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NOISE CONTROL FOR QUALITY OF LIFE

The detectability of conventional, hybrid and electric vehicle sounds by sighted, visually impaired and blind pedestrians

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ABSTRACT
The timely detection of the vehicles by pedestrians is a prerequisite for road safety. In this study, the traffic condition in which a vehicle approaching to the pedestrian from 50 meter distance with partial load acceleration was investigated. The binaurally recorded sounds of 14 internal combustion engine cars, 4 hybrid cars, and 6 electric cars were presented to the visually impaired, blind and sighted participants. The criteria for the vehicle sound selection was to include broad spectral range with different temporal characteristics. The reaction times of 37 subjects were measured. In the reaction time experiment, the subjects were asked to imagine that they are standing on the curb waiting to cross a one-way street when there may be vehicle approaching from the left. The results show that pedestrians detect the sound of electric vehicles (without sound generator) much later than the sound of vehicles with internal combustion engines and relatively few signal elements are used to detect the sound of internal combustion engine vehicles.
Keywords: Electric Vehicle, Detectability, Blind

1. INTRODUCTION

Perception allows us to gather information regarding our environment using sensory inputs and to identify events and objects in this environment [1, 2]. Therefore, each sound can be regarded as information carrier. Vehicle noise is a combination of several sound sources, such as, combustion engine and its ancillary units, transmission system, exhaust system, etc. Its spectrum contains various time-dependent and time-independent tonal and broad band components. In the context of road safety, the vehicle sounds are useful for pedestrians to detect the vehicles. In addition to the detection, various vehicle sound properties may indicate the operating condition or the place of the vehicle. The results of an investigation of the National Highway Traffic Safety Administration (NHTSA) show that hybrid vehicles cause more crashes than conventional vehicles [3]. The objective of this study is to compare the detectability of conventional, hybrid and electric vehicle sounds. Therefore a reaction time investigation was conducted.

2. EXPERIMENT

2.1 Travelling Situation

The traffic condition, which was investigated in this study, is that a pedestrian standing on the curb waiting to cross a one-way street when there may be vehicle approaching from the left. In this condition, a vehicle approaching to the pedestrian from 50 meter distance with partial load acceleration in the presence of an ambient (Figure 1).

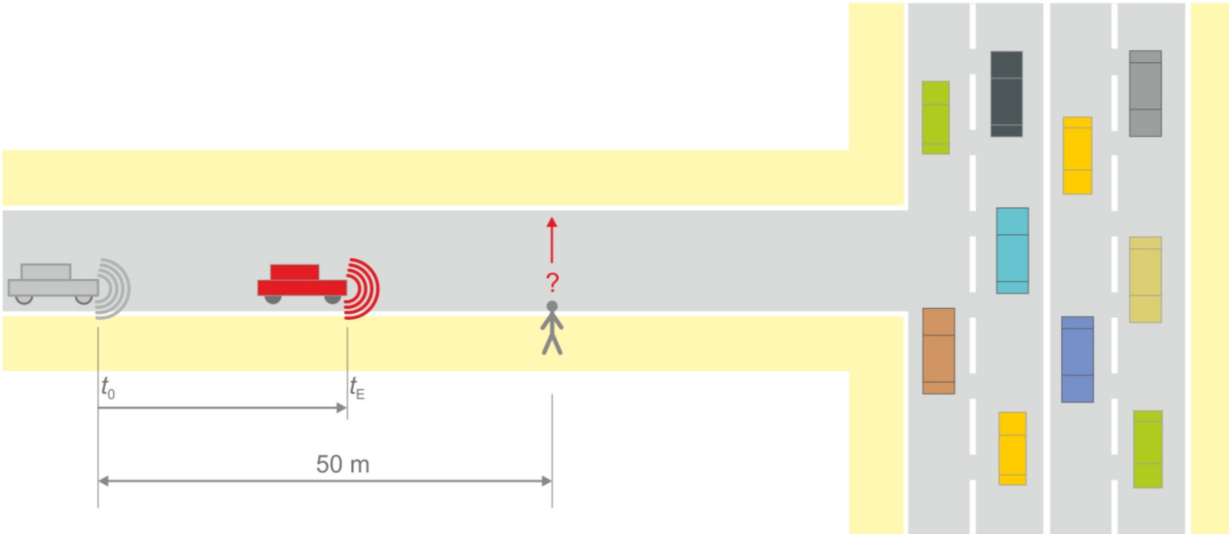

Figure 1 – Schematic representation of the investigated traffic condition

2.2 Stimuli

Several surrounding ambient noise level conditions were binaurally recorded and four of them (low, moderate, strong, very strong auditory masking), which are representative of many common urban ambient, were selected for the investigation. Although these ambient noises have a character of an ordinary road traffic noise, they don't consist of any exceptional instationary events. The sound pressure levels of the ambient noise conditions are given in Table 1.

Table 1 – Ambient noise level conditions

Ambient	Sound pressure level in dB(A)
Low	45
Moderate	47
Strong	57
Very strong	59

In this study, the driving condition is that car approaches with partial load acceleration with shift-operation. The binaural recordings of fourteen internal combustion engine (ICE), four hybrid, and four electric vehicles in this driving condition were used in the experiments. The vehicles were selected from different brands with different motorization. Additional criteria for the selection of the vehicles were the broad spectral range with different temporal characteristics and the mixture of old and new cars. In addition to the vehicle sound recordings, two sounds, which are 7 dB quieter than the quietest ICE sound, were synthesized (Figure 2). Both synthesized sounds consist of three sweeps in two different frequency ranges and therefore they have fewer spectral components than ICE sounds.

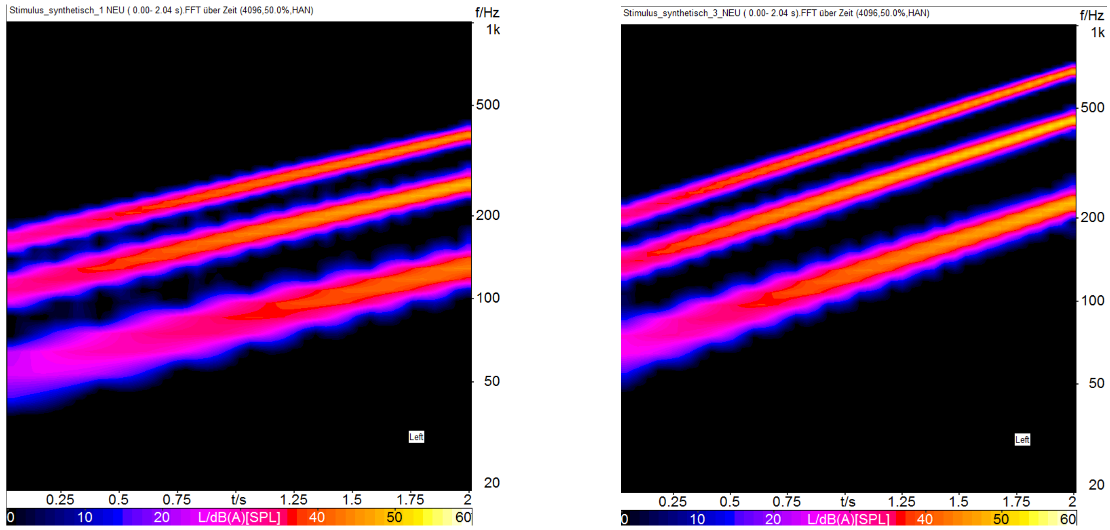

Figure 2 – The short-time Fourier transform (STFT)-based spectrograms of the synthesized sounds

2.3 Participants

Thirty-seven subjects, twenty-five men and twelve women aged between twenty and sixty-nine years (mean age: 34 years), participated in the experiment. Twenty-seven subjects are sighted and ten subjects are visually impaired or blind. All of the subjects were paid for their participation on an hourly basis.

2.4 Reaction time measurement

In this study, we examined the detection of vehicle sounds measuring the reaction time in presence of the ambient. Subjects were asked to imagine that they are standing on the curb waiting to cross a one-way street when there may be vehicle approaching from the left. They should to respond as quickly as possible by pressing a button, if they hear an approaching car. Presentations of the vehicle sounds followed each response with a random delay between 2 and 4s. Each sound was presented four times. The durations of the stimuli (accelerating pass-bys) were approximately 5 seconds. The reaction time values for the very loud ambient were averaged, and the mean scores (with standard deviation) are shown in Figure 3.

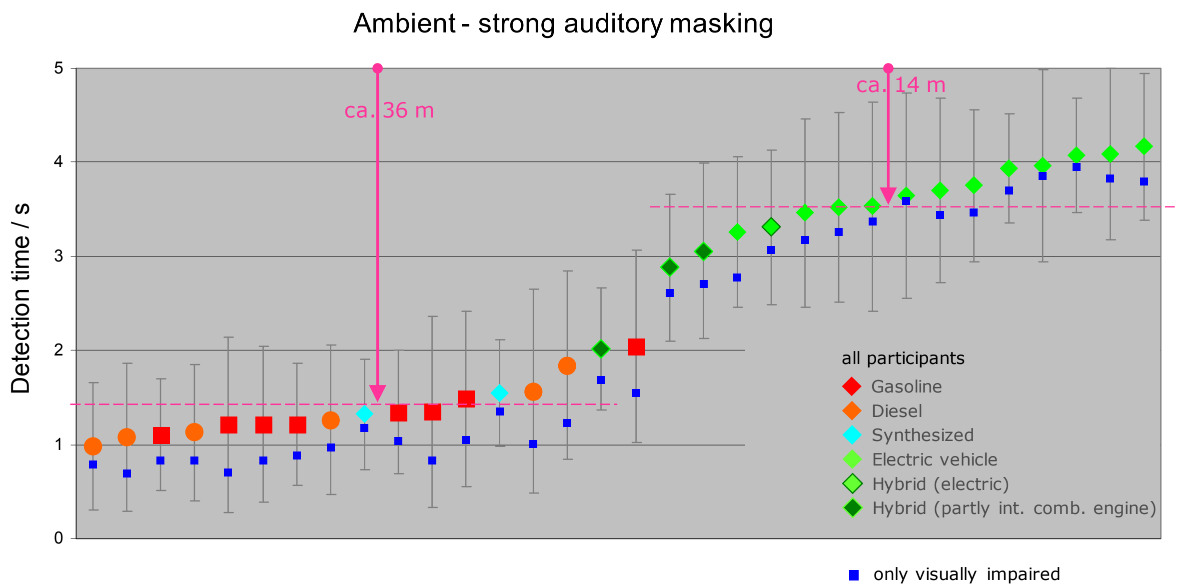

Figure 3 – Auditory reaction times to pass-by sounds of ICE, hybrid, and electric vehicles in the presence of loud ambience

The results show that pedestrians detect the sound of electric vehicles (without sound generator) much later than the sound of vehicles with internal combustion engines. While the sound of an internal combustion engine vehicle can already be detected at a distance of approximately 36 meters, the sound of an electric vehicle can be detected at a distance of approximately 14 meters. It is not observed a clear difference between the gasoline or diesel vehicles. The results of the visually impaired/blind participants show same trend with the results of the sighted participants. The results of the study also revealed that synthesized sounds, which are approximately 7 dB quieter than quietest ICE sound, have similar reaction time values as ICE sounds.

The reaction time values for different ambient conditions are compared in Figure 4. The results revealed that the ambients can be splitted into two groups. The results of the very low and low auditory masking ambients show great similarities and the results of the high and very high auditory masking ambients show great similarities.

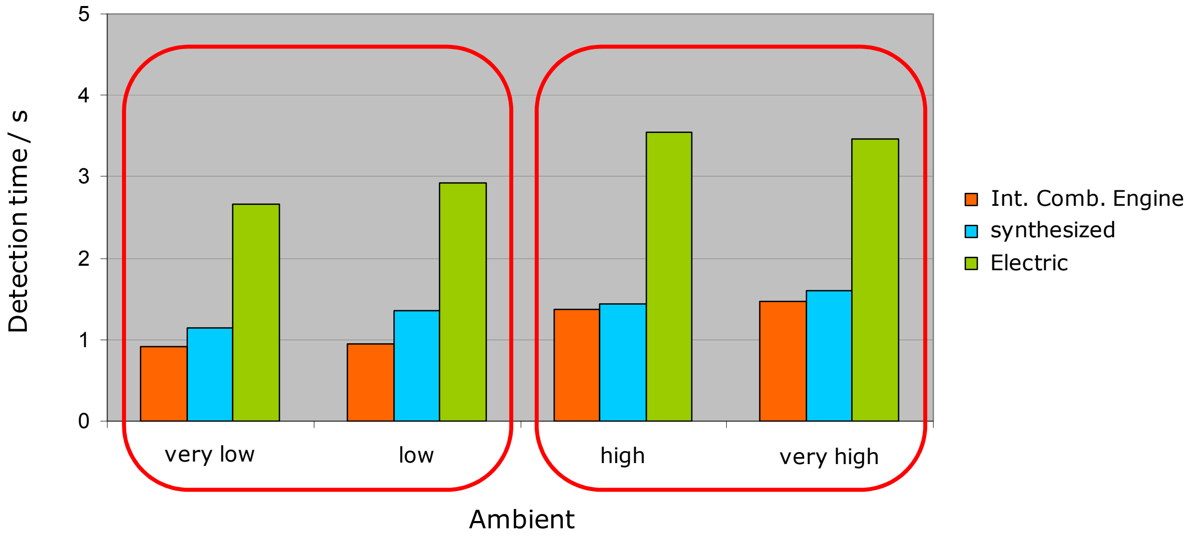

Figure 4 – The reaction times to vehicle sounds in the presence of four ambients

The comparison of the reaction time values with the detection sound pressure levels shows that there is no correlation between the reaction time of the pedestrians and the sound pressure level of the vehicle sound which is essential for the detection (Figure 5). Pass-by noises consist of various temporal and tonal properties, which may be useful for the detection.

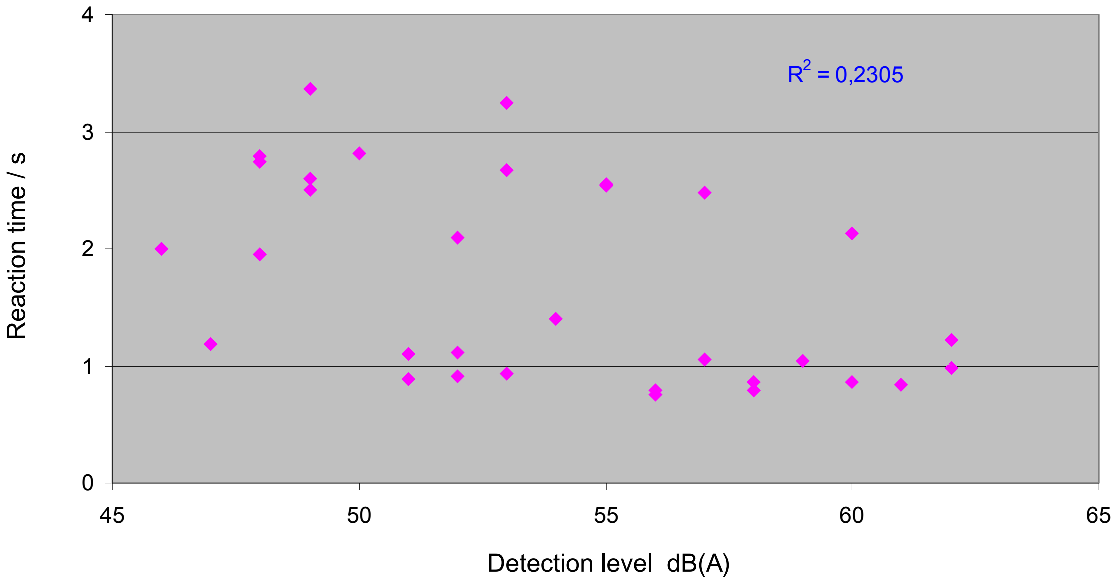

Figure 5 – Reaction time to vehicle sounds as a function of their detection level

Figure 6 shows one-third octave band spectra of fourteen ICE sounds (pink) and the strong auditory masking ambient (grey). For the one-third octave band analysis, the time period of 250 ms before and 250 ms after the detection was taken into account. The analysis results revealed that it is completely sufficient for detecting the sound of a vehicle from ambient, if individual one-third-octave bands (low or high frequencies) are prominent.

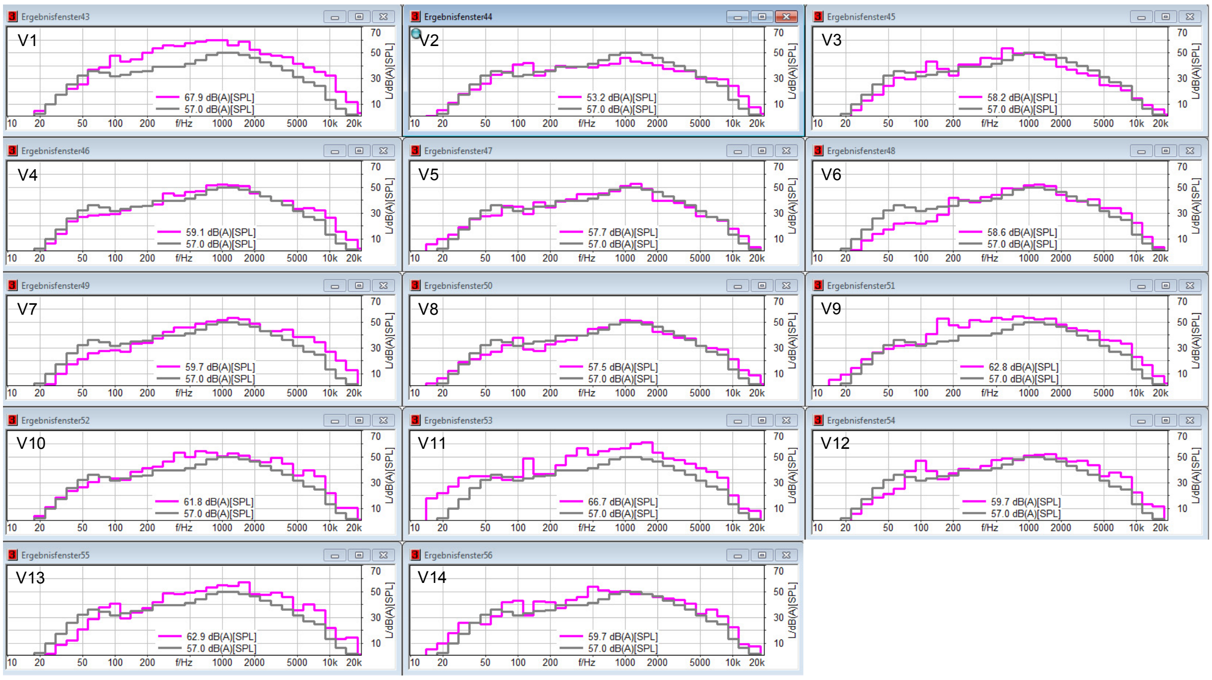

Figure 6 – One-third octave band analysis results of the ICE vehicle sounds and loud ambient

3. Conclusions

Pedestrians detect the sound of electric vehicles much later than the sound of vehicles with internal combustion engines. While the sound of an internal combustion engine vehicle can already be detected at a distance of approximately 36 meters, the sound of an electric vehicle can be detected at a distance of approximately 14 meters. There is no correlation between the reaction time of the pedestrians and the sound pressure level of the vehicle sound which is essential for the detection. It is completely sufficient for detecting the sound of a vehicle from ambient, if individual one-third-octave bands (low or high frequencies) are prominent. Synthetic sounds which are based on the engine speed can be detected as well as the sounds of internal combustion engine vehicle sounds.

ACKNOWLEDGEMENTS

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