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Perceptibility of approaching vehicles in urban background noise

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ABSTRACT

Vehicle noise emissions are an ongoing research topic in the field of sound quality design. Another area, which been hardly investigated in the past years, is the warning function of this noise for other road users, especially pedestrians. Therefore, this paper will show results of experiments dealing with the detection of the sounds of different cars in a typical urban background noise. Moreover, some considerations on road safety are given and will be related to the experimental results. Additionally, a method predicting the perceptibility of cars in background noise is introduced and evaluated.

1 INTRODUCTION

Following the data of "Deutsches Bundesamt für Statistik" [1] in the year 2003 35015 pedestrians got injured and 812 died in road traffic accidents in Germany. This is quite a large number when considering that everybody takes part in everyday traffic as pedestrian. The reasons why and where these accidents happen are also given by [1] and are displayed in Table 1. There we can see that most causualities occur when crossing a street, in most cases because of sudden appearance behind obstacles or no attention for the traffic. These reasons have a close relation to acoustics, because the auditory sense is our receiver for warning signals which are not influenced by the above meantioned reasons for accidents. This is also expressed by a paper by Blauert [2]: *"Generally, most sounds tell us a lot about the sound sources. This is essentially, what hearing is all about – and we have to keep this in mind when combatting noise."*

The present paper deals with these less addressed aspects of vehicle exterior noise. We show experimental results which relate the perception of vehicle exterior noise to considerations regarding road safety. Additionally, we propose a method to predict the perceptability of car sounds in background noises, based on masking thresholds.

2 MINIMUM REQUIRED DISTANCES FOR COLLISION AVOIDANCE

We start with a consideration of road safety and collision avoidance. Important to know is the minimum required distance between a vehicle and a pedestrian to have enough time to react and thus to avoid a collision properly. This distance has a close relation to the reaction time of humans. An overview of reaction times regarding the stopping of a car (driver-perception-brake times) is given by Green [3], who reviewed studys dealing with this topic.

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He states that for concentrated road users who are aware of a certain danger, the time between the perception and reaction can be as short as 0.7 seconds. People who are distracted or have to deal with an unexpected event need about twice the time, i.e. they need about 1.5 seconds.

Table 1: Typical lapses and locations of pedestrian accidents determined by the German police in 2003 [1].

Lack of road fitness	9.09 %
Wrong behaviour when crossing the street	77.92 %
No use of the sidewalk	1.68 %
No use of the correct road side	0.89 %
Playing on or next to the road	1.36 %
Other pedestrian errors	9.06 %
At controlled pedestrian crossings	8.92 %
At uncontrolled pedestrian crossings	0.76 %
Near intersections, pedestrian crossings, in dense traffic situations	7.37 %
In other places:	
- by sudden appearance behind obstacles	20.12 %
- by not paying attention to vehicle traffic	55.12 %
- by other misguided behaviour	7.70 %

Based on these reaction times, it is possible to calculate minimum distances which have to remain between an approching vehicle and a pedestrian for safe collision avoidance. Assuming a constant driving speed for the vehicle, the distances correspond to the overall stopping distance of a car. They are depicted in figure 1 as a function of driving speeds up to 50 km/h and different levels of concentration of driver and pedestrian as given by Green [3]. A pedestrian for example has to react to an approaching vehicle driving at constant speed of 20 km/h at a distance of 10 m to avoid a possible collision when assuming a distracted driver.

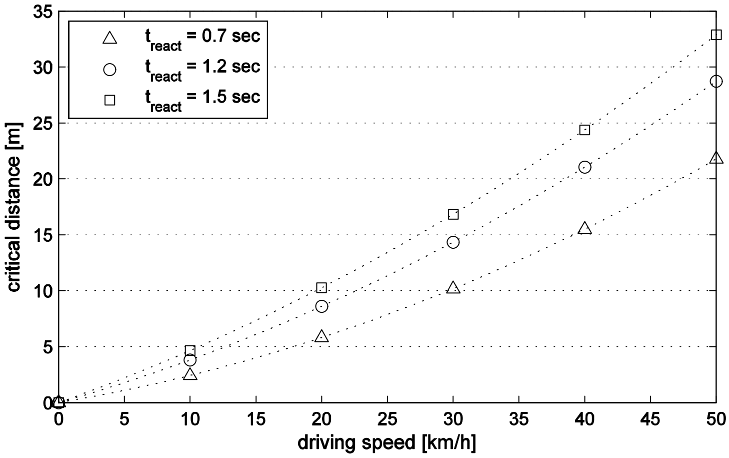

Figure 1: Critical distances for just in time perception of a vehicle driving at a given speed. Reaction times are for concentrated as well as for distracted drivers according to [3].

3 EXPERIMENTS

3.1 Experiment I – Reaction-time to approaching vehicles

To relate the above mentioned considerations on road safety to actual distances of cars when hearing them in a background noise, several psychoacoustic experiments were conducted. They are described in this section.

3.1.1 Experimental procedure

Our listening tests took place in the anechoic chamber of the institute for Mensch – Maschine – Kommunikation at the Technische Universität München. Subjects were seated at a distance of 2 m in front of a loudspeaker (Klein & Hummel O98) hidden by an acoustically transparent curtain, which played back a typical urban background noise continously. At unspecified times, sounds of approaching vehicles where added to this background noise. The persons had to react immediately after hearing the car sound by pressing a hand button, connected to a custom made device, which registered the exact reaction time with an accuracy of 1 ms. By evaluating the exact timespot where the subjects reacted, it was possible to derive the exact level and position of the vehicle which generated that sound during the recording.

3.1.2 Stimuli

Two types of stimuli were used in the experiments. First, a typical urban background noise was recorded at Munich, Marienplatz which consisted of a speech like noise (noise babble) at an overall A-weighted level of 62 dB(A). Out of this recording 14 seconds were extracted and played back with original level in a loop. Additionally for another experimental run a second background noise was recorded, which was processed as the first one with the only difference of an overall A-weighted level of 55 dB(A). For more detailed descriptions of the signals we refer to [4].

The sounds of the approaching vehicles were recorded on standard test tracks for vehicle exterior noise measurement based on DIN ISO 362 [5]. In order to fit better the requirements of sounds relevant for collision avoidance with pedestrians, some changes to the measurement procedure had to be applied as depicted in figure 2.

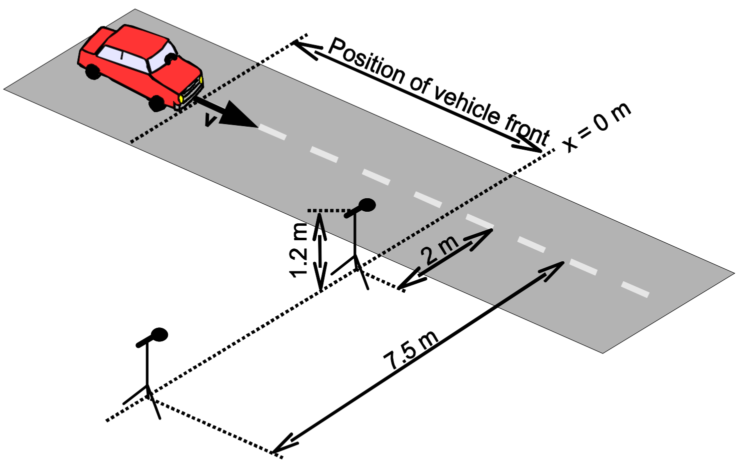

Figure 2: Measurement of investigated car sounds

To achive a better signal to noise ratio and to better simulate the percived signal at the position of a pedestrian who is about to cross a street, a microphone in a distance of 2 m from the midline of the test track was used. The second microphone was placed in a position as prescribed in the standard DIN ISO 362 to have the possibility to relate this signal to earlier measurements.

Not the whole recording was used for the listening test, but only a short part (3 seconds) of the signal which was recorded immediately before crossing the line x = 0 m with the vehicle’s front. In this way, a sound was generated which matches that part of the signal which a hypothetic pedestrian would hear before a collision occurs. Besides the audio signal, for every car the actual position on the testtrack was recorded synchronously to the audio signal.

In the described manner, 47 approaches of seven different vehicles in different operating conditions were recorded at three driving speeds (20, 30 and 50 km/h).

3.1.3 Subjects

23 subjects with ages from 24 to 61 years (median: 27 years) participated in our first experiment. All persons had normal hearing with maximum differences of 20 dB to the reference thresholds in quiet, measured with a custom-made audiometer [6]. The overall duration for a testrun was 10 minutes per person.

3.1.4 Results

The results for the 47 recorded approaching vehicles and the two background noises are depicted in figure 3 as medians and interquartile ranges from the data of all participating persons. Additionally, the minimum required distances for collision avoidance (figure 1) for the corresponding speeds and for reaction times of 0.7 and 1.5 seconds are plotted as horizontal lines.

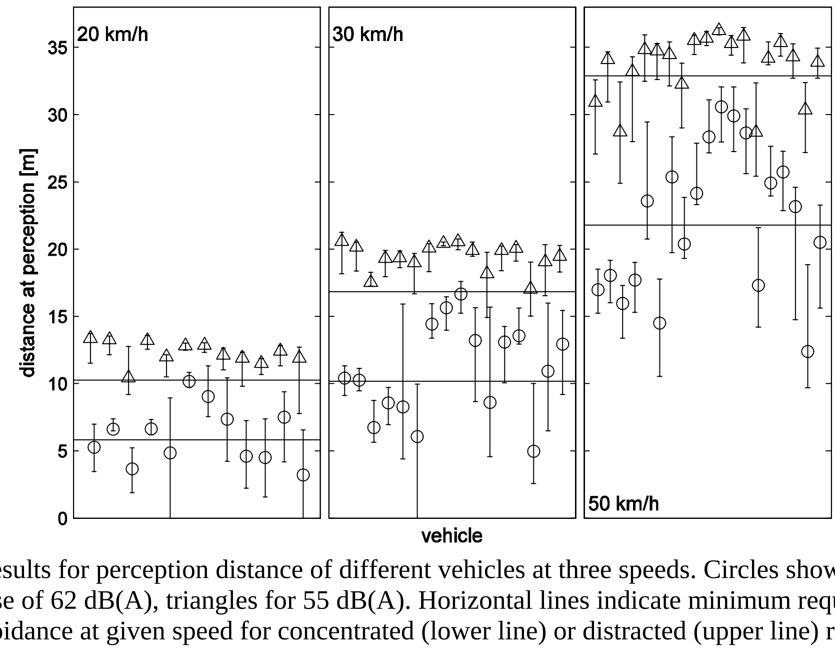

Figure 3: Results for perception distance of different vehicles at three speeds. Circles show results for a background noise of 62 dB(A), triangles for 55 dB(A). Horizontal lines indicate minimum required distance for collision avoidance at given speed for concentrated (lower line) or distracted (upper line) road users (cf. figure 1).

The data displayed in figure 3 show that for a background noise of 62 dB(A) (circles) most of the vehicles are not perceptible in time for safe collision avoidance even for concentrated road users. This can be seen because the distances between vehicle and pedestrian are smaller than requiered, i.e. the results lie beneath the lower horizontal line indicating critical distances for concentrated road users. For distracted road users (upper lines), none of the recorded vehicles is perceptible in time at this level of background noise. When we reduce the background noise by 7 dB(A) from 62 to 55 dB(A) (triangles), nearly all of the approaches would be heard in time by distracted as well as by concentraded road users. However, at a speed of 50 km/h, five out of 19 vehicles would not be perceived early enough by distracted road users.

3.2 Experiment II – Masked thresholds for approaching vehicles

Because the distances at perception should have a close relation to masked thresholds for the approaching vehicles these thresholds were measured in a second experiment.

3.2.1 Experimental procedure

The measurements were performed using the "method of adjustment" as described in [7]. Therefore, a graphical user interface was implemented in Matlab®, which allowed the subjects to listen to masker alone, vehicle alone, and vehicle + masker as often and in any order they wanted by pressing a corresponding button. With an additional slider the task of the subject was to set the level of the vehicle in such a way, that it was just audible in the background noise.

3.2.2 Stimuli

The experiments were performed with the 47 recorded vehicle sounds as described in 3.1.2., with the difference that not the whole recordings were used, but a section of 400 ms length ending with the vehicle passing the line x = 0 (cf. figure 2).

For the masker, short clips of 750 ms duration were extracted randomly from the recording of the masker as described in 3.1.2.

3.2.3 Subjects

Four highly experienced subjects particpated in this experiment, everyone with at least two years experience in psychoacoustical tests. All subjects possessed normal hearing, which was again verified prior to testing with our audiometer [6].

3.2.4 Results

Only the results for a background noise of 62 dB(A) shall be displayed, they can be seen in figure 4.

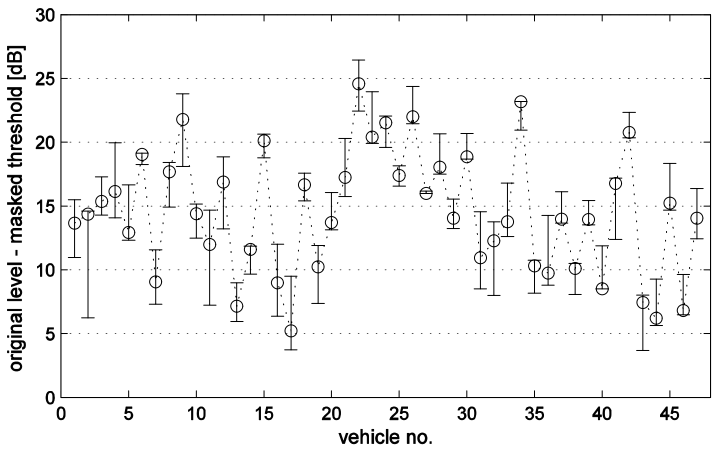

Figure 4: Difference between original levels and masked thresholds for the investigated vehicle exterior noises.

Figure 4 shows the differences between original level and masked threshold for all investigated vehicle sounds. This form of display was chosen because it might represent a good measure for the perceptibility of vehicle sounds in a background noise. Thus, a loud vehicle in a quiet background can be easily perceived, and a quiet vehicle in a loud background should not be audible at all. This reasoning is also confirmed by the correlation between the data of figure 4 and of figure 3. The Pearson - Correlation coefficient calculates to 0.69 with a significance of 5.9967e-8. This result can be seen as a hint that it should be possible to predict distances at perception based on masked thresholds. A method to do so is proposed in the following section.

4 PREDICTING THE DISTANCE AT PERCEPTION

4.1 Basic principle

The sound pressure level of an approaching source increases at the position of a fixed observer. Omnidirectional sound sources for example increase by 6 dB in level with every halfing of the distance between source and observer. This knowledge can be used to predict the distance at which an approaching vehicle should be heard, assuming a more or less constant level of the background noise at the observer's position. The basic principle for the prediction is illustrated in figure 5.

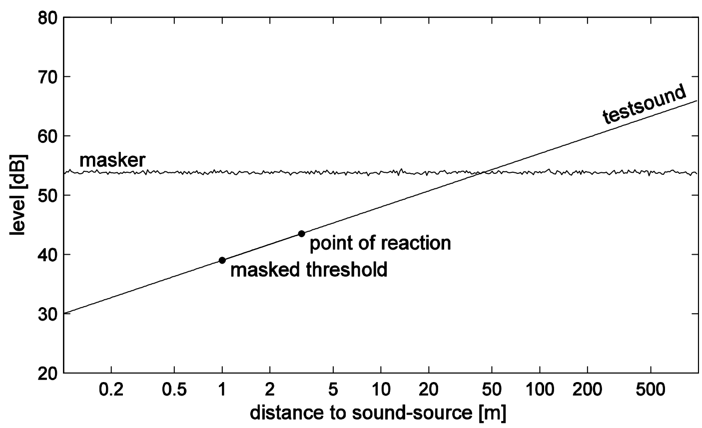

Figure 5: Basic principle for the determination of the distance of a sound source at the moment of perception.

We know the level and masked threshold for the test sound which in our case is the sound of an approaching vehicle. To predict the point of reaction, two other things have to be known, i.e. the reaction time of the person and the steepness of the level – curve of the test sound.

For the reaction time of the person we again refer to Green [3] and asume that in our experiments the test subjects were concentrated, which corresponds to a reaction time of 0.7 seconds.

To determine the steepness of the level – curve for an approaching vehicle as testsound we refer to [8]. In that thesis, different works considering sound propagation of light vehicles are reviewed. A main conclusion of this review that can be drawn is that the propagation matches more or less the behavior of an omnidirectional source with 6 dB decrease in level with every doubling of distance between source and receiver. This result was also supported by own measurements with sounds from idling cars.

Figure 6 shows the correlation between experimental data and the described prediction method for the three investigated driving speeds.

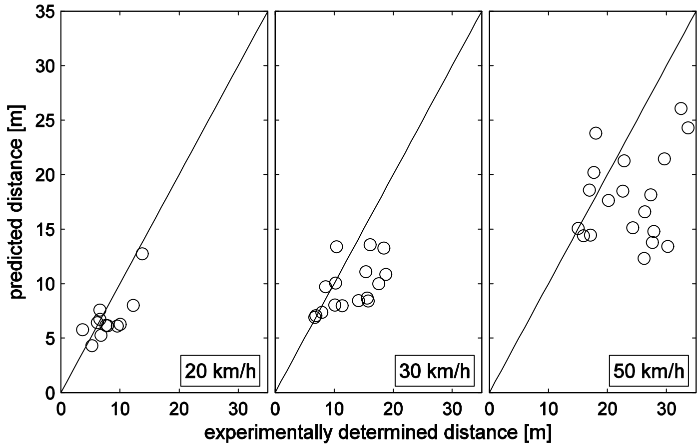

Figure 6: Predicted vs. experimentally determined distances for the three investigated driving speeds. Correlation according to Pearson from low to high speeds: r=0.75(p=0.0049) r=0.55(p=0.0266) and r=0.23(p=0.3333)

As can be seen in figure 6, a positive correlation between experimentally determined and predicted distance exists, which gets worse with increasing driving speeds. A possible explanation might be that at higher speeds, the distance at perception increases. Therefore, at larger distances errors due to the approximation of sound propagation get higher. Moreover, the assumption that the masked thresholds of a vehicle in background noise are independent of its distance to the receiver is not always valid. In particular, at larger distances, effects like air damping increase and therefore influence the masked thresholds.

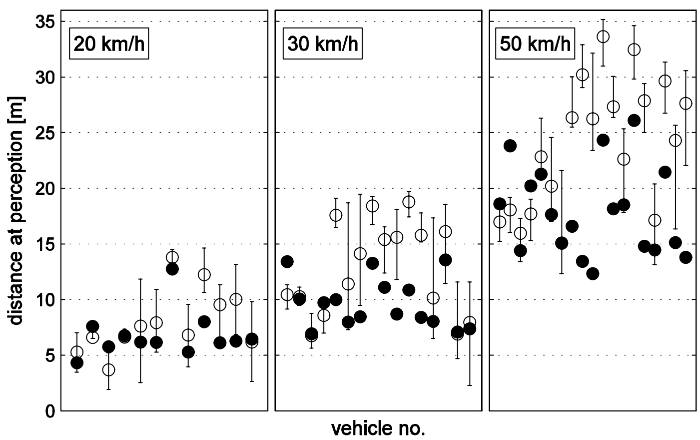

Figure 7: Comparison of experimentally determined distances (unfilled circles as medians with interquartile ranges) and predicted distances (filled circles).

Figure 7 enables a direct comparison of the data determined experimentally (unfilled circles) and the predicted distances (filled circles). Again it can be seen that for small distances at perception, the predictions frequently are within the interquartile ranges of the experimentally determined data. However, for distances larger than about 10 meters, the predictions become worse, presumably because of the reasons mentioned above.

5 SUMMARY AND OUTLOOK

The present paper describes investigations concerning the audibility of vehicle exterior noises in two different background sounds. As could be seen, none of the investigated vehicles was audible in time for safe collision avoidance in a background noise of 62 dB(A). However, by reducing the sound pressure level of the background noise by 7 dB(A) most of the vehicles investigated become audible just in time for safe collision avoidance. Additionally, a simple method for predicting the distance at perception was introduced. The method is able to predict the experimentally achieved results reasonably well for small distances. For larger distances, however, the predictions get worse, probably due to dependencies of the masked thresholds on the actual distance of a vehicle. As a following step, different methods for calculating masked thresholds (e.g. [7]) for vehicle exterior noises shall be examined and related to the data presented here. This should lead to predictions without the need for listening tests and hopefully to better results for the predictions at larger distances.

6 ACKNOWLEDGEMENTS

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