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Psychoacoustic experiments on some unwanted interior car sounds

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ABSTRACT

Unwanted components of car interior sounds include rattling, creaking, squeaking etc. which ideally should be inaudible. On the other hand, wanted sounds which convey information like the click of a switch should be audible also at typical driving speeds.

Therefore, in psychoacoustic experiments the audibility of both unwanted and wanted sounds were studied in silence as well as in background noise typical for premium cars at driving speeds of 50 km/h or 120 km/h.

In addition, 1/3-oct-band spectra were measured of all evaluated sounds in view of possible predictions of their audibility.

The present pilot study features results of psychoacoustic studies on the audibility of unwanted and wanted interior car sounds and gives guidelines towards related algorithmic predictions. Approaches based on spectral displays like Zwicker’s excitation pattern model or loudness patterns seem to be rather promising.

Keywords: Interior car sound, rattling, creaking, squeaking. I-INCE Classification of Subjects Numbers: 63.2, 63.7

1. INTRODUCTION

These days the indoor sound of premium cars is of decisive interest for prospective customers. In particular unwanted sounds like rattling, creaking or squeaking are considered unacceptable for premium vehicles (e.g. 1). On the one hand, these sounds can get on a customer’s nerves, and on the other hand, frequently they are considered as an indication of a technical fault or low quality of the vehicle (e.g. 2).

Fixing the causes of rattling, creaking or squeaking in a vehicle can be rather time consuming and expensive (e.g. 3). Therefore, it has to be decided, whether such sounds will also be audible while driving or will be masked by the vehicle noise.

Although the masking by vehicle noise might be regarded as a remedy for unwanted sounds, wanted sounds like flashing indicator or headlamp switch still should be audible since they provide helpful acoustic feedback to the driver.

In order to give some guidelines for future algorithms to predict appropriate aspects of wanted and unwanted sounds in premium cars, psychoacoustic experiments were performed as follows: the audibility of rattling, creaking or squeaking sounds as well as sounds of switches was studied in quiet or masked by the indoor noise of a premium vehicle driving at a constant speed of 50 km/h or 120 km/h. In addition, to establish some links to “classic” psychoacoustic masking data, the audibility of wanted and unwanted sounds was measured in a broadband noise background of uniform masking noise (4, p.63).

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2. PSYCHOACOUSTIC EXPERIMENTS

2.1 Subjects

Fourteen subjects with normal hearing ability (i.e. less than 20 dB hearing loss between 100 Hz and 12 kHz) took part in the experiments. Their age ranged between 20 and 29 years (median 25 years). Seven of the 14 subjects had ample experience in psychoacoustic experiments, and the other seven subjects were psychoacoustic novices.

2.2 Setup and procedure

Subjects were tested one by one in a sound attenuating booth. Sounds were presented diotically via electro-dynamic headphones (Beyer DT 48) with free-field equalizing according to Fastl and Zwicker (4, p.7). Thresholds were determined by a PEST algorithm (5) with 2 dB step size. The average duration of the psychoacoustic sessions was 25 minutes, respectively. Psychoacoustic results are given as medians with interquartile ranges derived from 14 data points each.

2.3 Sounds

Unwanted and wanted target sounds were recorded in a premium sedan from the 1990ties (since modern premium sedans seem to have no problems with unwanted sounds?!). Indoor noises at constant speeds of 50 km/h and 120 km/h were recorded at the head position of the front passenger seat in a current premium sedan driving on dry asphalt and at windless weather. For the psychoacoustic experiments it is of decisive relevance that the indoor noises and in particular the target sounds contain no additional, extraneous components. Table 1 gives an overview of the target sounds used.

Table 1 – Sources for unwanted and wanted target sounds

Rattling	Creaking	Squeaking	Switch sound
Power door lock	Center console	Crank of sun roof	Rear window heater
Headlamp switch	Ashtray (front)	Ashtray (rear)	Air condition

The 1/3-oct band spectra of the six unwanted and the two wanted target sounds are displayed in Figure 1.

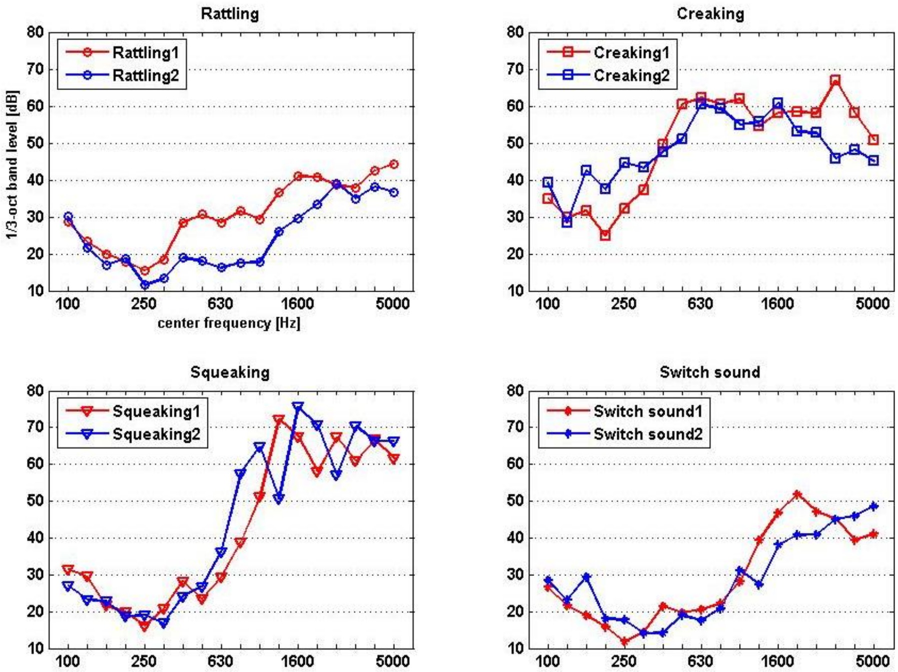

Figure 1 – Display of 1/3-oct band spectra of two rattling, creaking, squeaking, and switch sounds, respectively.

3. RESULTS AND DISCUSSION

3.1 Audibility of unwanted or wanted sounds

Figure 2 gives an overview concerning the audibility of unwanted or wanted target sounds in quiet or in background noise. The level of the target sounds at (masked) threshold is given on the ordinate for sounds listed along the abscissa.

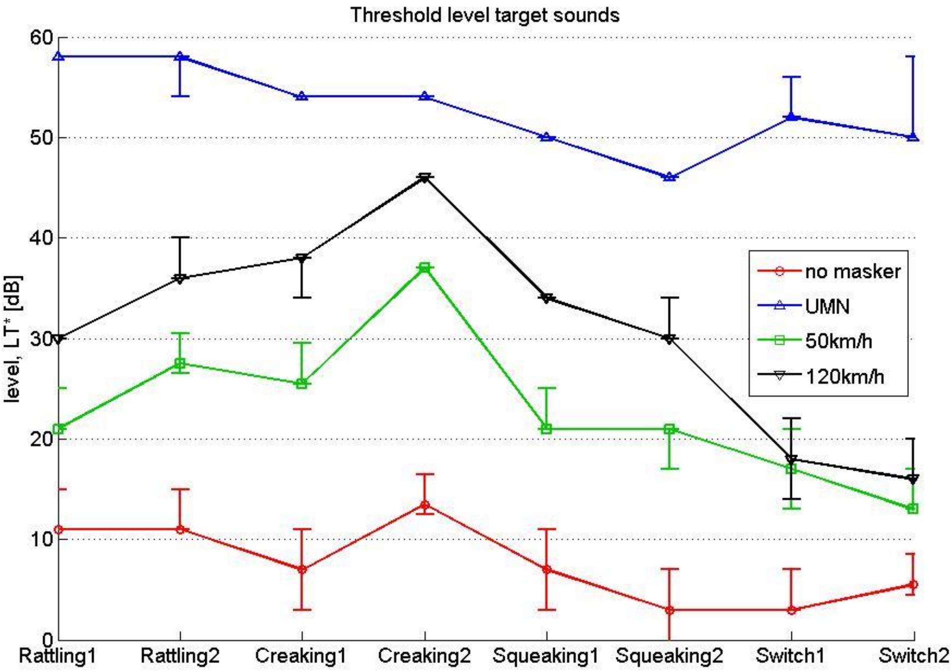

Figure 2 – Threshold level for eight target sounds indicated on the abscissa. Four different masking conditions: no masker (circles), indoor vehicle noise for 50 km/h (squares), indoor vehicle noise for 120 km/h (downward pointing triangles), uniform masking noise of 60 dB (upward pointing triangles).

As expected, without background noise (circles), the lowest levels are necessary to enable the audibility of the sounds. In contrast, uniform masking noise of 60 dB (upward pointing triangles) elevates the thresholds by some 40 to 50 dB. Indoor vehicle noise at 50 km/h (squares) leads to an increase in threshold, i.e. a masking effect of about 10 to 20 dB. When increasing the speed from 50 km/h to 120 km/h (downward pointing triangles), the threshold levels for the unwanted sounds increase by about 10 dB. However, the threshold values for the wanted switch sounds are only little elevated. This means that unwanted sounds like rattling, creaking or squeaking are better masked at higher speed. However, in this case, a wanted sound like the sound of switches largely remains audible also at higher speeds.

The reason that uniform masking noise represents the “best” masker is due to its spectral distribution, providing a masked threshold independent of frequency (cf. 4, Fig. 4.2). Moreover, uniform masking noise is rather similar to pink noise which shows a flat, frequency-independent 1/3-oct band spectrum. In contrast, indoor vehicle noise shows a sloping spectrum, i.e. higher level at low frequencies than at high frequencies. Therefore, high frequency components of the unwanted or wanted sounds are easier masked by uniform masking noise than by indoor vehicle noise.

3.2 Spectral distributions of vehicle indoor noise and target sounds at masked threshold

In view of a future algorithm to describe the audibility of unwanted sounds like rattling, creaking or squeaking in a driving vehicle, as a very first step the related 1/3-oct band spectra are displayed in figure 3 for 50 km/h and in figure 4 for 120 km/h. The 1/3-oct band level is given as a function of the center frequency of the respective filter. Squares illustrate the spectrum of the vehicle indoor noise, circles represent the spectra of the unwanted and wanted sounds at original level, and the triangles indicate these spectra at masked threshold.

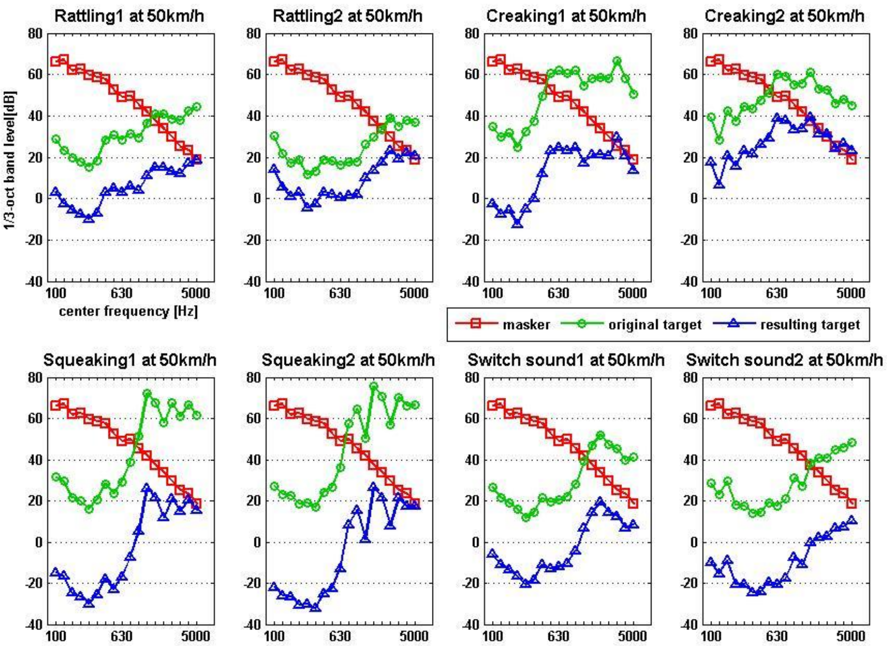

Figure 3 – Display of 1/3-oct band spectra for vehicle indoor noise at 50 km/h (squares) as well as spectra for unwanted and wanted sounds at original level (circles) or at masked threshold (triangles).

As expected, the spectrum of the vehicle indoor noise decreases towards higher frequencies with a slope of about 10 dB/oct. Interestingly, for reaching masked threshold, in most cases the original spectral display of the target sound (circles) has to be shifted towards lower levels until the 1/3-oct band levels of masker (square) and target sound (triangle) coincide, usually at high frequencies. This effect can be found at all unwanted sounds. However, for the wanted switch sounds, at masked threshold their 1/3-oct band level is somewhat lower than the corresponding level of the masking vehicle indoor noise.

The spectral distributions for the higher speed of 120 km/h are displayed in figure 4.

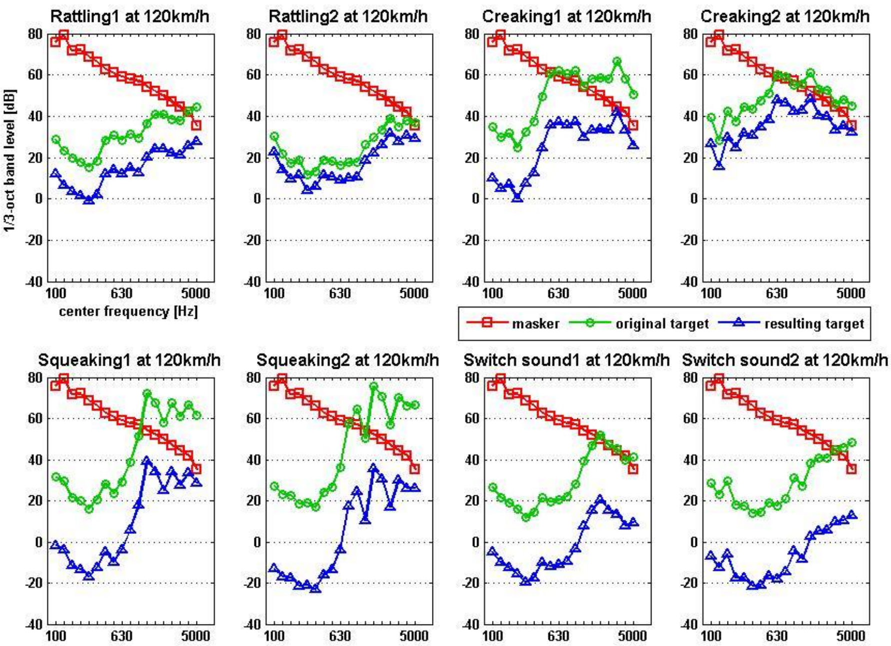

Figure 4 – Display of 1/3-oct band spectra for vehicle indoor noise at 120 km/h (squares) as well as spectra for unwanted and wanted sounds at original level (circles) or at masked threshold (triangles).

As expected, the spectrum of the vehicle indoor noise (squares) also decreases towards higher frequencies, but - because of the higher speed - the 1/3-oct band levels are by about 10 dB higher. This level difference nicely corresponds to the shift in masked thresholds as displayed in figure 2: For unwanted sounds masked thresholds for 120 km/h (downward pointing triangles) are by about 10 dB higher than masked thresholds for 50 km/h (squares).

When comparing in figure 4 the 1/3-oct band levels at high frequencies of vehicle indoor noise (squares) and target sounds at masked threshold (triangles), usually only small differences show up.

Taking these observations together, it seems to be advisable to base a future model for the prediction of the audibility of rattling, creaking and squeaking on Zwicker's classic excitation pattern model (cf. 4, chap.6 and 7).

4. CONCLUSIONS

The audibility of unwanted car interior sounds like rattling, creaking or squeaking can be assessed using classic psychoacoustic procedures. However, for practical applications it would be desirable to have an algorithm which predicts the results of the psychoacoustic experiments. Although in the present pilot study no algorithm can be proposed which faithfully predicts the audibility of unwanted and wanted sounds, an approach based on Zwicker's excitation pattern model seems to be worthwhile. Along these lines, the use of psychoacoustically based magnitudes like instrumentally measured percentile loudness N_{10} has been proposed (e.g. 6) for the assessment of unwanted sounds. However, results from our pilot study suggest to utilize instead of the total (percentile) loudness the distribution of loudness patterns for both background and target sounds.

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