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# Noise annoyance is related to the presence of urban public transport

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## HIGHLIGHTS

- The presence of public transport is a predictor of high noise annoyance.
- At daytime, the number of public transport vehicles is related to noise annoyance.
- At night, the type of public transport is significantly related to noise annoyance.
- The combination of buses and trams at night is the most annoying.
- The role of public transport on noise annoyance is independent from noise levels.

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ABSTRACT

*Background:* The association between noise annoyance and public transport as a source of noise has not been studied previously. The aim was to study noise annoyance in an urban population due to the presence, the type and the number of public transport vehicles, in relation to other acoustical and non-acoustical parameters.
*Method:* The study sample comprised 5861 adults residing in 118 streets in the city center of Belgrade. The presence, the type and the number of public transport vehicles were assessed using official transport maps and matched with residential addresses. Noise annoyance was assessed by a questionnaire including a self-report five-graded scale. 'High noise annoyance' was defined by merging 'very' and 'extremely' annoyed answers.
*Results:* Significant predictors of high noise annoyance were the presence of public transport at daytime (yes vs. no) (odds ratio = 1.47, 95% confidence interval = 1.28–1.70), and at night (yes vs. no) (OR = 1.39, 95% CI = 1.20–1.61). Residing in the streets with more than 79 public transport vehicles per hour (3rd tercile vs. 1st tercile) predicted high noise annoyance at daytime (OR = 1.64, 95% CI = 1.18–2.27). Residing in the streets with buses and trams at night ('bus and tram' vs. no public transport) increased the risk of high noise annoyance (OR = 2.67, 95% CI = 1.78–4.09). These associations were independent from noise sensitivity, orientation of bedroom windows, floor level, and equivalent noise levels. Living in the apartment with bedroom windows facing the street was the strongest confounder for the association between noise annoyance, noise levels and public transport.
*Conclusion:* The study has identified the presence of public transport at daytime and at night as a significant and independent predictor of high noise annoyance. Future intervention measures should concern the presence, the type and the number of public transport vehicles in order to reduce noise annoyance reactions in urban areas.


## 1. Introduction

Noise is a major environmental factor causing annoyance in humans. Noise affects exposed people because it disturbs communication, concentration, and activities and provokes adverse emotional reactions (Miedema, 2007). Noise annoyance may be affected by psychological or non-acoustical characteristics, primarily on subjective noise sensitivity, attitudes toward noise, gender, age, health status, or socio-economic situation (Michaud et al., 2005; Ouis, 2001; Van Kamp et al., 2004). Specific features of noise exposure (place, time of day, and type of exposure), as well as a number of dwelling characteristics (floor level, window orientation, window insulation) may affect noise annoyance by modifying noise exposure (Fields, 1993; Jakovljevic et al., 2009). The importance of acoustical factors for noise annoyance (sound level and frequency, number of events) is also well-documented; the association between noise levels and annoyance reactions is converted into mathematical models (Miedema and Oudshoorn, 2001), and presently incorporated into the Directive 2002/49/EC of the European Parliament and of the Council, relating to the assessment and management of environmental noise (Directive, 2002/49/EC of the European Parliament of the Council, 2002).

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Most of previous studies on noise annoyance focused on single noise sources, such as road traffic, aircrafts or railway traffic (Miedema and Oudshoorn, 2001). Some recent studies, however, concentrated on annoyance from mixed sources, such as road traffic combined with railway (Di et al., 2012; Lam et al., 2009; Ohrström et al., 2007), and road traffic combined with industrial facilities (Pierrette et al., 2012). On the other side, there are only a few studies focusing on annoyance from specific types of motor vehicles. For example, Paviotti and Vogiatzis (2012) studied the characteristics of noise from motorbikes and scooters that may induce annoyance. To the authors' knowledge, the association between public transport vehicles and noise annoyance has not been studied previously.

We hypothesized that the presence, specific types of public transport or the number of vehicles may account for noise annoyance in an urban population. Specific public transport vehicles, such as buses, trams or trolleybuses, may be more prominent among other road-traffic sources. Noise annoyance may be affected by the characteristics of the emitted noise from public transport vehicles and/or by the number of disturbing events. Our assessments may be useful for transport authorities to propose appropriate noise abatement measures related to the position of public transport routes, and the type and the number of public transport vehicles. The aim of this research was to investigate the relationship between noise annoyance in an urban population with the presence, the type and the number of public transport vehicles, in addition to other acoustical and non-acoustical factors.

## 2. Material and methods

### 2.1. Study sample

This cross-sectional study was performed in the municipality of Stari Grad, located in the center of Belgrade, Serbia. The municipality is characterized by a homogenous and stable demographic structure (low migration rate due to high property values), as well as by the predominance of road traffic over other sources of urban noise. According to the census in 2002, the population of Stari Grad was 55,543 inhabitants; 55.68% were women; 67.8% were adults aged 18 to 65, whereas 20.4% were the elderly (over 65 years) (Institute of Public Health of Serbia, 2010).

The study was conducted in two phases: the first phase lasted from 2004 to 2006, and the second phase lasted from 2007 to 2009. The sampling procedure was described previously (Jakovljevic et al., 2009). In short, adult residents of every tenth apartment in all streets were interviewed by distributing questionnaires to post boxes inside the buildings according to the list of dwelling occupants. During the first phase 6000 questionnaires were distributed, and 3169 were filled out and returned (response rate 52.8%). During the second phase, 5420 questionnaires were distributed, and 2880 were filled out and returned (response rate 53.1%). Persons who failed to report their noise annoyance level ($n = 188$) were excluded from the study. The final sample, therefore, comprised 5861 participants, i.e. 3093 persons from the first phase, and 2768 persons from the second phase of the investigation. The two samples were comparable by age, gender, education level, dwelling characteristics, subjective noise sensitivity and noise annoyance level; both samples were, thus, united for further analysis. In total, 3263 respondents (55.7% of the sample) were women; mean age of the study population was $42.91 \pm 17.88$ years. The study was approved by the Ethics Committee of the Faculty of Medicine, University of Belgrade before the study commenced.

### 2.2. Noise level measurements

Noise levels were measured in the middle of all 118 streets of this municipality during September–October 2008. A hand-held noise level analyzer type 2250 'Brüel & Kjær' was used, according to recommendations of the International Standard Organization for the measurement of community noise (ISO, 1982). Noise measurements were performed on working days. Equivalent noise levels [Leq (dBA)] and maximum noise levels (dBA) were measured in two intervals during the daytime (between 8 and 10 am, and between 2 and 4 pm), in one evening interval (between 6 and 8 pm), and in two night intervals (between 10 pm and midnight, and between midnight and 2 am). A noise level meter was positioned on the pavement by the road, around 3 m away from the nearest façade, at an approximate height of 1.5 m. The measurement sites were located roughly in the middle of the street between the crossroads, and away from other possible sources of noise (construction works, schools, public parking spaces, entertainment facilities, etc.). The time interval of each measurement was 15 min; the speed of sampling was 10 per second, with 9000 samples collected per measurement at one site. From the obtained Leq levels, the composite daytime Leq and nighttime Leq were calculated for each street. Each participant was assigned to daytime and nighttime Leq values measured at the street of current residence. All respondents lived within 100 m of any measurement site in one street.

### 2.3. Public transport assessment

The official public transport maps in Belgrade show that 24 out of a total of 139 public transport lines run through this municipality, including 5 out of 12 tram lines, 7 out of 8 trolleybus lines and 12 out of 119 bus lines (Public Transport Company 'Belgrade', 2008). Participants' home addresses were matched with these maps in order to assess the presence of public transport (no public transport vs. public transport running), and the type of public transport (bus only, tram only, trolleybus only, bus plus tram, bus plus trolleybus). Both daily lines (running from 4–5 am to 11–12 pm), and night lines (running from midnight to 4–5 am) were taken into consideration. The number of public transport vehicles in the given street was calculated as the sum of the number of all vehicles running in both directions for all lines and averaged per hour. Each participant was assigned to the presence and the type of daytime and nighttime public transport in the street of current residence.

For the purposes of logistic regression, the number of public transport vehicles was stratified according to tercile distribution of values. In the streets where public transport was running at daytime, the average number of vehicles was classified as: 1st tercile ($\leq$48 vehicles/hour), 2nd tercile (49–78 vehicles/hour), and 3rd tercile ($\geq$79 vehicles/hour). In the streets where public transport was running at night, the average number of vehicles was re-grouped as follows: 1st tercile ($\leq$3 vehicles/hour), 2nd tercile (4–7 vehicles/hour), and 3rd tercile ($\geq$8 vehicles/hour). Streets without public transport were excluded from this stratification.

Simultaneously with noise measurements, investigators counted the number of vehicles running in all streets of this municipality on a working day. Vehicles were counted once during daytime (between 2 and 4 pm) and once at night (between 10 pm and midnight) for 15 min per street. Light vehicles (motorbikes, motors and cars) and heavy vehicles (vans, trucks, lorries, buses, trams, and trolleybuses) were counted separately and were averaged per hour.

### 2.4. Questionnaire

The anonymous questionnaire included general socio-demographic data: age, gender, marital status (coded as: 0 — singe/divorced/separated/widowed, 1 — married/partners), years of education (coded as: 0 — less or equal 12 years, 1 — over 12 years), duration of residence (categories were based on 25th percentile of values, equal to 5 years of residence; coded as: 0 — less than 5 years, 1 — equal or more than 5 years), apartment size, number of dwelling occupants, floor level (coded as: 0 — apartment on second floor or above, 1 — apartment on first floor or below), and orientation of bedroom windows (coded as: 0 — bedroom windows away from the street, 1 — bedroom windows facing the street).