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

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Summary
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 presented project "INTRANOISE" 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 120 test subjects with objective measured psychoacoustic and physiological parameters. The crucial point of the designed project is that all measurements will be done in the free field with real-life situations. Based on past experiences of the Graz University of Technology with acoustical measurement techniques in free field areas a standardized method for objective acoustical measurements in residential environments of test subjects was developed. The goal of acoustical measurements is to achieve a time-synchronicity between the results of a questionnaire (traffic noise annoyance-rating, experiences, feelings and behaviour) and acoustical parameters including sound pressure level and psychoacoustics reflecting the total quantity and quality of the test subject's acoustic exposure. The study concept and first results of a selected sample will be shown.

1. Introduction

The most important effects of noise extracted from the literature can be summarized as followed [8,13]:

- 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

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Exposure to noise in the environment from transport sources is an increasingly prominent feature [2,4]. The direct effect of sound energy on human hearing is well established and accepted [1,16]. 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 [30]. 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 [31].
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) [3,10,24]. 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 [25,28,20,21]. 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 [23]. 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 modelled 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 [5].

1.1. 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 [11].
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 [18,19]. 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 [15]. 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.

1.2. 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 [22,32]. 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.

1.3. Cardiovascular reactions

An indication of noise events is the prompt increase of the heart rate and change in systolic blood pressure. Carter et al. [6] 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. Griefahn et al. 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 [10,3].
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 [32] 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.

2. 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.

2.1. Study design, measurement area and choice of test subjects

In the first step test subjects were 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) [7,9,27,29]. For this study 120 representative test subjects will be investigated.
Three different areas for measurements are provided:

- Areas dominated by road traffic noise
- Areas dominated by 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 fixed:

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

2.2. Free field study

For the field study different relevant parameters were investigated and analysed. These parameters will be described in the following sub-chapters and in Figure 1 the process of a measuring week is presented.

2.2.1. Subjective and socio-demographic data and health status

Collection of socio-demographic data and health status is 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, further residential surroundings and health status of each test subject.

2.2.2. Annoyance questionnaire

In the “evening” and “morning” measurement periods questioning of the current traffic noise annoyance on basis of the ICBEN 11-graded interval scale [14] and with the so called „experience sampling method” (time near seizing of experiences, feelings and behaviour) [12,17] is done. In individual investigation areas the test subjects evaluate their half hourly annoyance by rail and/or road traffic noise and also respond the questions of the experience sampling method in the measurement periods on the days of investigation. In addition to annoyance rating a morning and an evening questionnaire was 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

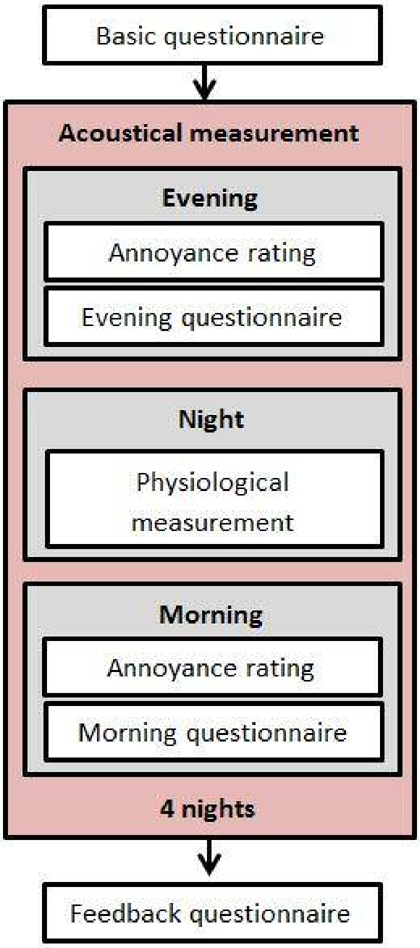

Figure 1: Flow diagram of one measuring week for one test subjekt in the project "Intranoise"

2.2.3. Objective acoustical (psychoacoustic) measurements

Goal of the acoustical measurements is to achieve a time-synchronicity between result of the annoyance questionnaire (traffic noise annoyance-rating, experiences, feelings and behaviour) and acoustical parameters including sound pressure level and psychoacoustics reflecting the total quantity of the test subject's acoustic load. Measurements (recordings) of current existing sound emissions with 2 binaural dummy heads HSU III.2 in combination with a SQuadriga II mobile recording system (HEAD acoustics GmbH) were done to get a realistic illustration of the traffic noise exposure of each test subject in the investigated area. For each test subject one measuring point was in front of the house or apartment (Figure 2) and second one was in the sleeping room (Figure 3). The recordings were done during all three time periods and statistically correlated with the collected subjective and physiological data.

Figure 2: Measuring point – indoor – dummy head 1

Figure 3: Measuring point – outdoor – dummy head 2

Data collection of traffic volume in the investigated time period as comparison was also done.

2.2.4. Measuring physiological parameters

In this project heart rate and also body movements were measured by using a wrist-actigraph, specifically type "wActiSleep-BT Advanced Activity Monitoring Solution with Heart Rate" from ActiGraph. The measurement and interpretation of heart rate variability (HRV) allows conclusions concerning the adaptability of the heart to internal and external stimuli. 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.

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

3. Results and Conclusion

In the first phase 15 test subject were analyzed over 15 weeks on different investigations sides. In general the methodology was understood by test persons and also physiological and acoustical measurements worked well. Also rating of subjective annoyance and infilling of questionnaires was done without problems. Figure 4 and 5 show the A-weighted SP Level indoor and outdoor against rated annoyance in pre- and post-sleep-phase.

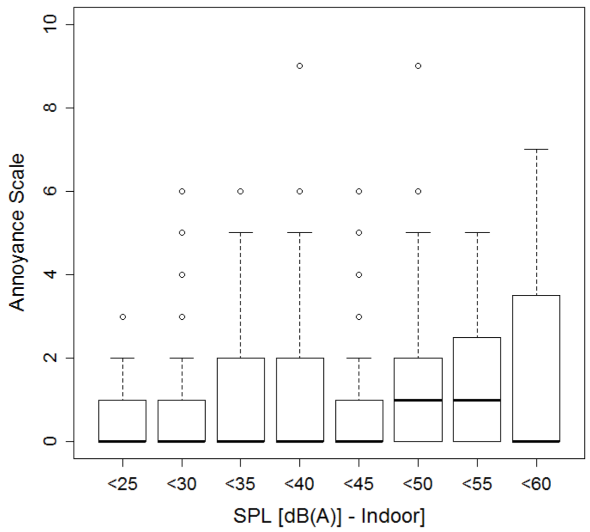

Figure 4: SPL [dB(A)] – Indoor against Annoyance rating (N=520 ratings in pre and post sleep phase)

Boxplots in Figure 4 show complexity of indoor Sound Pressure Levels in correlation with annoyance rating, because of low level measurements.

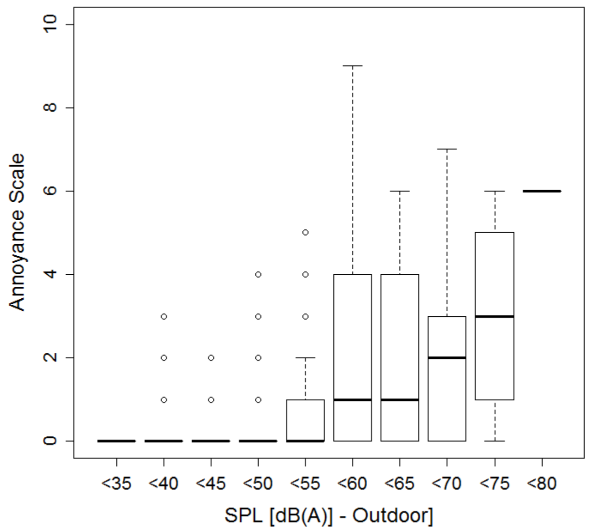

Figure 5: SPL [dB(A)] – Outdoor against Annoyance rating (N=520 ratings in pre and post sleep phase)

Boxplot in Figure 5 show significant increasing of annoyance from Sound Pressure Level between 50 und 55 dB(A) outdoor.

As a conculsion we can say that the methodology work very well and methods for statistical calculation and analysis are fixed. As a next step 105 test subjects will be investigated in the next 2 years to get a significant sample and discussable results.

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