Free field evaluation of the influence of naturalistic road and rail traffic noise on both psychological and physiological parameters

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INTRODUCTION

The most important effects of noise extracted from the literature can be summarized as followed (Ising & Kruppa 2004; Den Boer & Schroten 2007):

- impairment of well-being reflected by the grade of annoyance
- impairment of sleep reflected by various sleep disorders
- physical stress reactions reflected by activation of the autonomic nervous system
- arterial hypertension and associated cardiovascular diseases reflected by ischemic myocardial dysfunctions.

Exposure to noise in the environment from transport sources is an increasingly prominent feature. The growing demand for air, rail and road travel means that more people are being exposed to noise, and noise exposure is increasingly being seen as an important environmental public health issue (Bluhm et al. 2004; Babisch 2006). The direct effect of sound energy on human hearing is well established and accepted (Kryter 1985; Babisch 2005). Traffic noise is presented at a level clearly below the noise level causing hearing damage, so that the aural effects can be neglected. In contrast, non-auditory effects of noise on human health are not the direct result of sound energy. Instead, these effects are the result of noise as a general stressor: thus the use of the term noise not sound: noise is unwanted sound. Non-auditory effects of noise include annoyance, mental health, sleep disturbance and physiological functions as well as having effects on cognitive outcomes such as speech communication, and cognitive performance (WHO 2000). However, these effects of noise are less well established and accepted than auditory effects.

Large parts of the population – there are estimates that it concerns about 28 % of the total population in the European Union – are constantly impaired in their quality of life, their well-being or their sleep pattern, leading to an increased health risk (WHO 2009).

The question regarding a meaningful, clinically relevant threshold of noise level caused by traffic is discussed controversially and no clear consensus has been reached to date. Also, it is not clear which parameters should be used in order to scale serious health impairment. Mostly, data either have been obtained from epidemiological field studies or from studies performed in sleeping laboratories. These laboratory based studies have the clear advantage of the presence of standardized conditions where testing results are achieved (e.g. polysomnography (PSG) (Basner et al. 2009; Griefahn et al. 2006; Ögren et al. 2008). Such a grade of standardization of testing conditions cannot be achieved in field studies where a broad range of influence factors are present, however, these studies clearly allow for better simulation of actual in-situ conditions and further allowing epidemiological studies with representative sample sizes (Öhrström 2000; Skånberg & Öhrström 2006; Miedema & Oudshoorn 2001; Miedema & Vos 2007). It is noteworthy that in all of the epidemiological studies, only questionnaires reflecting the subjective estimation of noise-induced discomfort were applied for data generation lacking any objective variables.

The subjective estimation of noise-induced discomfort can be predicted only with difficulty in general (Morgan & Dirks 1974). The informational quality of a certain sound like semantic or pragmatic aspects plus the intentional attitude of a person are highly situation-specific and therefore cannot be modeled in a reliable way. Thereby, fuzzy mathematical soft-computing methods describing the relationship between noise-induced discomfort and objective noise parameters are important to consider as reported previously (Booteldooren & Lercher 2004).

Annoyance resulting from noise exposure

Used in connection with environmental effects, the term annoyance continues to be the subject of some ambiguities. Annoyance is in general used to mean all those negative feelings like disturbance dissatisfaction, displeasure, irritation and nuisance, but according to Guski the list may even be made longer by including somatic damage, loss of control and orientation, negative assessment of the noise source and high sound levels (Guski et al. 1999).

Noise annoyance may be conceived as an emotional process as this reaction is closely tied to the affective experience of the individual towards the noise source. Evidence of this assertion stems from investigations on aircraft noise where there has been found the existence of some correlation between the judgment of annoyance caused by aircraft noise and the fear of aircraft accidents (Leonard & Borsky 1973; Miedema & Vos 1999). In relation to this, noise annoyance may be given an attitudinal dimension as the rating of annoyance severity often depends on the acquired verbal information about the source of noise (Jonsson & Sorensen 1970). This relation noise-subject may be extended through considering the dependence of the subject to the source of noise. Hence, subjects who for instance depend economically on the source of noise tend to feel less annoyed by it than those who do not.

Traffic noise is a subject of continuous and increasing concern to people causing annoyance and associated sleep disturbances representing the direct and most relevant factors affecting health.

Psychoacoustics in traffic noise

Psychoacoustics covers one important field of the different dimensions involved in the environmental noise evaluation process. It describes sound perception mechanisms in terms of several parameters, such as loudness, sharpness, roughness and fluctuation strength as well as further hearing-related parameters. It should be noted that psychoacoustics research is a natural progression from the research that led to the equal loudness contours, and has resulted in continuous improvements in models that predict people's perception of sounds. There are now very accurate models that can be used to predict how people for example perceive the loudness of a sound through time (Zwicker & Fastl 1999; Moore & Glasberg 1996). These models have been shown to produce levels highly correlated to people's perception of loudness of sounds in a variety of applications and yet they are getting more and more relevant when evaluating environmental noise or when trying to explain noise-annoyance dose-response relationships.

Cardiovascular reactions

The heart is a central organ that needs to respond quickly to external influences in order to enable fight or flight reactions. Mean heart rate, mean systolic and diastolic blood pressure as well as heart rate variability in sleeping subjects are therefore criteria for cardiovascular involvement. An indication of noise events is the prompt increase of the heart rate and change in systolic blood pressure. Carter et al. (1994) were able to show the immediate rise in heart rate following a noise event under laboratory conditions. Intermittent or periodic noises during sleep induce a biphasic heart reaction with a transient constriction of the peripheral blood vessels as well as clear changes in the electrocardiography (ECG). The biphasic response of the heart first shows a rise in heart rate followed by a decompensation reaction with a marked drop in heart rate. The vasoconstriction is ascribed to the peripheral stimulation of the sympathetic nerve triggered by auditory reflex.

Griefahn et al. (2008) found a connection between the autonomic arousals during sleep and traffic noise in their study. The response of the heart rate to traffic noise during sleep was analyzed. The extensive study took place in a laboratory under standardized conditions.

These studied cardiac effects have been solely based on laboratory data. Large epidemiologic studies that examine the cardiac risk are solely based on questioning but are however, essential for scaling the burden and identifying the meaningful limits for preventive actions against noise emissions. It is obvious that the natural surroundings and habits describe a risk better than the unfamiliar surroundings of a sleeping laboratory. Presently, the Night Noise Guidelines for Europe of the WHO (WHO 2009) demanding for a NOAEL (no observed adverse effect level) of NOAELAmax ≥ 42 dB. The heart rate reacts very sensitive to external stimuli as it is regulated by the autonomic nervous system. WHO recommends in the Night Noise Guidelines for Europe that field studies must be carried out, to better describe the influence of traffic noise regarding its potential in causing chronic disorders e.g. sleep disturbances or cardiovascular diseases.

A suitable tool to monitor changes in the depth of sleep is an actimeter. This is a simple method that can be used on several subjects simultaneously. The results obtained are in good comparison of those obtained using the PSG allowing the assessment of changes in depth of sleep at home.

METHODOLOGY

The two main goals of the present concept are to investigate the influence of road and rail traffic noise on sleep of individuals and additionally to explore the relationship of subjective perception of test subjects with objective measured psychoacoustic and physiological parameters. The crucial point of the project is that all measurements will be done in the free field.

Study design, measurement area and choice of test subjects

In the first step test subjects will be selected from a database consisting of test subjects having participated in our previous studies (510 persons were tested in their general health, well-being and connectivity to traffic noise) (Cik et al. 2008, 2009; Cik & Fallast 2010; Gallasch et al. 2008; Raggam et al. 2007; Wagner et al. 2010). For this study about 80 representative test subjects are intended to be investigated.

Three different areas for measurements are provided:

- Areas dominated by road traffic noise
- Areas dominated by rail traffic noise
- Areas with a combination of equivalent road and rail traffic noise
- Quiet areas with test subjects as a comparison group.

All measurements will be done at home of the test subjects and they will be performed for 5 days (4 nights) per test subject each. For the study 3 relevant time periods are intended:

- Evening: pre-sleep phase
- Night: sleep phase
- Morning: post-sleep phase.

Free field study

For the field study different relevant parameters will be investigated and analysed. These parameters will be described in the following sub-chapters:

Subjective data acquisition including traffic noise annoyance-rating

Collection of socio-demographic data will be done by means of a basic questionnaire at the beginning of the investigation including most important factors for test subjects in connection with environmental influences, especially traffic noise: Sex, Age, Education, Housing conditions regarding traffic noise exposure and further residential surroundings.

Electronic questionnaire:

In the "evening" and "morning" measurement periods questioning of the current traffic noise annoyance on basis of the Personal Noise Ranking Scale (PNRS) (Raggam et al. 2007; Cik et al. 2008) and with the so called „experience sampling method" (time near seizing of experiences, feelings and behavior) (Larson & Csikszentmihalyi 1983; Hektner et al., 2006) will be developed and done. The PNRS was assigned as an 11-graded interval scale, ranges were defined from "less annoying" to "very annoying" and it is based on the ICBEN-scaling (ISO 15666, 2003). In individual investigation areas the test subjects evaluate their hourly annoyance by rail and/or road traffic noise and also respond the questions of the experience sampling method with help of portable data recording equipment (PDA) in the measurement periods on the days of investigation. In addition to electronic questioning a morning and an evening questionnaire will be designed:

- Morning questionnaire including data of the past night: sleep times, sleep quality and night disturbances
- Evening questionnaire including data of residence times at home, noise disturbance by day and work and acceptance of the measurement instruments.

Objective acoustical measurement

Goal of the acoustical measurements is to achieve a time-synchronicity between result of the electronic questionnaire (traffic noise annoyance-rating, experiences, feelings and behavior) with PDA and acoustical parameters including sound pressure level and psychoacoustics reflecting the total quantity of the test subject's acoustic load.

Relevant factors for the acoustical measurement:

- Measurements (recordings) of current existing sound emissions to get a realistic illustration of the traffic noise exposure of each test subject in the investigated area

- Selection of measuring points in the natural residential surroundings of the test subjects which will be an individual adjustment at the investigated site (max. 5 measuring points):
    - Outside
    - Inside

- For audio-recording of traffic and environmental sounds two different technologies will be applied:
    - Binaural dummy head recordings
    - Monaural sound pressure level meter recordings

  The recordings will be done during all three time periods and statistically correlated with the collected subjective and physiological data. Especially current high sound pressure level can have a strong influence on the traffic noise annoyance-rating and these data is only with difficulty verifiable.

- Analysis of all sound recording data will be done by post-processing:
    - Monaural recordings: Calculation of all norm-parameters in combination with the sound pressure level (ÖNORM S 5004: 2008 12 01)
    - Binaural recordings: Calculation of all relevant psychoacoustic parameters (ÖNORM S 5006:1995 10 01; Aures 1985; Terhardt et al. 1982; Zwicker & Fastl 1999) and of all norm-parameters (ÖNORM S 5004:2008 12 01) in combination with the sound pressure level.
    - During the project research will also focus on possible new relevant psychoacoustic parameters.

- Data collection of traffic volume in the investigated time period as comparison

- Collected data will be used to establish environmental noise maps and will be compared to those already existing, especially to those reported in international studies.

Measuring physiological parameters

Heart rate has always been measured using an ECG in prior laboratory studies. This is certainly the gold standard, as the leads allow for an exact beat to beat analysis and therefore also the variability in heart rate can be investigated (Basner et al. 2009). Field studies differ significantly where the study subjects sleep in familiar surroundings in their own house not allowing the use of ECGs. In addition, being able to reliable discriminate significant relevant variables, epidemiological studies require a much larger number of study subjects.

Polar® watches were developed for professional sports and multi-athletes in order to measure their achievement potential and to increase it through heart rate controlled training. For this study, heart rate measurements are necessary which are as precise as ECGs. The measurement and interpretation of heart rate variability (HRV) allows conclusions concerning the adaptability of the heart to internal and external stimuli. The new generation of Polar® watches allows for a beat to beat measurement, and the sensitivity is high enough to permit its use in epidemiological studies.

Body movements will be registered by using a wrist-actigraph, specifically type MicroMini-Motionlogger® Actigraph from Ambulatory Monitoring Inc. The actigraph is based on an acceleration sensor that translates movements to a numeric presentation that is stored in a memory.

Sleep disturbances, defined both as awakenings or changes in depth of sleep, are frequently associated with traffic noise and are an important criterion in defining limits for noise pollution. Polysomnography is the gold standard for detecting of sleep disturbances, by using the EEG (Basner et al. 2009). The above-mentioned method is not suitable for on-site epidemiological studies. The setup and handling of the instruments is too complicated for on-site use, so that a large number of subjects cannot be studied with regard to the different stressors in the environment.

The term "Actigraphy" refers to methods using computerized wristwatch-size devices (generally placed on the wrist, but also on the ankle or trunk) to record the movement it undergoes. Collected data are displayed on a computer and analyzed for change in rhythm parameters that in turn provide an estimate on wake-sleep parameters such as total sleep time, percent of time spent asleep, total wake time, percent of time spent awake, number of awakenings and number of movements.

Actigraphy provides a useful, cost-effective, non-invasive and portable method for assessing specific sleep disorders. The present review is an amalgam of current knowledge with proposed clinical application and for research of actigraphy (Tahmasian et al. 2010).

The physiological measurements will be done during the night period for each test subject in the investigated area.

Statistical analysis

Data of statistical analyses from former laboratory studies realized at Graz University of Technology show significant results and serve as basis for the project in which extended analyses will be done (Cik et al. 2008, 2009; Cik & Fallast 2010; Gallasch et al. 2008; Raggam et al. 2007; Wagner et al. 2010).

Following advanced statistical analysis will be performed:

- Descriptive analysis of the subjective, physiological and objective data
- Correlation of the results obtained from subjective and physiological data with results obtained by objective acoustical measurements and calculations
- Regression and multiple regression analysis between

- subjective data and objective acoustical measurements
- subjective data and physiological measurements
- and objective acoustical measurements and physiological data

- Comparisons of field study results with results obtained in the laboratory studies.

CONCLUSION

The direct effects of sound energy on human hearing are well established and accepted but previous research about the effects of noise exposure on medical parameters has been carried out mainly under laboratory conditions. Such test arrangements are not representative of the real impacts on humans, especially at night during sleep phases.

The two main objectives of this designed project are to investigate the influence of road and rail traffic noise on human sleep patterns and additionally to explore the relationship of subjective perception of test subjects with objective measured psychoacoustic and physiological parameters. The crucial point of the project is that all measurements will be done in the free field with real-life situations. The goal of acoustical measurements is to achieve a time-synchronicity between the results of the electronic questionnaire (traffic noise annoyance-rating, experiences, feelings and behavior) and acoustical parameters including sound pressure level and psychoacoustics reflecting the total quantity and quality of the test subject's acoustic exposure.

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