Psychoacoustic indicators of road and rail traffic noise, subjective perception and psychological and physiological parameters

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ABSTRACT

Classic research about the effects of noise exposure on non-auditory health effects has been carried out with established sound indicators like L_{den} or L_{night} – using the A-weighting. The relation between psychoacoustic indicators and objective health parameters is less well investigated also in soundscape studies.

The two main objectives of the project “INTRANOISE” are to study the effect of road and rail traffic sound on human sleep patterns and explore the relationship between the subjective perception of 120 test persons and objectively measured psychoacoustic and physiological parameters. The crucial point is, that all measurements will be done in the free field in real-life situations.

A standardized method for objective acoustic measurements in residential environments of test persons was developed based on past experiences. The total quantity and quality of a test person’s acoustic exposure is assessed by a time-synchronized comparison between the results of a traffic-noise-annoyance-questionnaire and psychoacoustic parameters.

The study concept and first results of a selected sample of 45 participants will be shown. Preliminary results indicate that outdoor traffic noise is a significant factor for subjective noise ratings of people in their living area. When it comes to physiological reactions during sleep, indoor noise seems to be the dominant factor.

Keywords: Naturalistic traffic noise, annoyance, physiological parameters

I-INCE Classification of Subjects Number(s): 52.3, 52.4

1. INTRODUCTION

The most important effects of noise extracted from 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.

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

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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, in which 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 in general only be predicted with difficulty (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 in general is used to mean all those negative feelings like disturbance dissatisfaction, displeasure, irritation and nuisance, but according to Guski the list may even be elongated 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 the existence of some correlation between the judgment of annoyance caused by aircraft noise and the fear of aircraft accidents has been found (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 by 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 $NOAEL_{Amax} \geq 42$ 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.
Two different areas for measurements are provided:

- Areas dominated by road traffic noise
- Areas dominated by rail traffic noise

All measurements will be done at the home of the test subjects and they will be performed for 5 days (4 nights) per each test subject. 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 analyzed. 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 a continuous questioning of the current traffic noise annoyance on basis of the ICBEN 11-graded interval scale (14) using 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 to the questions of the experience sampling method in the measurement periods on the days of investigation. In addition to the annoyance rating a morning and an evening questionnaire was designed:

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

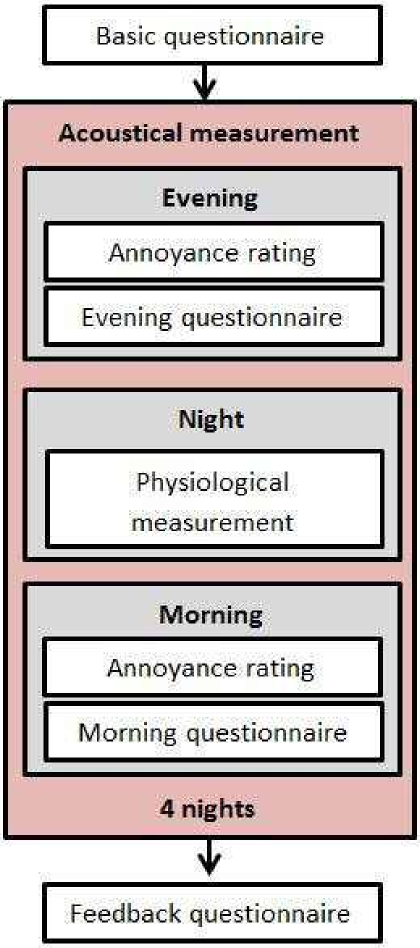

Figure 1 - Flow diagram of one measuring week for one test subject in the project "INTRANOISE"

2.2.3. Objective acoustic (psychoacoustic) measurements

Goal of the acoustic measurements is to achieve a time-synchronicity between the result of the annoyance questionnaire (traffic noise annoyance-rating, experiences, feelings and behavior) and acoustic 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 were done in combination with a SQuadriga II mobile recording system (HEAD acoustics GmbH) 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 outside in front of the house or apartment (Figure 2) and the second one was inside the house in the sleeping room (Figure 3). Measurements were done during all three time periods and afterwards statistically correlated with the collected subjective and physiological data. The recordings were analyzed using the software package “ArtemiS SUITE V7” by HEAD acoustics GmbH by means of the latest acoustic und psychoacoustic standards.

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 was also done for comparison.

2.2.4. Measuring physiological parameters

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 4 night periods for each test subject in the investigated area.

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, LLC. 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 equipped with an acceleration sensor that translates arm movements into a numeric presentation that is stored in memory. Afterwards the acquired raw data was analyzed using the proprietary software package “ActiLife V6” by ActiGraph, LLC. For the in-depth analysis two algorithms for different age groups are used. At the moment two sleep scoring algorithms are widely accepted for analyzing sleep data obtained using actigraphy:

- Sadeh algorithm: Is considered for younger test subjects, because it was developed using subjects of an age span ranging from 10 to 25 years (33).

- Cole-Kripke algorithm: Is considered for adult test subjects, because it was developed using subjects of an age span ranging from 35 to 65 years (34).

Therefore, two different age groups are distinguished when analyzing the obtained sleep data. Sadeh's algorithm is applied to sleep data from test subjects who were 18 to 25 years old and Cole-Kripke's algorithm is used for sleep data from test subjects who were 26 years and up at the time of data acquisition.

3. RESULTS

During the first phase 45 test subject were analyzed over 45 measuring weeks on different investigation sites. In general, the methodology was understood well by test subjects and also the technical part consisting of physiological and acoustic measurements worked well. The rating of subjective annoyance and completing of questionnaires was done without problems.

3.1 Results of acoustic measurements

Figure 4 and 5 show the 30 minute A-weighted Sound Pressure Level (SPL) indoor and outdoor against rated annoyance in pre- and post-sleep-phase based on the acquired raw data, which hasn't yet been statistically modified.

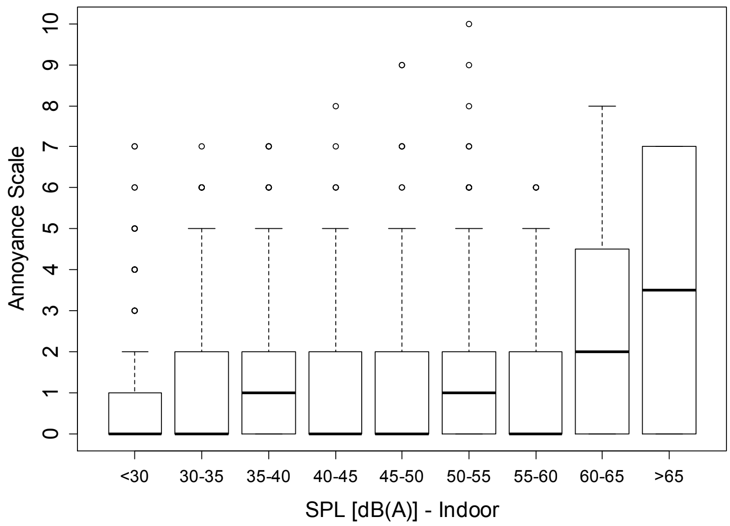

Figure 4 - Sound Pressure Level (SPL) [dB(A)] – Indoor against Annoyance rating (n=1849 ratings in pre and post sleep phase)

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

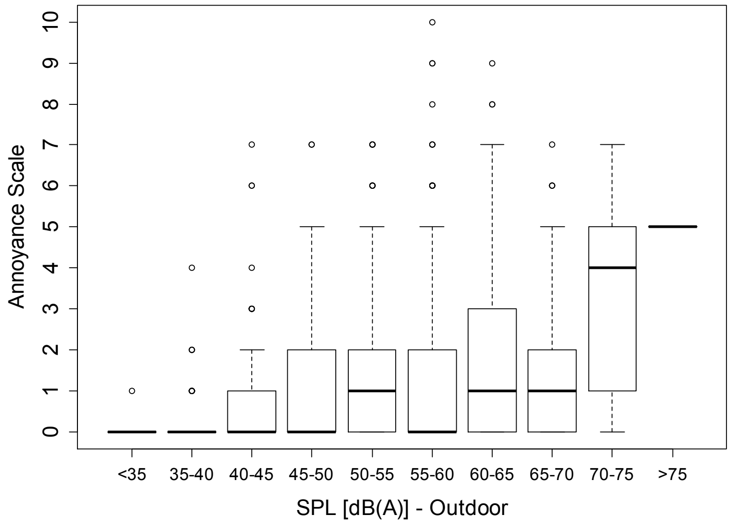

Figure 5 - Sound Pressure Level (SPL) [dB(A)] – Outdoor against Annoyance rating (n=1849 ratings in pre and post sleep phase)

The boxplot in Figure 5 show a significant increase of annoyance from Sound Pressure Level between 47.5 and 52.5 dB(A) outdoor.
It should be highlighted, that the test subjects so far seem to be very careful with their annoyance rating and are able to concentrate as well as focus on their subjective annoyance resulting from traffic noise, as figures 4 and 5 illustrate.

3.2 Results of sleep measurements

Figure 6 shows a considerable decrease in sleep efficiency (85% efficiency and more are mainly considered as "good sleep"), if the indoor SPL increases to 45 dB(A) and up.

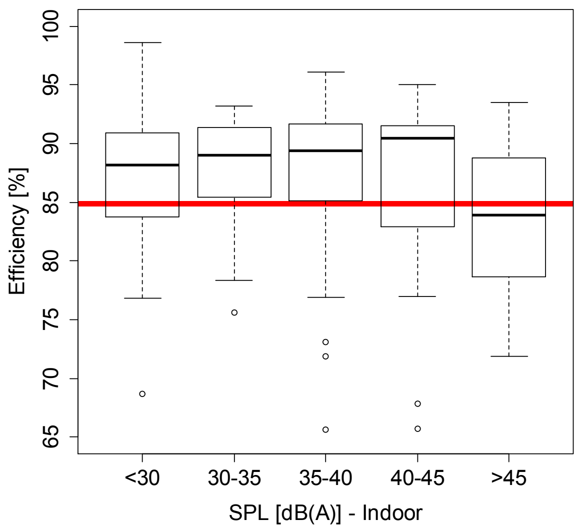

Figure 6 - Sound Pressure Level (SPL) [dB(A)] – Indoor against sleep efficiency (n=176 nights of 44 test subjects)

This development is also observable in terms of the indicator "Wake after sleep onset" (WASO), where test subjects who are exposed to more the 45 dB(A) are experiencing a noticeable higher wake after sleep onset, as Figure 7 illustrates.

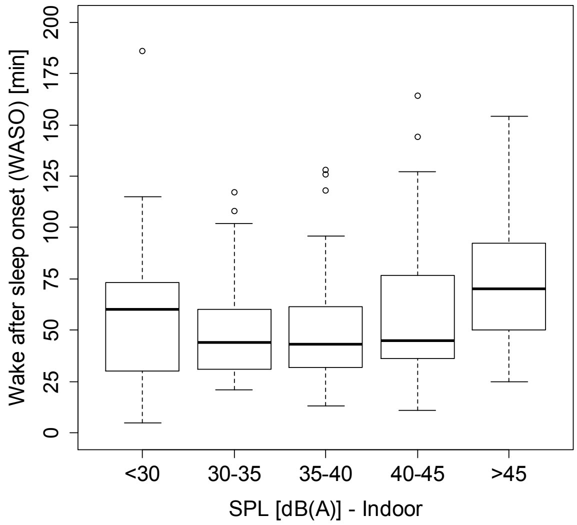

Figure 7 - Sound Pressure Level (SPL) [dB(A)] – Indoor against WASO (n=176 nights of 44 test subjects)

This increase in wake time after sleep onset seems to involve a slight increase in the average awakening length, as shown in Figure 8.

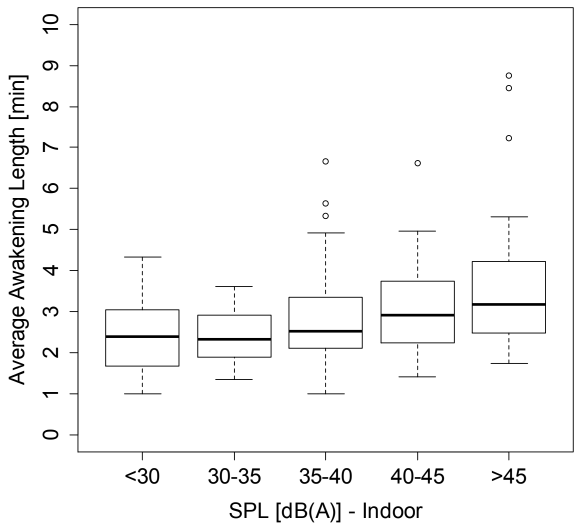

Figure 8 - Sound Pressure Level (SPL) [dB(A)] – Indoor against Average Awakening Length (n=176 nights of 44 test subjects)

4. CONCLUSION and OUTLOOK

When considering the preliminary results of the sleep measurements of 44 test subjects so far, it seems that the $NOAEL_{Amax} \geq 42$ dB demanded by the WHO's Night Noise Guidelines for Europe is to a certain extent appropriate. Nevertheless, this assumption has to be further investigated during the next phase of the project "INTRANOISE".

In terms of acoustic and psychoacoustic analysis the next step will be the investigation and calculation of psychoacoustic parameters and statistical correlation with the results of the annoyance rating. A subsequent step is to categorize activities before the annoyance ratings took place and process the acquired raw data accordingly, in order to get a more detailed impression of the role of psychoacoustics in terms of annoyance because of traffic noise.

As a conclusion we can say that the methodology works very well and methods for statistical calculation and analysis are fixed. In the next step 75 more test subjects will be investigated in the next year to get a more significant sample and results, which should be the foundation for further research.

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