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# PSYCHOACOUSTIC EVALUATION OF SOUND ABSORBING ROAD SURFACES

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**ABSTRACT**
In psychoacoustic experiments, the reduction of road traffic noise obtained by sound absorbing road surfaces was studied. Loudness of pass-by sounds produced by passenger cars on different road surfaces was rated by a magnitude estimation procedure in relation to the loudness produced for a standard ISO 10844 road surface. In a first set of experiments, always the same tire was used in combination with different road surfaces. In a second set, for a relatively "silent" road surface, the influence of using different tires was studied. The results of the psychoacoustic evaluations are compared to data from physical measurements. When using A-weighted level and the well-known rule of thumb “10 dB less means half loudness” the noise reduction of sound absorbing road surfaces as perceived by the broad public can be considerably underestimated. On the other hand, subjective evaluations of sound absorbing road surfaces can be predicted by physical measurements of the percentile loudness $N_5$ with a loudness analyzer.

## INTRODUCTION

Road traffic noise is the dominant source for complaints about noise (e.g. Babisch 2004). At same energy-equivalent A-weighted level, railway noise is less annoying than road traffic noise, an effect which has been termed “railway bonus” (e.g. Möhler 1988, Fastl et al. 1996). Therefore, it is of great importance to reduce road traffic noise. As concerns engine noise, in the last decade substantial noise reductions have been achieved e.g. by shielding measures in the underbody area and engine encapsulations (Patsouras et al. 2001, Patsouras and Pfaffelhuber 2002). As a consequence, even at lower speeds from about 30 km/h, road-tire noise is becoming dominant.

In addition to research on the development of low-noise treads of tires (Saemann 2006, Gauterin et al. 2007) sound absorbing road surfaces gain more and more importance. In extensive studies (Beckenbauer 2001, Beckenbauer et al. 2002) it could be shown that single layer absorbing road surfaces can lead to noise reductions of about 3 to 6 dB(A). With multi-layer road surfaces, noise reductions up to 10 dB(A) can be obtained (Beckenbauer et al. 2005, Beckenbauer et al. 2007).

While experts acclaim the corresponding success in noise abatement, the broad public usually can hardly understand what 10 dB(A) reduction mean in “real life”. Therefore, psychoacoustic experiments were performed in which the noise reduction by sound absorbing road surfaces is assessed in terms of the reduction of perceived loudness (e.g. Fastl and Zwicker 2007). Also, differences in tone colour of the noises produced by traditional versus sound absorbing road surfaces were studied using the hearing sensation sharpness (v. Bismarck 1974).

In this paper, parts of a larger study are reported, concentrating on two effects:

1) Noise produced by a passenger car with one and the same tire on different road surfaces, and
2) Noise produced by a passenger car with different tires on a relatively “silent” road surface.

The resulting subjective evaluations are compared to physical measurements of A-weighted level as well as loudness according to DIN 45 631.

## EXPERIMENTS

Eleven subjects with normal hearing, aged between 23 and 40 years (median 26 years) participated in the experiments. Sounds were presented diotically via electro-dynamic headphones (Beyer DT 48) with free-field equalizer (Fastl and Zwicker, 2007, p.7). Sounds of passing passenger cars were edited to obtain 4 seconds duration of the test sounds. A procedure of free magnitude estimation was used: each test sound was presented four times in different order with intervals of 3 seconds in which the estimate had to be entered in a response sheet. Before each run, 6 test sounds were presented for training, and throughout the experiments, no feedback was given. Loudness and sharpness were evaluated in different experiments on different days. All individual data were normalized relative to the number given for the sound on the standard ISO 10844 road surface. From the resulting 44 data points, medians and inter-quartiles were calculated.

## RESULTS AND DISCUSSION

In a first experiment, the loudness produced by pass-by sounds of a passenger car on different road surfaces was studied. A “normal” tire was used and a speed of 50 km/h was chosen. The distance to the recording microphone was 7.5 m. In figure 1, subjective loudness evaluations, normalized to the loudness evaluation for the ISO road surface are plotted for different road surfaces. ISO means a road surface in accordance with ISO 10844, A1, A2, and A3 indicate different sound absorbing road surfaces, and B represents a conventional, non-absorbing road surface.

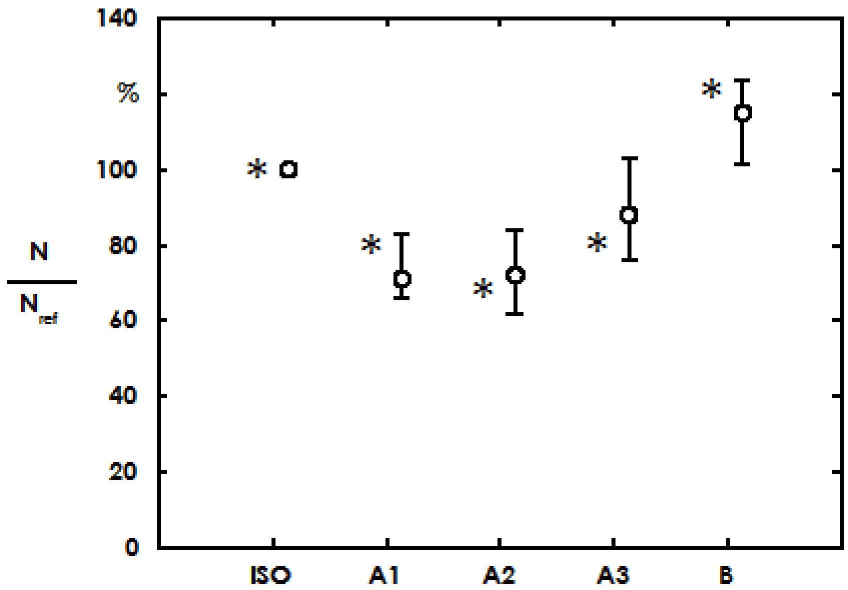


Figure 1-Loudness of pass-by sounds from a passenger car at 50 km/h in 7.5 m distance for a “normal” tire on different road surfaces. ISO represents the ISO10844 road surface; A1, A2, A3 stand for three different sound absorbing road surfaces, and B for a conventional, non-absorbing road surface. Data from psychoacoustic experiments (circles) in comparison to physically measured values of percentile loudness $N_5$ (stars)

The data displayed in figure 1 suggest that the loudness of pass-by sounds from passenger cars is substantially reduced by sound absorbing road surfaces. A passenger car on a conventional, non-absorbing road surface (B) produces in comparison to the same car on a sound absorbing road surface (e.g. A2) a loudness which is by more than 60 % larger. Also, in comparison to the standard ISO 10844 road surface, a passenger car can produce on the sound absorbing road surface A2 about 30 % less loudness. The same holds true for the road surface A1, whereas the road surface A3 leads to only about 12 % loudness reduction compared to the ISO road surface. However, in comparison to the conventional, non-absorbing road surface (B), the sound absorbing road surface A3 still reduces the loudness of the pass-by sound by more than 25 %.

The stars in figure 1 indicate results from physical measurements of the percentile loudness $N_5$ using a loudness analyzer (e.g. Fastl and Zwicker 2007, p. 237). As with the subjective results, also for the physical measurements all data were normalized relative to the value for the ISO road surface. There is good agreement between subjective (circles) and physical (stars) results. This means that the loudness reduction by sound absorbing road surfaces can be assessed by measuring percentile loudness $N_5$ with a loudness analyzer.

Table I gives an overview of the maximum of the A-weighted level for the pass-by sounds when using the time constant “fast” of 125 ms. Also the resulting relative loudness values are given when using the rule of thumb “10 dB less means half loudness”.

Table I.- Maximum of the A-weighted level in dB(A) for the pass-by sounds of a passenger car on different road surfaces using the time constant “fast” and estimated relative loudness in % using the rule of thumb “10 dB less means half loudness”

| ISO | A1 | A2 | A3 | B |
|---|---|---|---|---|
| 63.4 dB(A) | 63.0 dB(A) | 60.5 dB(A) | 62.0 dB(A) | 64.8 dB(A) |
| 100 % | 97 % | 82 % | 91 % | 110 % |

The data displayed in Table I indicate a level reduction by a sound absorbing road surface (e.g. A2) in comparison to a conventional, non-absorbing road surface (B) of 64.8 dB(A) – 60.5 dB(A) = 4.3 dB(A). For experts, this level reduction by a sound absorbing road surface may be disappointing, since much larger values up to 10 dB(A) can occur (e.g. Beckenbauer et al. 2007). However, the main goal of this pilot study is not to show the “best” sound absorbing road surfaces. Rather, the benefit of sound absorbing road surfaces shall be described in terms which are understood not only by experts, but also by a broad public.

When comparing the values of relative loudness obtained by the rule of thumb given in Table I in % with the data from psychoacoustic experiments (circles) plotted in figure 1, substantial differences can be noted. For example, for the road surface A1 a value of 70 % relative loudness is obtained from the psychoacoustic experiments whereas the prediction by the rule of thumb (“10 dB less means half loudness”) displayed in Table I yields 97 %. The reason for this discrepancy can be found in spectral differences: Different sound absorbing road surfaces attenuate spectral regions with different amounts. Therefore, the tone colour of each pass-by sound is different leading to differences in perceived loudness even if the values of the A-weighted level are almost the same.

In this context it should be remembered that the well known rule of thumb “10 dB less means half loudness” is only true, if the spectrum and hence the tone colour of the sound does not change. More specifically, the rule of thumb holds exactly only for pure tones at 1 kHz since e.g. for broad-band noise, 12 dB less can mean half loudness.

Another aspect of interest is the noise reduction by a sound absorbing road surface when using different tires. Results of a corresponding psychoacoustic experiment using the absorbing road surface A2 are given in figure 2. The loudness evaluations of the pass-by sounds of a passenger car at 50 km/h in 7.5 m distance were normalized to the data obtained for the “normal” tire used in the former experiment. In figure 2, BS denotes a broad tire with no tread (slick), BA and BB indicate two broad tires with different treads, N stands for the “normal” tire, and T represents the tire of a truck.

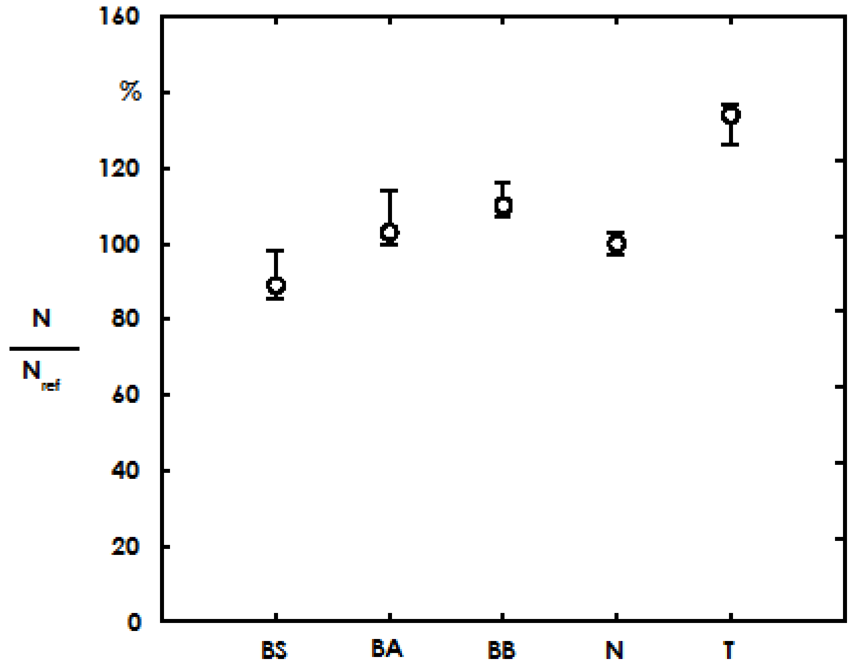


Figure 2-Loudness of pass-by sounds from a passenger car at 50 km/h in 7.5 m distance for different tires on the sound absorbing road surface A 2. BS broad tire without tread (slick); BA and BB broad tires with different tread; N “normal” tire; T tire of a truck.

The data displayed in figure 2 illustrate that the pass-by of a passenger car with a slick (BS) produces the smallest loudness, even smaller than a “normal” tire. However such tires are only feasible for expert drivers in races and – despite their small loudness – can not be recommended for daily use. The broad tires evaluated produce up to 10 % more loudness than the “normal” tire. As expected, the truck tire elicits about 35 % more loudness than the “normal” tire. Again, in this pilot study, not the “best” combinations of absorbing road surface and specific tire are shown. Rather, it shall be indicated that also from a perceptual point of view the “optimum” absorbing road surface can not be engineered, since for the loudness produced by passing vehicles, the *combination* of road surface and tire is relevant.

In addition to loudness differences also differences in the tone colour occur when comparing pass-by sounds of a passenger car on different road surfaces. Therefore, the hearing sensation sharpness was assessed in psychoacoustic experiments analogue to those illustrated in figure 1. It could be shown that at 50 km/h, a conventional, non-absorbing road surface leads to about 70 % higher values of sharpness than sound absorbing road surfaces. Since the hearing sensation sharpness is used in sound quality evaluations to describe the aggressiveness of sounds (e.g. Fastl 2006), sound absorbing road surfaces have significant influences on the sound character outside as well as inside a car. At 100 km/h, the difference in sharpness between non-absorbing and absorbing road surface amounts to only about 40 %. Nevertheless, when driving along a highway and the road surface changes from non-absorbing to absorbing, the driver immediately notices a reduction in loudness and sharpness.

When using as illustrated in figure 2 on one and the same sound absorbing road surface different tires, for the pass-by sounds of a passenger car, the differences in sharpness are relatively small and around some 10 % for the tires evaluated in the present study. However, it is to be expected that for a specific sound absorbing road surface an optimum tire can be engineered for which presumably significant reductions in both loudness and sharpness will show up. In addition it should be mentioned that the sharpness of the truck tire on sound absorbing road surfaces was not yet evaluated in psychoacoustic experiments.

## OUTLOOK

In this pilot study it could be shown that it is quite worthwhile to assess the noise reduction by sound absorbing road surfaces not only by physical magnitudes like A-weighted level but also by psychoacoustic magnitudes like loudness or sharpness. When using A-weighted level and the well-known rule of thumb “10 dB less means half loudness” the noise reduction of sound absorbing road surfaces as perceived by the broad public can be considerably underestimated. Therefore, more psychoacoustic studies e.g. with truck tires or tires engineered for a specific sound absorbing road surface are proposed. Moreover, it is to be expected that the results of psychoacoustic evaluations can be predicted by physical measurements with analysis systems simulating hearing sensations. For loudness and sharpness the corresponding standards are DIN 45 631 and DIN 45 692. In this respect, the data displayed in figure 1 of this paper are rather encouraging since the subjective evaluations could be predicted by physical measurements of the percentile loudness $N_5$ with great accuracy.

## ACKNOWLEDGEMENTS

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