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Effect of nocturnal road traffic noise exposure and annoyance on objective and subjective sleep quality

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ABSTRACT

Background: Various epidemiological studies have found an association between noise exposure and sleep quality, but the mediating role of annoyance is unclear for this association.
Objectives: To investigate the effects of both objectively modeled road traffic noise exposure as well as noise annoyance on subjective and objective sleep quality measures.
Methods: 1375 randomly selected participants from Basel, Switzerland, were enrolled in a questionnaire survey in 2008 with follow-up one year later (1122 participants). We assessed sleep quality by using a standardized sleep disturbance score, as well as the level of annoyance with road traffic noise at home. Objective sleep efficiency data was collected in a nested diary study by means of actigraphy from 119 subjects for 1551 nights. Residential nocturnal exposure to road traffic noise was modeled using validated models. Data were analyzed with random intercept mixed-effects regression models.
Results: In the main study, self-reported sleep quality was strongly related to noise annoyance (p for trend <0.001) but only moderately correlated with modeled noise exposure ($p = 0.07$). In the nested diary study objectively measured sleep efficiency was not related to annoyance ($p = 0.25$) but correlated with modeled noise exposure ($p = 0.02$). Strikingly, noise induced decreased sleep efficiency was even more significant for study participants who were not annoyed with traffic noise ($p = 0.001$).
Conclusions: This study indicates that effects of nocturnal traffic noise on objective sleep quality are independent of perceived noise annoyance, whereas the association between self-reported sleep quality and noise is mediated by noise annoyance.

Introduction

Environmental noise is a consequence of modern lifestyle and its impacts on health are of growing concern. In urban environments, road traffic noise is the most widespread source of noise exposure. It has been estimated that about 50% of the EU-population is exposed to A-weighted day-evening-night equivalent sound pressure level (L_{den}) of road traffic noise levels that exceed 55 dB(A) and 16% are exposed to nocturnal road traffic noise above 55 dB(A) (WHO, 2011).

Exposure to traffic noise has been shown to disrupt sleep, both in laboratory and field studies, leading to noise-related sleep disturbances (Öhrström et al., 1990; Miedema and Vos, 2007; Aasvang et al., 2008; de Kluizenaar et al., 2009; Aasvang et al., 2011; Basner et al., 2011; Brink, 2011). According to the WHO, sleep disturbances constitute the most serious consequence of environmental noise in western European countries (WHO, 2011). Sleep disturbances can lead to serious long term health effects, and there is increasing evidence from epidemiological studies that long-term noise exposure leads to cardiovascular diseases (Huss et al., 2010; Babisch et al., 1999; Babisch, 2011; Sorensen et al., 2011; WHO, 2011; Dratva et al., 2012; Sorensen et al., 2012).

It has been hypothesized that the effect of noise exposure might be mediated through annoyance rather than through a direct exposure effect, and that noise annoyance is a better marker of stress-related noise impacts than objective noise as it includes the perception and disturbance of the exposed individual (Nivison and Endresen, 1993; Marquis-Favre et al., 2005; Jakovljevic et al., 2006; Dratva et al., 2010; Birk et al., 2011). It is even recommended by the EU Directive 2002/49/EC that environmental noise exposure is evaluated by means of the estimated noise annoyance (European Union, 2002). Noise annoyance was shown to be associated with health related quality of life (Dratva et al., 2010). It is less clear, however, to which extent noise exposure affects sleep quality directly, independent of perceived annoyance due to traffic.

The aim of this study was to investigate the effect of both, road traffic noise exposure and annoyance on subjective, self-reported as well as objective sleep quality measures, assessed by actigraphy.

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In order to study the effects of noise exposure on sleep without the influence of noise annoyance we put a special focus on individuals who were not annoyed by road traffic noise.

Material and methods

Main study: participants and questionnaire

The present study was conducted within the framework of the QUALIFEX study (health related quality of life and radio frequency electromagnetic field (RF-EMF) exposure: prospective cohort study), a study with a focus on health effects due to environmental exposures, in particular RF-EMF exposure (Frei et al., 2010; Mohler et al., 2010; Röösli et al., 2010; Frei et al., 2012). The recruitment procedure including detailed definitions of sleep parameters is described in detail elsewhere (Mohler et al., 2010). In brief, in May 2008 we sent out questionnaires entitled "environment and health" to 4000 randomly selected residents from the region of Basel (2000 from the canton of Basel-City and 2000 from the canton of Basel-Country), Switzerland, aged between 30 and 60 years. After one year, a follow-up was conducted by sending the same questionnaire to the respondents of the baseline survey. Reasons for non-eligibility at both surveys were severe disabilities, death, incorrect addresses, absence during study time or language problems.

In the written baseline and the follow-up questionnaire, we used two standardized questions relating to the quality of sleep. Firstly, we used seven items of the Epworth Sleepiness Scale (Johns and Hocking, 1997) ranging from 0 (no daytime sleepiness) to 21 (excessive daytime sleepiness) to assess daytime sleepiness. Due to a technical problem in the production of the questionnaire, the eighth question from the Epworth Sleepiness Score was accidentally excluded ("Lying down to rest in the afternoon when circumstances permit"). Secondly, sleep disturbances were determined by means of four standardized questions on sleep disturbances from the Swiss Health Survey 2007 (Schmitt et al., 2000). The four questions asked about the frequency of difficulty in falling asleep, agitated sleep, waking phases during night, and waking too early in the morning: these were assessed on a four-point Likert scale with categories "never", "rare", "sometimes" and "most of the time". All responses were summed to produce a linear score ranging from 0 (no sleep disturbances) to 12 (heavy sleep disturbances). Annoyance due to road traffic noise at home was assessed using a four-point Likert scale with categories "no", "slight", "considerable", and "heavy". Finally, the questionnaire contained questions on socio-demographic factors (e.g. age, gender, marital status) and on lifestyle characteristics (e.g. alcohol use, physical activity).

Nested diary panel study

120 respondents of the baseline survey were recruited for a nested diary study. The selection of the participants of this diary sleep study was originally based on their residential exposure to RF-EMF sources and was not connected with residential noise exposure. Exclusion criteria for the diary study were the presence of children less than 2 years of age and a long-distance flight within the last three weeks. During 2 weeks, participants of the diary study wore, on their non-dominant wrist, an actigraphic device (AW7, Cambridge Neurotechnology) that measured activity by means of an accelerometer recording the combination of intensity, amount and duration of movement, with the corresponding voltage converted and stored as an activity count. Activity counts were summed over an interval of 15 s and sleep status of this interval was scored using the software provided by the manufacturer with medium sensitivity setting (Actiwatch Activity & Sleep Analysis version 5.51 from Cambridge Neurotechnology Ltd.). Subsequently, total sleep duration (time from start to end of sleep excluding waking phases) and sleep efficiency (percentage of the time scored as sleep compared to time spent in bed) were derived from these measurements. Prior to these calculations, the data were systematically checked by a study assistant for artifacts. Nights were excluded when the actigraphic devices were not worn, when the participants did not sleep at home, when they used sleeping pills or where the clock changed from summer to winter time or vice versa.

Every morning and evening during the study period, participants filled in a sleep diary. This diary was based on the sleep diary suggested by the German Sleep Society (http://www.charite.de/dgsm/dgsm/fachinformationen_frageboegen_schlaftagebuecher.php?language=german) collecting information on wake phases during the night, alcohol and caffeine consumption prior to sleep, and physical activity during the day. In the morning, participants rated the restfulness of their sleep using a scale from 1 (very restless sleep) to 5 (very restful sleep) as well as their well-being using a scale from 1 (depressed) to 6 (lighthearted). In a separate questionnaire, participants were again asked about their annoyance due to road traffic noise at home, whether they shared their bed with a partner and about the frequency of having the bedroom window open during night (never, sometimes, always).

Noise exposure assessment

The Swiss Federal Statistical Office provided geographic coordinates for the residential addresses of all study participants. For participants who moved between baseline and follow-up ($n = 56$), we received coordinates for both addresses. We obtained data on average traffic noise during night (22:00–6:00 h) for each address from two sources. For the canton of Basel-City, we used the road traffic noise cadaster provided by the Basel-City Office for the Environment and Energy. It is based on a detailed 3D city model that was developed by the land surveying office using photogrammetrically analyzed aerial photographs. The road traffic data were derived from a traffic model from the year 2008. Reflections, absorptions and noise protection walls are accounted for in the model. Nocturnal equivalent continuous noise level (L_{eq}) is calculated for each house for the most exposed floor (mostly the first floor at a height of 4.5 m above ground), 5 cm in front of each house façade. The model also takes into account noise from trams if they follow the same route as a car route. For the canton of Basel-Country, we obtained data from the national SonBase model (Höin et al., 2009). With SonBase night time equivalent continuous noise level (L_{eq}) at the most exposed façade point were calculated. Building data was obtained from SwissBUILDINGS3D database of Swisstopo. Building height was either derived from SwissBUILDINGS3D or DOM-DTM, a photogrammetric digital altitude model operated by the Federal Office of Topography (http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/height/dom_dtm-av.html). First order reflections and noise barriers were considered in the model. Noise calculations were based on the Swiss national traffic model 2010 from the Federal Office for Spatial Development ARE.

Both models are based on the noise calculation software CADNA_A (computer aided noise abatement) and the emission model STL-86 and STL-86+, respectively.

Statistical analyses

In the main study, the baseline and follow-up survey data were combined and analyzed with a multivariable mixed-effects linear regression model with random intercept, clustered at the level of the individual to investigate the association between nocturnal road traffic noise exposure and sleep outcomes. Noise exposure was categorized into 4 exposure levels (<30 dB, 30–<40 dB, 40–55 dB