample

A cross-sectional study was performed on a sample of the adult population in a downtown Belgrade municipality. The estimated adult population of this municipality was about 60,000 according to census data. To obtain a 10% randomized sample of 6,000 people, we used a step method in interviewing all adult residents of every tenth flat in all streets. The appropriate numbers of questionnaires were delivered to post boxes inside the buildings according to the list of dwellers. The response rate was 52.8%, or 3,169 filled questionnaires.

The inclusion criteria for the selection of the final subsample of residents were period of residence longer than 10 years and a bedroom oriented toward the street. The exclusion criteria included a high level of noise annoyance at work and the presence of diseases that might influence the occurrence of arterial hypertension. Using these criteria, the sample was further reduced to 2,803 residents, 1,095 men and 1,708 women.

Diagnosis of Arterial Hypertension

The subjects who reported taking antihypertensive drugs were classified into a group of arterial hypertensives ($n=318$, 139 men and 179 women). Subjects who denied having medically confirmed arterial hypertension or taking antihypertensive drugs ($n=2{,}485$) were contacted by phone and invited for blood pressure measurement. The response rate was 87.9% ($n=2{,}185$, 856 men and 1,329 women). The final sample for investigation thus included a total of 2,503 subjects (995 men with an average age of 42±18 years [range 18–96 years] and 1,508 women with an average age of 40±17 years [range 18–91 years]). Participants were asked to avoid drinking coffee or smoking for half an hour before physical examination. A cardiologist took the blood pressure measurements with a Fazzini mercury sphygmomanometer (cuff sizes 50–60 cm; width 14–17 cm; Fazzini, Italy). This instrument complies with the decision of Annex VI of the European Council Directive 93/42/EEC concerning medical devices. The measurements were performed on a working day in an outpatient department, between noon and 2 PM, after a short rest of about 5 min. The subject was in a sitting position, and the mean value was determined from two measurements performed on each arm. If the difference between measurements exceeded 5 mmHg, a third measurement was performed on the same arm. Arterial hypertension was diagnosed according to the criteria established by the Seventh Report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure (JNC 7) (systolic pressure ≥ 140 mmHg and/or diastolic pressure ≥ 90 mmHg) (*16*). Ambulatory blood pressure monitoring was applied in 175 participants (64 men and 111 women) with borderline blood pressure levels and fluctuation from normal to hypertensive values. Blood pressure was measured every 30 min over a 24-h period including both waking and sleeping hours on workdays. The criteria for hypertension based on the ambulatory blood pressure measurements were a mean systolic pressure > 135 mmHg and/or a mean diastolic pressure > 85 mmHg (*17*).

Table 1. Characteristics of Nighttime-Traffic Noise of the Two Investigated Areas in Belgrade

Measurement parameters	Noisy area	Quiet area	*p* value
L_{eq} (dB(A))	53.8±4.9	42.0±2.3	<0.001[a]
L_{max} (dB(A))	82.4±6.0	68.9±4.7	<0.001[a]
Light vehicles (No./h)	320±325	20±25	<0.001[b]
Heavy vehicles (No./h)	18±28	0	

[a]Student's *t*-test. [b]Mann-Whitney *U*-test. L_{eq}, equivalent noise level; L_{max}, maximum noise level.

The proportion of subjects in whom hypertension was diagnosed through the blood pressure measuring procedure was 7.5% ($n=163$), out of which there were 79 men (9.2%) and 84 women (6.3%). Within this group, 98 cases of arterial hypertension (52 men and 46 women) were diagnosed by blood pressure measurement with a sphygmomanometer, and 65 cases of arterial hypertension (27 men and 38 women) were diagnosed by additional ambulatory blood pressure monitoring.

In the whole investigated sample the total proportion of subjects with arterial hypertension was 19.2% ($n=481$) out of which there were 218 men (21.9%) and 263 women (17.4%).

Statistical Analysis

Data are presented as the means±SD for numeric variables, or as percentages (relative numbers) for categorical variables. Differences between groups were compared using Student's *t*-test for parametric data and Mann-Whitney *U*-test and χ^2 test for non-parametric data. Univariate logistic regression was performed to calculate OR for arterial hypertension in relation to relevant independent variables. Multiple logistic regression was used to calculate adjusted OR for arterial hypertension in relation to noise exposure. STATISTICA software was used for all data analyses (Version 6, StatSoft Inc., Tulsa, USA).

Results

The noisy and quiet areas were significantly different in terms of both noise levels and traffic density (Table 1).

Table 2. Basic Characteristics of the Studied Population of Belgrade

Characteristic	Men (n=995)			Women (n=1,508)		
	Noisy area (n=715)	Quiet area (n=280)	p value	Noisy area (n=1,062)	Quiet area (n=446)	p value
Age (years)	42.6±17.8	40.0±16.5	0.033[a]	40.5±17.2	39.7±16.3	0.393[a]
Apartments size (m^2 per person)	23.9±16.1	23.1±12.9	0.442[a]	23.3±12.6	23.9±12.8	0.400[a]
Time of residence (years)	17.6±7.8	16.7±6.0	0.113[a]	15.8±6.5	16.2±4.3	0.246[a]
Time spent in apartment (h)	12.8±4.1	12.5±3.4	0.251[a]	14.1±4.1	13.9±4.1	0.318[a]
Employment (%)	79.8	75.4	0.122[b]	72.1	69.6	0.331[b]
Education (%)						
Primary school	1.8	2.2	0.546[b]	2.5	2.8	0.892[b]
Secondary school	40.7	45.1		43.5	41.5	
College	16.4	16.2		12.3	13.1	
University	41.1	36.5		41.7	42.6	
Body mass index (kg/m^2)	27.5±3.8	27.7±4.0	0.440[a]	26.0±4.4	25.7±4.5	0.179[a]
Smoking habits (%)						
Smoker	39.8	39.0	0.912[b]	43.0	41.2	0.501[b]
Non-smoker	40.5	42.0		45.1	44.8	
Ex-smoker	19.7	19.0		11.9	14.0	
Alcohol consumption	2.6±1.2	2.5±1.2	0.777[c]	1.9±1.1	2.0±1.1	0.461[c]
Regular physical activity (%)	13.1	13.2	0.987[b]	7.7	8.4	0.645[b]
Family history of hypertension (%)	54.8	52.5	0.520[b]	60.4	62.8	0.379[b]
Subjective noise sensitivity	81.2±16.5	79.8±15.1	0.247[a]	83.2±16.1	83.3±16.2	0.914[a]
Noise annoyance						
Verbal scale	2.0±1.0	1.8±0.8	0.002[c]	2.0±0.9	1.9±0.9	0.002[c]
Numeric scale	4.9±2.8	4.4±2.4	0.010[c]	5.2±2.9	4.5±2.8	<0.001[c]

[a]Student's *t*-test. [b]χ^2 test. [c]Mann-Whitney *U*-test.

The socio-demographic characteristics and risk factors for arterial hypertension were similar in both groups of residents, except for the higher average age of men in the noisy areas. As expected, residents from the noisy areas were more annoyed by noise (Table 2).

Univariate logistic regression revealed common predictors of arterial hypertension in both sexes: age, body mass index, family history of hypertension, and physical activity. Additional specific predictors identified for women were employment, subjective noise sensitivity and noise annoyance, while for men the only additional specific predictor was education level (Table 3). Significant independent variables from univariate logistic regression models were included in a multiple logistic regression model when calculating adjusted OR for arterial hypertension. Although insignificant in the univariate model, alcohol consumption was included in the multifactorial model, since many studies have pointed out its relation to arterial hypertension (*18*). Residents of the quiet areas were used as a reference category. Men living in the noisy areas were under a higher risk of arterial hypertension compared with men from the quiet areas, after adjustment for relevant factors (Table 4). The adjusted OR for hypertension in relation to noise was insignificant for women (Table 5).

Discussion

This cross-sectional study showed that nighttime road-traffic noise above 45 dB(A) L_{eq} was significantly related to arterial hypertension in an adult male urban population. This is in accordance with our previous findings, which revealed that men highly annoyed by noise are at higher risk for arterial hypertension, compared to those with low noise annoyance (*11*). In two German studies performed in Luebeck and Berlin, significant relative risks of 1.3 for arterial hypertension were also observed for men who described their streets as loud compared to those who described their streets as quiet (*19*, *20*).

In a population study conducted in Bonn, subjects living in areas with an average 24-h traffic noise over 65 dB(A) had a relative risk for hypertension of 1.5, compared with residents living in areas with an L_{eq}<60 dB(A) (*21*).

However, a study in the city of Solentuni, Sweden, with a noisy area of 50–65 dB(A) L_{eq} and a control area of L_{eq}<50 dB(A), revealed a significant relative risk of 3.3 among women, whereas in men the effect failed (relative risk 1.0). The authors explained these findings by the fact that women spend more time in their apartment than men, a statement that must be taken with a great deal of caution (*22*).

Table 3. Odds Ratios (OR) and 95% Confidence Intervals (CI) for Arterial Hypertension in Relation to Relevant Independent Variables and Gender

Independent variables	Men (n=995)			Women (n=1,508)		
	OR	95% CI	p value[a]	OR	95% CI	p value[a]
Subjective noise sensitivity	1.01	1.00–1.02	0.052	1.02	1.01–1.03	0.001
Noise annoyance						
Verbal scale	1.15	0.98–1.34	0.080	1.32	1.14–1.52	<0.001
Numeric scale	1.02	0.97–1.08	0.386	1.06	1.02–1.12	0.010
Family history of hypertension	1.84	1.34–2.52	<0.001	2.05	1.52–2.76	<0.001
Age (years)	1.05	1.04–1.06	<0.001	1.11	1.09–1.12	<0.001
Body mass index (kg/m^2)	1.20	1.16–1.26	<0.001	1.20	1.17–1.24	<0.001
Education	1.26	1.07–1.48	0.006	0.92	0.80–1.05	0.208
Employment	0.79	0.54–1.16	0.225	0.72	0.53–0.99	0.043
Smoker	1.01	0.85–1.19	0.942	0.89	0.77–1.03	0.118
Alcohol consumption	1.05	0.92–1.19	0.517	0.97	0.86–1.10	0.662
Regular physical activity	0.35	0.19–0.65	0.001	0.86	0.02–0.35	0.001

[a]Univariate logistic regression.

Table 4. Prevalence of Arterial Hypertension (AH) and Odds Ratios (OR) with 95% Confidence Intervals (CI) for Arterial Hypertension in Male Adult Population of a Belgrade Municipality in Relation to Noise Exposure (n=995)

L_{eq}	Number of residents	AH (n (%))	Crude OR (95% CI)	p value[b]	Adjusted OR (95% CI)[c]	p value[d]
>45 dB(A)	715	169 (23.6)	1.46 (1.03–2.08)	0.036	1.58 (1.03–2.42)	0.038
≤45 dB(A)[a]	280	49 (17.5)	1		1	

[a]Reference category. [b]Univariate logistic regression. [c]Adjusted for age, body mass index, physical activity, education, family history of hypertension and alcohol consumption. [d]Multiple logistic regression.

Table 5. Prevalence of Arterial Hypertension (AH) and Odds Ratios (OR) with 95% Confidence Intervals (CI) for Arterial Hypertension in Female Adult Population of a Belgrade Municipality in Relation to Noise Exposure (n=1,508)

L_{eq}	Number of residents	AH (n (%))	Crude OR (95% CI)	p value[b]	Adjusted OR (95% CI)[c]	p value[d]
>45 dB(A)	1,062	191 (18.0)	1.14 (0.85–1.53)	0.390	0.90 (0.59–1.38)	0.644
≤45 dB(A)[a]	446	72 (16.1)	1		1	

[a]Reference category. [b]Univariate logistic regression. [c]Adjusted for age, body mass index, physical activity, subjective noise sensitivity, noise annoyance, family history of hypertension and alcohol consumption. [d]Multiple logistic regression.

In another study conducted on a German population, the association between hypertension and noise disturbance did not reach the expected statistical significance (relative risk: 0.92; men: 1.18; women: 0.90) (*23*). Several other studies carried out in Doetinchem (*24*), Amsterdam (*25*), Tyrol (*26*), and Luebeck (*27*) also failed to establish a statistically significant relation between exposure to road traffic noise and risk of arterial hypertension (range of relative risk: 0.81–1.05). However, the advantage of these studies is that they provided much better control of the confounding factors for arterial hypertension, such as obesity, smoking, stress and physical inactivity.

So far, few studies have focused on the influence of nighttime noise. One that has is a study conducted in the city of Erfurt in Germany. It was designed as a longitudinal 5 year prospective study investigating the health benefits of lowering traffic noise levels by 10 dB(A) in the residential area (*28*). The results showed that the recovery of the patients with arterial hypertension was more frequent than in the control group where no such measures were undertaken. Only one German survey distinguished the effects of nighttime *vs*. daytime noise exposure, showing slightly higher relative risk for hypertension in association with night noise (*29*). That study revealed significant risk for the occurrence of hypertension among men exposed to nighttime noise levels exceeding 55 dB(A), independent from other possible confounders, including age, body mass index, physical activity or family history of hypertension.

In a comprehensive review of transportation noise and cardiovascular risk, Babisch concluded that if outdoor noise levels were used as an exposure indicator, no consistent relationship between traffic noise level and the prevalence of hypertension could be established. However, when subjective noise annoyance was considered, the results looked somewhat more consistent (the relative risks ranged from 0.8 to 2.3) (*30*). To decrease the discrepancies in the results of population studies on noise and hypertension we suggest that the nighttime noise level be taken as an exposure criterion rather than the daytime noise level. The rationale for this suggestion is the fact that, on workdays, people are generally at home during the nighttime but not during the daytime. This approach thus offers an effective solution to the exposure bias underlying the discrepancies in the results from noise studies.

This study has several limitations. First, we relied on information about antihypertensive therapy as a health outcome. Possible underreporting was overcome by inviting the participants for blood pressure measurement. Second, we could not control for blood cholesterol, triglycerides and glucose levels as possible risk factors for hypertension. Third, we relied on the residents' self-reporting of their body weight and height. Fourth, we did not measure indoor noise levels. Fifth, we did not check the hearing level of the subjects. Sixth, this study did not assess a dose-response relationship, since we neither obtained the noise exposure data for each address of the subjects, nor the data from personal dose meters. Seventh, there exists a possibility of a confounding effect of air pollution from noisy and heavily trafficked streets on blood pressure. In a population based study in Augsburg (Germany), continuous concentrations of total suspended particulates and sulfur dioxide were associated with an increase in systolic blood pressure (*31*). Finally, we did not control for possible habituation and coping strategies. However, EEG reactions during sleep show no evidence of habituation, even after a long exposure time, a fact that contributes to the occurrence of chronic health effects (*32*).

The World Health Organization has recognized nighttime noise as an important stressor for adverse health effects, including cardiovascular diseases (*33*). Furthermore, an EU Directive concerning community noise strongly recommends a nighttime equivalent noise level as a standard noise indicator in member states (*34*). The results of our study support these official policies.

In conclusion, this cross-sectional study on an adult population of a Belgrade municipality showed a significant association between nighttime urban road-traffic noise of $L_{eq}>45$ dB(A) and the occurrence of arterial hypertension in men.

To alleviate existing discrepancies between the results of population studies on road-traffic noise and arterial hypertension, we suggest that nighttime noise levels be used as exposure indicators instead of daytime noise levels. Nighttime noise countermeasures might have a greater public health impact compared to their daytime counterparts, including a possible influence on the incidence of arterial hypertension in urban populations, predominantly in males.

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