Psychoacoustic Evaluation of Traffic Noise

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Introduction

The evaluation of noise is mostly done on the basis of the L_{Aeq}. In the European research project "Quiet City Transport" [1] the quantitative characterization of annoyance (beyond the L_{Aeq}) caused by single pass-by noise [2] and complete traffic noise using psychoacoustic descriptors for a better consideration of human perception were major objectives. An improved quantitative characterization of noise and respective annoyance would allow for the identification of most promising noise mitigation measures and actions leading to a sustainable reduction of noise annoyance.

To achieve the goal of the mentioned research topic, diverse measurements were carried out, listening tests were performed and the annoyance levels of a wide variety of road traffic scenarios subjectively were evaluated. On the one hand, the acoustical stimuli were gained by means of artificial head recordings and on the other hand several stimuli were synthesized using different noise simulation techniques. The acoustical data as well as the evaluation data collected from the listening tests were analyzed by means of a principal component analysis (PCA). The most important factors were correlated with several acoustical and psychoacoustical parameters. It was observed, that the A-weighted SPL predicts the resulting annoyance for few situations adequately. However, it was also observed that in some cases the noise annoyance estimated on the basis of the L_{Aeq} was over- or underrated. A psychoacoustic metric was developed combining perception-relevant acoustical parameters, which predict the subjective annoyance of people exposed to traffic noise more accurate.

Synthetic Creation of Specific Traffic Scenarios

Some noise stimuli were created by using syntheses methods to explore certain effects and influences of traffic parameters on noise perception and evaluation in detail. On the one hand, the noise examples were created on the basis of a tool, which was developed in the research project "Sound Quality of Vehicle Exterior Noise" (SVEN) [3]. Moreover, since this synthesis tool was partly limited, a new synthesis technology, called "Traffic Noise Synthesizer" was developed and applied within Quiet City. This syntheses technology process traffic simulation data and generates time signals and was an important outcome of the Quiet City project. A detailed explanation of this synthesis tool can be found in [4]. The advantage of using synthesized scenarios is that scenarios of similar type can be created, where only one or few parameters are systematically changed. That way it is possible to measure the effect of certain (traffic) parameters upon annoyance (see Table 1).

Varied parameter	Conditions
Speed	50km/h; 30km/h; mixed
Traffic density (veh. per time interval)	3; 5; 6; 7; 8; 9; 11; 13; 14; 18; 23
"Distribution" of veh.	Regular, irregular
Driving direction	Right; right and left
Stimulus duration	30s; 35s; 40s; 45s

Table 1: Parameters that were specifically changed

The Measurement of Traffic Noise

Besides the systematic creation of traffic noise stimuli it was necessary to consider real traffic noises, where lots of "unstable", "uncontrollable" noise events occur. To cover a wide spectrum of traffic noises ranging from low to heavy traffic volume several traffic situations were recorded. Figure 1 shows examples of selected locations.

Figure 1: Measurement "Roundabout" with artificial head (left), Measurement "Single Road" with artificial head

The recordings were made on different days without rain and wet road surfaces and on different times of the day at different locations and measurement spots to collect a variety of traffic noises. The duration of the recordings ranged from 20 to 45 minutes per location.

Listening Tests

The realization of listening tests is essential for environmental noise studies to get a deeper understanding of human reactions to noise. The listening tests were carried out in a listening studio, which is optimized for the execution of laboratory listening tests. [5] It is already known, that results of laboratory listening tests differ from results of "listening tests" carried out in field-related contexts. In the presented study, the laboratory setting was chosen to control potential confounding variables. These „confounding variables" are not insignificant, since these variables influence the noise assessment in reality. However, the study of "confounding variables" was not the focus of the study.

The test subjects were randomly chosen. Furthermore, they had to pass an audiometry check. Subjects with a hearing loss of 20dB or more were excluded from the listening test. Altogether, 49 test subjects took part in the different listening tests. Several subjects took part several times in the different listening test series.

The instruction with respect to the evaluation task was as follows: “Please, imagine you are sitting in a bus stop and you are experiencing traffic noise. How annoying is the traffic noise?” The annoyance was evaluated on a scale from 1 to 9 for every sound. “1” stands for “not annoying” and “9” for “very annoying”. The hypothetical situation used in the instruction - an open bus stop with vehicles passing by - was applied to form a common (hypothetical) context for all subjects.

A complete listening test consisted of four to five sound sets. The first one usually served as a training sequence to on the one hand familiarize the test subjects with the evaluation task and on the other hand to present different stimuli to show the potential range of traffic noises. Five to seven sounds were presented and judged per sound set. The duration of the sound stimuli was between 30 seconds and 1 minute.

The order of the noise stimuli was randomly changed to reduce sequence effects. Furthermore, to check the consistency of the judgments and the potential influence of sequence effects, few stimuli were presented twice. After the training sequence the test subjects had the possibility to ask questions, which occurred during their first evaluations.

After the listening test a short standard questionnaire was filled out by the test subjects and a guided interview followed, where the test subjects had the opportunity to express their feelings and thoughts with regard to the test, test procedures and their evaluation strategies in detail.

Evaluation Item “Annoyance”

The assessment of annoyance in a laboratory setting is not unproblematic. It is a difference to directly evaluate the annoyance of a sound stimulus, when the sound is within your main focus of attention in contrast to daily life long-term noise exposure and felt annoyance respectively. In general, noise is annoying if the noise distracts from activities or focuses. In studies, the annoyance item is often questioned, where the subjects should reflect the noise impact over a long time period, such as months or years. The subject memorizes the noise exposure and cumulates its memorized emotional states to a numerical or verbal value. However, for the development of a metric, which directly link acoustical parameters with subjective reactions to noise, a database is required with evaluations closely linked to “known” stimuli. In contrast to it, the memory of an averaged annoyance over a long period of noise is often very ”inaccurate” and biased by memory effects since the noise assessment is also influenced by several non-acoustic parameters. The direct, immediate noise annoyance evaluation was verified in some pre-tests, where the plausibility of the given context and the evaluation item annoyance were discussed in detail with the test subjects. After all, there was no negative feedback on the term “annoyance” or on the constructed context. This indicates that the test subjects are able to relate a meaning to the term ‘annoyance’ regarding the instructed setting.

Data Analysis

For the objective description of noise several acoustic parameters were analyzed which could reflect major perception-related sound properties. The acoustical parameters were calculated and then considered in subsequent statistical analyses. Furthermore, a principal component analysis (PCA) was applied to the evaluations for each listening test set. It enables the determination of common factors that underlie the single evaluations.

To determine the meaning of the detected factors the respective factor values can be correlated with other values that represent certain characteristics (e.g. sound analyses) of the respective sounds. (Figures 2 and 3) A high correlation between the factors values and a specific property indicates that the factor is a good representation for that characteristic. This is an opportunity to translate the subjective perception into physical sound analyses.

By means of cluster analyses according to Ward and average linkage method few test subjects (<5%) were identified which must be excluded from further statistical analyses.

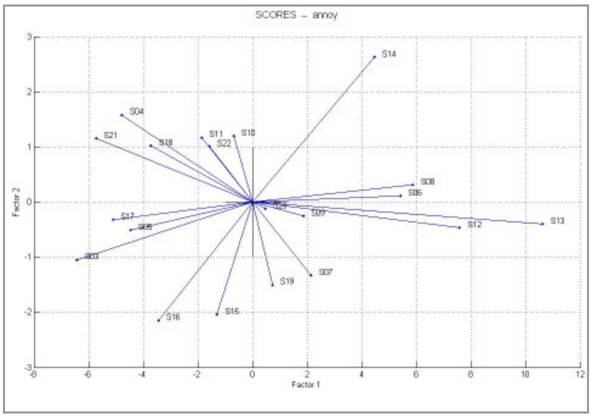

Figure 2: Distribution diagram of one listening test series with four relevant factors. Here, the distributions of several traffic sounds related to factor 1 and 2 is shown

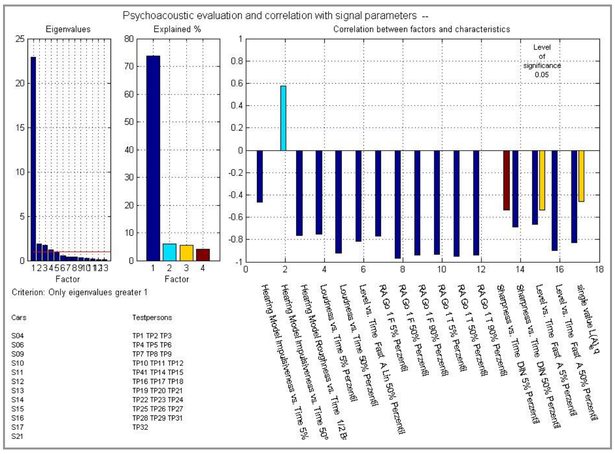

Figure 3: Correlation between factors and acoustical parameters of one sound subset

Interviews

The interview data gives insight into the evaluation process of the test subjects and helps to identify relevant acoustical parameters. The answers to the different questions of the interview guide gave information about the (assumed) causes for their judgments and the quality of their ratings. For example, several test subjects have remarked that in particular loud single noise events affect adversely their judgments. In these cases, the time-averaged sound pressure level is presumably not of high significance, but rather 5 or 10 percentile sound pressure level values appear to be more important, as for example also proposed for loudness in DIN 45631/A1. In this standard it is defined that the N_5 Loudness corresponds to the perceived overall loudness. These comments and remarks were additionally used with respect to the selection of the acoustical analyses and the interpretation of the results.

Related to	Frequently used verbal descriptors
Temporal aspects	Constant or time-varying, temporal patterns, "level of regularity", "quiet periods"
Sound properties	Loudness, spectral content, braking noise, frequency, diesel knocking, impulsive events, booming, droning, sharpness, low frequency content
sources in general	Heavy vehicle, motor bike, bus, engine noise, rolling noise
traffic in general	Speed, traffic lights, traffic volume, numbers of cars, traffic composition

Table 2: Selection of verbal items used in the interviews

The test subjects used a broad variety of verbal items to describe the reasons for their annoyance judgments. Some phrases and descriptions are frequently found in the interview data (table 2). These comments gave valuable information about the sound properties that should be considered during the development of a quantitative description of the annoyance of traffic noise.

The interview analysis shows for example that "ear-catching", prominent noise sources (e.g. occurrence of heavy vehicles and/or motorbikes) provoke strong emotional reactions to noise, leading to increased annoyance. Here, a penalty of few dB appears meaningful, because the increased sound pressure level does not completely cover this phenomenon. The cause for the increased annoyance is resulting from several psychoacoustic aspects in the sound signals, such as tonal components, impulsive noise, short-time patterns.

Metric Development

After the identification of relevant acoustical parameters using the comments given in the interviews and the PCA results, some parameters were identified as meaningful. On the basis of multiple regression analyses a metric was developed which predicts values close to the subjective ratings. Several combinations were tested using the existing database and moreover, these combinations were applied to new sounds and their subjective evaluations. Thus, the metric was successively refined. By means of the multiple regression analyses leading to a refinement of the weighting factors of the relevant acoustical parameters, namely Relative Approach (RA_{50}(FT)) [6], Loudness (N5) [7], Sharpness, Hearing Model Roughness [8], Hearing Model Impulsiveness, the final Evaluation Index (EI) predicting the subjective responses to complex traffic noises was developed (1).

$$EI_{traffic} \sim RA_{50}\,(FT) + N_5 + S + HMR + HMI \qquad (1)$$

However, the area of validity is limited, since the tests were carried out in laboratory and only noise considering road traffic was presented. Thus, the developed metric is only valid concerning annoyance caused by road traffic noise.

Some Results

The standardized questionnaire filled out after the listening test and interview contained few questions for example about "sensitivity to noise" and "periodicity of car driving". However, no significant influence of these aspects on the evaluation behavior of the test subjects was found.

The L_{Aeq} works for several sounds regarding the prediction of noise annoyance. However, in some cases this predictor failed and overestimated or underestimated the annoyance considerably. Over 30% of the predicted values based on the A-weighed equivalent sound pressure level lie outside of a defined ± 0.5 category hose compared to subjective ratings (Figure 4).

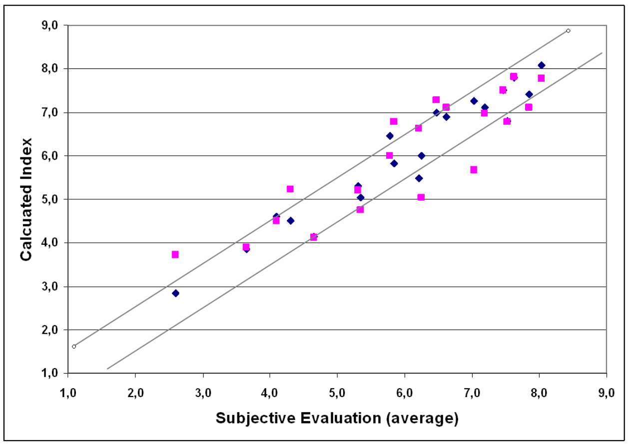

Figure 4: Correlation between ratings and acoustical parameters of one listening test series; blue dots represent calculated EI-values over the averaged subjective evaluations, pink dots represent calculated L_{Aeq}-values over the averaged subjective evaluations (L_{Aeq}-values are scaled to 1 to 9 scale)

The analysis of these failed annoyance predictions can give valuable information with respect to required bonus and malus values. Here, psychoacoustics can help to identify the more or less annoying sound properties, which are not covered by the sound pressure level. Partially, certain effects could be quantified with dB(A)-penalties, as for example required for traffic light situations, where apparently noise events, caused by braking and accelerating, lead to an increase of annoyance. With respect to this traffic situation it seems that also the idling noise of standing vehicles causes strong reactions by the test subjects although the SPLs were relatively low. Here, the introduction and increase of alternative drives and start-stop-engine concepts can lead to a significant reduction of this effect in the future.

In the following some examples are shown, where the L_{Aeq} does not represent the annoyance potential of traffic noises. Figure 5 displays traffic noise stimuli with almost identical traffic volume per given time interval. There it could be clearly observed that the judgments do not correlate with the L_{Aeq}-values (pink) very well. In these cases, the C-weighted L_{Ceq} corresponds to the collected subjective evaluations better (green). Finally, on the basis of the Relative Approach analysis a good prediction of noise annoyance is possible (blue).

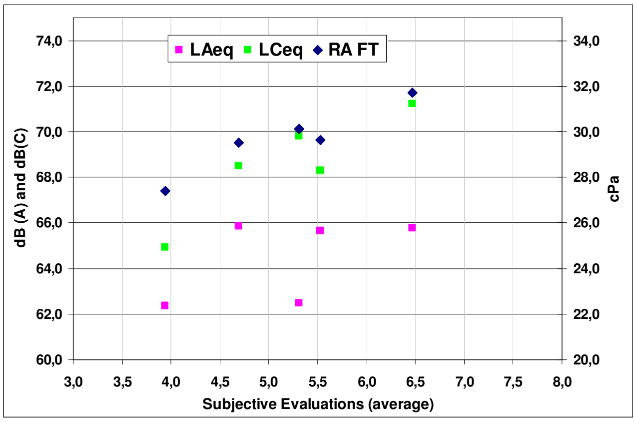

Figure 5: Five traffic noises with same traffic volume: L_{Aeq} and L_{Ceq} (related to left y-axis) and Relative Approach (related to right y-axis) vs. subjective evaluations (average)

Figure 6 illustrates the application of the Relative Approach for analyzing environmental noises. This example shows two traffic noise stimuli, which possess comparable SPLs but achieved different annoyance ratings. The first stimulus (left: 62.6dB(A)/right: 65.0dB(A)) recorded close to a traffic light obtained an averaged rating of 4.31 on a 9-point scale, whereas the second traffic noise (left: 64.5dB(A)/right: 66.3dB(A)) was rated with 7.03. This great difference cannot be explained on the basis of the lower SPL at the left ear, but rather with the annoying patterns within stimulus two discovered by using the Relative Approach analysis.

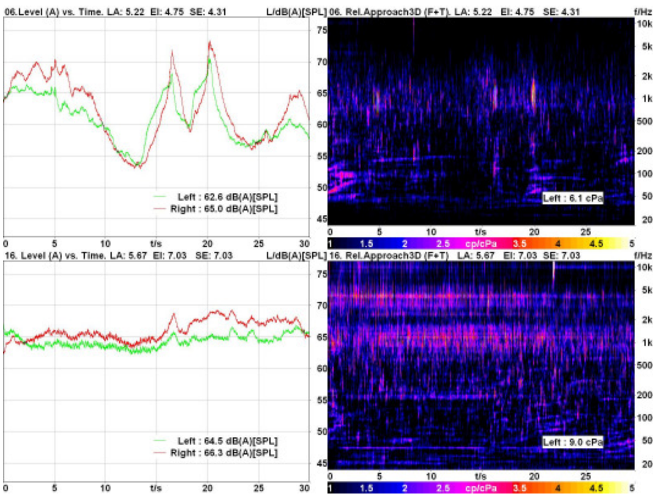

Figure 6: Comparison of two traffic noises with comparable L_{Aeq} but different subjective ratings (4.31 to 7.03); Level (A) vs. time (left) and Relative Approach 3D (TF) vs. time (right)

Summary

The acoustical descriptor L_{Aeq} cannot grasp all relevant noise features, which can lead to an increased annoyance. In the executed laboratory study several cases of overestimation and underestimation of noise annoyance by the L_{Aeq} due to specific noise properties were found.

Certain noise properties, such as impulsive noise events, perceivable spectral and time patterns, high sharpness or loud single noise events, or strong low frequency contents were identified as meaningful for annoyance and are not sufficiently covered by the L_{Aeq}. On the basis of few perception-related parameters some of these phenomena can be identified and taken into account when estimating the annoyance caused by environmental noise. Possibly, these phenomena can be partially covered by the use of penalties to the measured/calculated L_{Aeq}.

It appears to be recommended that in areas where the noise exposure is slightly below the noise limits regulated by law psychoacoustic parameters and specific noise properties should be considered closely. In these cases, on the basis of the L_{Aeq} it is concluded that the affected people are not exposed to harmful noise. However, as observed in the presented study, certain noise effects can lead to unexpected high annoyance.

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