DIFFERENCES IN TRAFFIC NOISE MEASUREMENTS WITH SLM AND BINAURAL RECORDING HEAD

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Schwarz, Henrik
schwarzingenieure GmbH, consultants in civil engineering
Franckstrasse 38
71665 Vaihingen an der Enz, Germany
Tel: +49(7042) 5653
Fax: +49(7042) 1 3811
E-mail: henrik.schwarz@schwarzingenieure.de

ABSTRACT

This study aims to describe the differences in measurements of road traffic noise made with a standardised microphone and a binaural recording head. In addition to the A-weighted SPL this comparative study also takes account of unweighted SPL and the psychoacoustic variables loudness, sharpness and roughness. The effect of distance and the influence of direction on the difference in the measurements is investigated and described in detail. In light of the results of the study, a proposal is put forward as to how developments in acoustic measurement instrumentation and psychoacoustics might be applied to the field of traffic noise assessment in the future.

INTRODUCTION

Since the mid-1970s, attention has increasingly been drawn to the negative environmental effects of the continuous increase in road traffic in the post-war era. Initially the central concern was the problem of air pollution caused by gas and particulate car exhaust emissions, leading to considerable progress being made in this field. Although the number of vehicles and the total traffic flow in kilometres has undergone continual growth, both pollutant emissions per vehicle and the absolute overall emission level of the vehicle fleet are rapidly decreasing. Thus, as the importance of air pollution caused by vehicles declines, attention begins to turn to a second significant detrimental effect of road traffic: traffic noise emissions. Equally, this field has seen the legal regulations for new vehicles tightened in recent years, yet this development has been counteracted by the growth in the number of vehicles and the increase in traffic flow in congested urban areas. In Germany repeated empirical studies have shown that the percentage of the population that is exposed to excessive levels of traffic noise has remained virtually constant over a period of many years. Developments in measurement instrumentation and the results of research in psychoacoustics over the last 25 years have as yet had no influence on measuring regulations, prognostic models and limit values in the field of road traffic. Whereas sound quality management has been an integral component of motor vehicle development for many years, making use of both recording and reproduction instruments that authentically reflect human sound perception as well as psychoacoustic variables, the assessment of road traffic noise has remained at the level of the purely physical measurement of the mean sound pressure level followed by frequency weighting. This study takes the first step towards achieving the aim of a more authentic assessment of traffic noise. The two main input parameters of the proposed model of road traffic noise annoyance are a measurement technique which more accurately depicts signal processing in the human ear and assessment factors that give a better reflection of the perceived annoyance level. By conducting comparative measurements between levels recorded with a binaural recording head and a standard microphone, the study undertakes to quantify the variation from the legally required single microphone measurement. The measured differences in both the measured levels and the psychoacoustic variables are then statistically analysed in correlation to the varying input parameters “distance to road“ and “alignment of head relative to road”. Inasmuch as plausible and mathematically logical correlations between the varied input parameter and the expected differences arise, regression models are devised and described with their parameters and the respective determination coefficient.

PROBLEMS OF THE STANDARDISED METHOD

Following an extensive analysis of the literature, the criticisms of the standardised measurement parameters and problems involved in measuring and assessing traffic noise can be divided into the following five central aspects:

- the use of the sound pressure level in decibels,
- the use of the A-weighted level,
- use of the energy equivalent continuous sound pressure level,
- measurement with a single microphone and, lastly,
- the neglected use within the field of subjective assessment by a human subject.

The use of the sound pressure level as a measure of the extent of traffic noise pollution is unfortunate in that, although the ear is a sound pressure receptor, it does not directly translate sound pressure into a sensation of annoyance. The correlation between physical stimulus and perceived strength that is assumed in calculating the logarithm in decibels is no longer tenable in the light of recent studies. Frequency weighting using the A-curve has been criticised because it is derived from the 40-phon curve and thus is not suitable for the volume levels of traffic noise, which are often considerably higher. In addition, this approach also results in systematic underestimates of the loudness of low-frequency and high-frequency sound fractions for broadband traffic noise, as it does not take into consideration the parallel signal processing of all frequencies in the ear. Assessing the perceived annoyance of noise events with low background noise and a small number of peaks, and sounds with a constantly high level of background noise is not possible using the mean level L_{eq}. Different time constants in generating means do not allow a satisfactory approximation of perceived loudness. The measurement and recording of noise events with a single omnidirectional microphone does not allow for either direction-dependent or direction-independent elements of the filtering of the signals by the human ear, in which the influence of head geometry and of the outer, middle and inner ear vary. Equally, neglecting subjective assessment by a human subject, which varies due to personality traits such as sex and age, as well as individual characteristics such as experience, education, motivation and mood, also generates large discrepancies between physical measurements and the levels of annoyance of those exposed to noise pollution, as documented in empirical studies.

METHOD AND MEASUREMENTS

Instrumentation

The instrumentation used for the comparative measurements consists primarily of a binaural recording head and a measurement microphone in the form of a standard noise level meter (see picture 1). The signals from both meters are stored synchronously in digital form during measurement for subsequent quantitative analysis. In addition to the standard A-weighted sound pressure level (dB(A)), the unweighted level in decibels (dB(lin)) and the psychoacoustic variables loudness, sharpness and roughness are also examined. Loudness as a measure of the subjective evaluation of volume is calculated according to international standard (DIN 45631 / ISO 532), the standardised unit of loudness is the “sone”. The method is based on a frequency grouping of the sound, and thus, in addition to generating the total loudness from the partial loudnesses, can also describe the masking characteristics of the ear. The sharpness of a sound is produced by the sound’s high-frequency elements. There is a variety of non-standardised calculation methods to determine sharpness in the unit “acum”. In this study Aures’ method is used. The roughness of a noise event refers to envelope oscillation frequencies between 20 Hz and 300 Hz, caused by amplitude or frequency modulation, and is not yet standardised. Zwicker’s (1982) calculation method as used here generates roughness values in the unit “asper”. After the levels and the psychoacoustic variables have been calculated, the results of the measurements are presented, discussed and, where possible, correlations are illustrated in models.

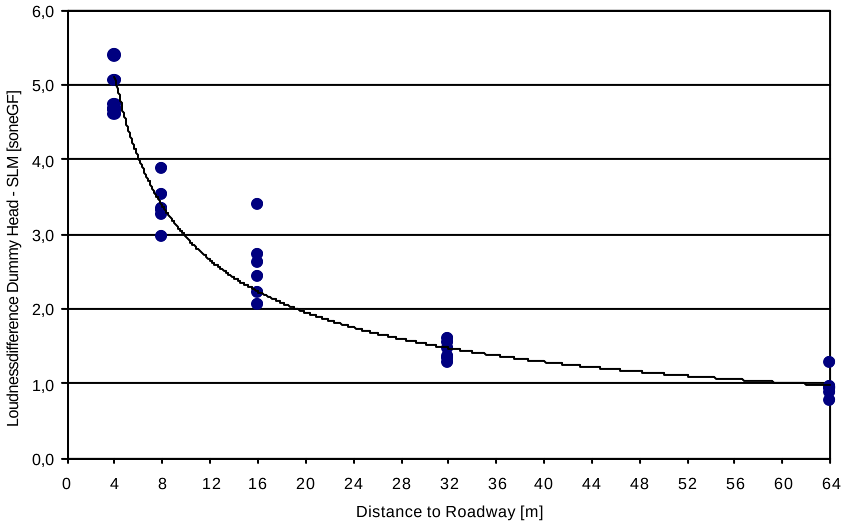
Picture 1: Set-up for Measurement at 2 Metres Distance in built-up Area

Measurements

The central focus of the investigation is the variation of the distance between the microphones and the road as noise source, and also the variation of the alignment of the binaural recording head relative to the road with distance constant. Variations in distance were conducted at three different measurement cross-sections: in a built-up area, by a single-lane federal road outside a built-up area, and by a six-lane motorway. In addition to the acoustic recordings, the traffic flow, the percentage of trucks and the average speed in the direction of travel were determined for each measurement cross-section.

For the variables of sound pressure level (linear and A-weighted), loudness and sharpness, statistically significant differences between the binaural recording head values and the values for the measurement microphone were found. For the calculated roughness values no significant difference could be found. The sound pressure levels and loudness for the binaural recording head are above the comparable measurement values of the standard microphone, whereas the sharpness of the binaural recording head measurements remains below the sharpness values of the standard microphone.

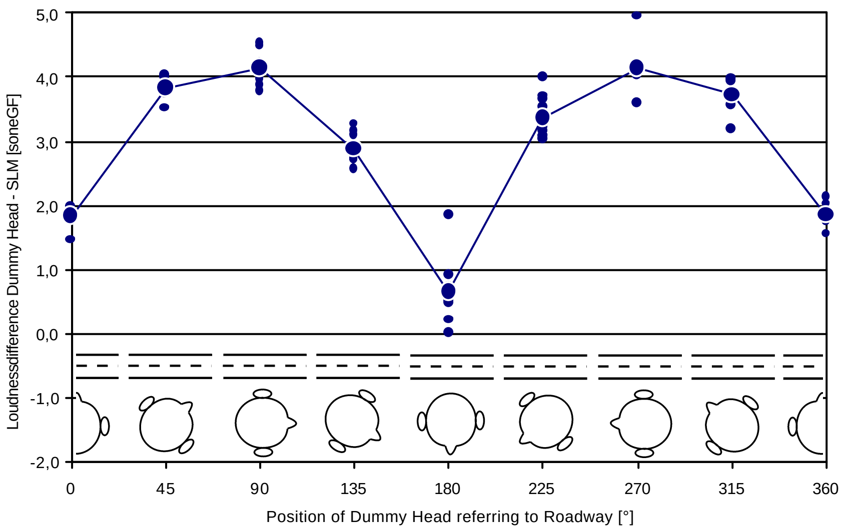
The changes in these differences with increasing distance to the noise source were described by means of models based on the falling branch of power functions for both the noise level outside built-up areas and loudness. The differences between the values of the binaural recording head and the standard microphone are thus at a maximum in the direct vicinity of the road and then decrease exponentially with distance. As distance tends towards infinity, the differences fall back to zero. For the measurements in the built-up area the distance-dependent effects from 6 m and up were so strongly masked by other influences such as reflection from buildings that a increase in level difference was observed. The changes in differences with increasing distance can here be described by a quadratic function. The smallest differences between the binaural recording head values and those of the standard microphone occur with unweighted sound levels. For the lowest value of the sound level meter, the difference at a distance of 4.0 metres from the roadside is 0.67% at the cross-section in a built-up area, 4.6% by the federal road, and 3.8% by the motorway. In comparison, the differences for the A-weighted levels in the built-up area relative to the standard microphone are considerably higher at 4.4%, while for the two cross-sections outside the built-up area there are only marginal increases in the differences to 5.0% (federal road) and 4.8% (motorway). The loudness values differ the most relative to the loudness values of the standard microphone, at 7.6% (built-up area), 8.9% (federal road) and 11% (motorway, see picture 2).



Picture 2: Differences in Loudness between Dummy Head and SLM depending on Distance to Roadway (small dots) and Regression Curve (line) for a 6 Lane Motorway

Here an increase in the differences can be ascertained with increased traffic flow and/or speed on the investigated road sections. For the psychoacoustic variable sharpness, the values for the binaural recording head are below those of the standard microphone value. The difference relative to the latter at a distance of 4.0 metres was -6,7% (built-up area), -8,4% (federal road) and -4,2% (motorway).

For the investigation of the influence of the alignment of the head relative to the road the binaural recording head was rotated at intervals of 45° from the forward position (0°) through the reverse position (180°) and back to the original position (360°). Simultaneous measurements were also made each time with the fixed standard microphone, which was positioned at the same elevation and distance to the road as the binaural recording head. For the interaural differences in level a high-quality sine model was estimated, which allows it to be assumed that predominantly symmetric acoustic conditions existed at the point of measurement on both sides of the median plane of the binaural recording head in the 0° position.
The main focus here was also the differences between the values measured by the binaural recording head and the standard microphone. Statistical tests showed significant differences between the variables of sound pressure level, loudness and sharpness between the values measured by the binaural recording head and the standard microphone. As the measured differences in roughness are not significantly different, no interpretation of the differences was undertaken.
In general, the binaural recording head measures higher sound pressure levels and loudness values than the standard microphone, whereas the sharpness values measured by the binaural recording head remain below the sharpness values for the standard microphone. The differences in the levels for the sound level, loudness and sharpness between the binaural recording head values and the standard microphone show similar characteristics. The minimum difference is always obtained in the reverse position (180°), the maximum in a lateral position relative to the road. Here, too, the relative differences vary greatly compared to the values measured by the standard microphone (see picture 3).



Picture 3: Differences in Loudness between Dummy Head and SLM depending on Dummy Head Position referring to Roadway (small dots) and average Differences per Direction (big dots)

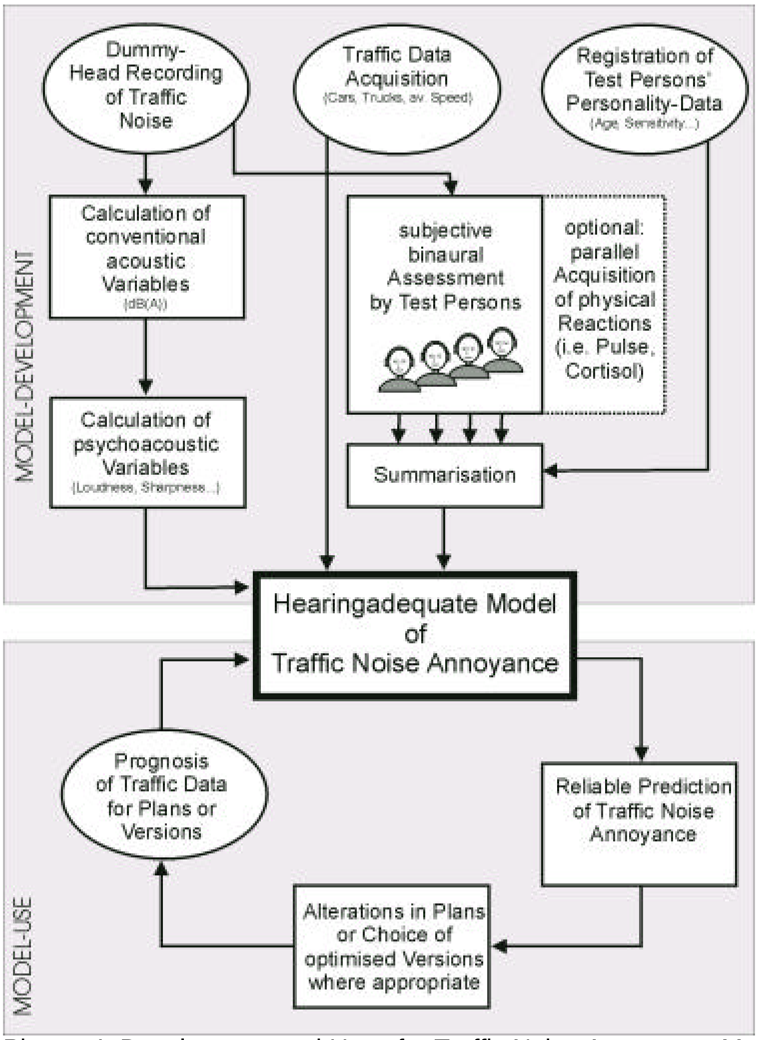
Each of the following values is for the position of the binaural recording head with the greatest differences to the standard microphone. The lowest differences are obtained by the unweighted levels at around 3%, whereas the A-weighted levels differ by approximately 6%. The largest differences are obtained for loudness at 13.2%. For the binaural recording head sharpness is a maximum of 11.9% below the sharpness values of the standard microphone. As the description of the differences in the reverse position have an irregular section, and the symmetry of the head would lead us to expect a symmetric curve on both sides of this position, it is sufficient to model the area between 0° und 180°. For loudness, a model defined in two sections was estimated as an illustration of this area. The underlying sine function is subtractively masked by a linear component between 90° and 180°, which describes an increasing shadowing by the ear. This provides high model quality.

RESULTS

Overall the inclusion of psychoacoustic variables in the assessment of traffic noise pollution is considered to be necessary. However a basic agreement has to be made in advance about the locality noise judgements aim at. This could be the annoyance of the human being that stays in the open or the physiological independent immissions in front of a buildings facade in which humans live and work. In the first case the results of dummy head measurements are the preferable approach compared to the standardised microphone. If the physiologically independent noise immission stays the basis for noise judgement, the standard measurement method remains adequate.

For the aim of a head related noise assessment a two-stage method is recommended. As a first step a model of traffic noise pollution that more authentically reflects human sound perception must be developed, so that model calculations may continue to be used in future instead of measurements (see picture 4). The quantitative determination of conventional acoustic variables can then be complemented by psychoacoustic variables and subjective assessments of binaural recording head recordings by test subjects, as well as by the possible parallel measurement of physiological reactions during the tests. Suitable means of establishing the personality traits of test subjects should be used to ensure that they exhibit an average sensitivity to noise.
When the phase of model development is completed, the model allows a comparative noise pollution prognosis for traffic noise for construction proposals and variants thereof, even without the binding introduction of limit values for psychoacoustic variables. Yet this study makes it clear that a model of this kind, despite considering psychoacoustics and subjective assessment by test subjects, can never explain the annoyance of traffic noise completely due to the variety

of influencing parameters and the differences in personality of those affected. Nevertheless, improvement in the current situation seems to be possible and is to be welcomed.



Picture 4: Development and Use of a Traffic Noise Annoyance Model

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