There's a car coming? - Psychometric function for car pass-by in background noise based on simulated data

Alice Hoffmann, Penny Bergman, Wolfgang Kropp
Division of Applied Acoustics, Chalmers, Gothenburg, Sweden

Summary
To detect an approaching car in background noise is an important aspect of traffic safety. Therefore it is essential to understand the determinants that makes people recognize an approaching car especially when the cars become very quiet at low speeds as it is the case for electrical cars for instance. Most studies on the detection of passenger cars in background noise are based on recorded signals. This requires that suitable recordings are available both for the background sound as well as the test sound (i.e. the sound of the approaching vehicle). Due to the limited control of such situations the degrees of freedom to be varied in such experiments is limited as well. In the presented study a different approach has been employed. The utilized sounds are based on an auralization method that allows for simulating vehicle sounds including both tyre/road noise and propulsion noise. Single car events can thus be superposed to background sound with full control of all relevant parameters. The used auralization method has in earlier studies been validated for giving good perceptual ratings compared to recorded sounds. The method allows for evaluating the psychometric functions for single parameters and hopefully give a deeper understanding of the perceptual space for a car in background noise. In the present study the reaction time is measured for the detection of a car (test vehicle) passing by in the presence of background noise from a road with high traffic flow. The distance between the the path of the test vehicle and the highly trafficked road is varied. All other parameters (i.e. car-type, road surface, speed, etc.) are kept constant. The study shows that there is a logarithmic relation between the response times and the distance between the the track of the test car and the road with high traffic volume. At the same time there is a linear relation between reaction time and signal to noise ratio (i.e. the equivalent sound pressure level in relation to the background level).

PACS no. xx.xx.Nn, xx.xx.Nn

1. Introduction

For the traffic safety of pedestrians it is important that approaching cars are detected in the background noise due to overall traffic. This question has rendered increasing interest with more silent vehicles, such as hybrid or electrical vehicles (see e.g., [1] [2]). The addition of artificial sound is discussed at least for low speeds where these vehicles are quietest. In this context it is essential to know the parameters that a listener uses to identify an approaching car. Based on these parameters it might be possible to lower the emitted sound levels from vehicles, but maintain the information relevant for identifying them in time when approaching. Recent studies have focused on the perception of electrical vehicles (see e.g., [3] [4]). In [3] by Grosse the differences in audibility between cars using a combustion engine and cars using electric engines were evaluated. The sounds of vehicles passing by were recorded binaurally and presented with either recorded traffic noise or pink noise as background noise. The results indicate that electric cars are less audible than cars with conventional combustion engines when approaching at low speeds. The study also indicated that pink noise is not a suitable substitute for the recorded traffic noise since the reaction times differed substantially when using pink noise as background noise. A study by Altinsoy [4] measured reaction time differences between cars with combustion engines and cars with electric engines. The results showed that the participants detected the electric cars later than the cars with combustion engine. This study also utilized recordings for the different stimuli.

The drawback however when using recordings is, that it is difficult to vary the contents of the sound signals systematically as needed for a thorough parametric study since e.g. the composition of the traffic responsible for the background noise cannot be controlled. Therefore in the present study simulated data has been used instead of recordings. This allows for systematically varying parameters such as speed, traffic composition, tyres, road surfaces or vehicle type individually.

1.1. Aim

The aim of the the study is to investigate the reaction time for detecting a car with combustion engine (test vehicle) passing by in the presence of background noise from a road with high traffic flow. The distance between the path of the test vehicle and road with high traffic volume is varied. All other parameters (i.e. car-type, road surface, speed, etc.) are kept constant. The hypothesis is that the closer the distance between the lane of the test vehicle and the road with high traffic volume the more difficult it will be for the listener to detect the single car. The change in distance will strongly effect the signal-to-noise ratio (SNR) and thus have a strong effect on the detection of the test car. The SNR is here defined as the difference between the equivalent sound pressure level from the test vehicle and the equivalent sound pressure level from the road with high traffic flow.

1.2. Simulation of traffic sound from vehicles

The method for simulating traffic sound from vehicles combines the SPERoN prediction model [5] with the Auralization tool developed by Forssén [6]. It allows for simulating a pass-by sound of a single car with desired speed and distance from the listener. The simulation utilizes information of the road surface, the tyres, the car and the engine sound. The propagation of sound can also include multiple reflections or noise barriers. It is further possible to include tonal components in the source characteristics, either in order to integrate the sound by an electric engine ore as additional warning sounds.

In the simulation process the SPERoN model defines tyre and road types, the driving speeds and load (i.e. weight of the vehicles) and provides the source characteristics in the form of third octave band spectra to the auralization model. SPERoN is a so-called hybrid model where physically based parameters (i.e. calculated contact forces) are related to sound pressure levels measured under controlled pass-by conditions by a statistical model. The underlying measurements are included in an extensive database [9] created in the so-called Sperenberg project. The SPERoN demands detailed information about the road surfaces (measured roughness, flow resistance) and the tyres (mechanical properties and profile). In addition speed and vehicle load are given as the input data.

The auralization approach used in this study is based on the Listen Demonstrator, which was developed by Forssén [6] in the so-called Listen Project . The main concept of the demonstrator is to separate the source signal and the propagation effects form recordings. The starting point was a recorded monaural pass-by signal of a car with defined parameters like speed, tyre specifications and road specifications. The propagation was treated in five steps, considering directivity, ground reflections, air attenuation, distance effect and Doppler effect. Applying the inverse propagation effects to the pass-by signal, a stationary signal is obtained that can be considered as source signal. This source-signal is separated in two therms. One therm characterizes the propulsion related sound sources like the engine, air intake, air exhaust etc.. The second source therm characterizes the tyre/road noise. Both therms can be modified to create new driving scenarios with differing speeds, road surfaces and tyres.

For the applied auralization method, the source therm that characterizes the tyre/road noise is shaped by the third octave band spectra calculated by SPERoN. To create new pass-by signals according to the source parameters defined in SPERoN, the propagation effects are added to create the final signal at a defined receiver position.

This approach to generate signals offers a method with full control and flexibility of all parameters. By adding up the single vehicles it is possible to design and investigate complex traffic situations. The approach that is based on previous studies where the perception of simulated pass-by noises where shown to be in good agreement with corresponding recordings for different tyres and different road surfaces (see [7] and [8]).

1.3. Test situation

For the auralization of the signals used in the present study, a Pirelli tyre (type P600, size 205/60-R15 91V) on an asphalt concrete surface 0/8 constructed to fulfill the requirements of ISO 10844-1994 was used. For the car a combustion engine was chosen. Figure 1 shows the position of the listener in relation to the track of the test car and road with high traffic responsible for the background noise

The test car had a driving speed of 50 km/h. The test car was always approaching from the left side. The pass-by duration of the test car was 6 seconds where after 3 seconds the car was directly in front of the listener.

For the background noise the traffic flow was created by superposing single car pass-by events that are based on the same vehicle properties as the test vehicle. For this a traffic flow of 3600 vehicles per hour and lane was assumed (i.e. 1 car per second and lane in average). The sequence of the vehicles were varied

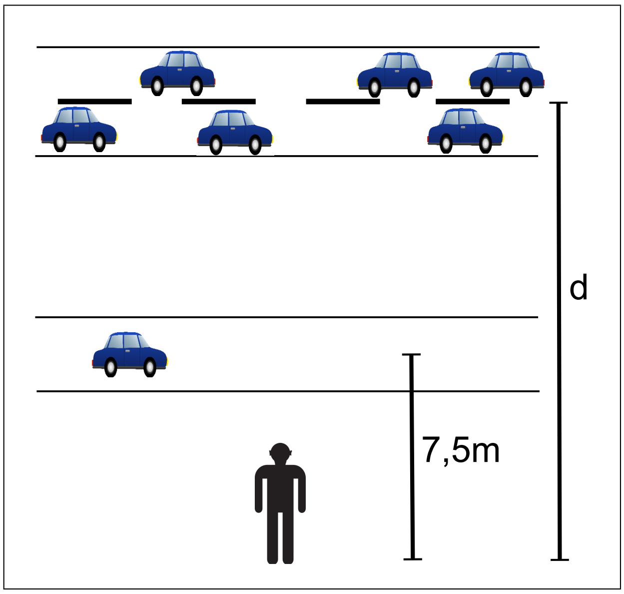

Figure 1. Illustration of the auralized traffic situation. The distance d was varied between $7.5m$ and $100m$

Table I. A-weighted Levels of the used simulated background sound files Given are the mean values over the 6 cases of the same distance from the simulation for each distance

d	$L_{eq}, dB(A)$
7.5m	61.25
10m	59.69
20m	55.27
30m	52.32
40m	49.98
50m	48.18
60m	46.85
70m	45.71
80m	44.80
90m	43.82
100m	43.04

in a band of $+/-0.4$ seconds to consider traffic density fluctuations without overlapping the virtual positions of the cars. The speeds were distributed with an approximated normal distribution around $50km/h$ (from $44km/h$ to $56km/h$ in $2km/h$ steps) for each lane.

The distance d between the road with high traffic flow and the listener was varied between $7.5m$ and $100m$. 7.5 meters was included, to have a case where the background street and the test street are at the same position. Further on the distances were varied from $10m$ to $100m$ m in $10m$ m steps.

For the binaural impression open source KEMAR dummy head recordings by Gardner and Martin at MIT [10] were utilized. These recordings provide head related transfer functions in an angular resolution of 5 degree on the horizontal plane.

2. Method

25 participants (15 male, 10 female) participated in the listening test ($M = 29.2$ years old, $s.d. = 9.7$ years). All participants reported normal hearing. The participants were paid for their participation and gave their informed consent prior to the inclusion of the study.

To evaluate the impact of distance in the recognition of a car in a traffic noise background a set of stimuli were created as described in the auralization method. The background traffic noise was created for a varying distance d from the listener as described above. For each distance six different sound files were generated, in total 66 different background noises were created. The levels of the resulting background traffic noises in the simulation without calibration are given in table I. The test car had the level of $L_{eq} = 50.40dB(A)$ in the simulation.

The table reveals that the equivalent sound pressure levels do not decay with the 3 dB per distance doubling as expected. This is due to the length of the single pass-by events of 6 seconds which do only represent a road of about $80m$ length for a driving speed of $50km/h$.

The listening test was conducted in a soundproof and neutral room. The test was set up on a computer and the sounds were presented via open headphones (Sennheiser HD 650). The focus of the experiment was to investigate the influence of the distance and subsequently the relative changes in sound levels on the reaction time; hence the sound levels were adjusted to never be too loud, but still audible, without changing the relation between the signals.

The participants were given the information that they were standing in front of two roads (see 1), the more distant road was described as a road with heavy traffic and the closest road was described as a street with few single cars passing by from time to time. The participant were asked to listen for an approaching car on the nearer road and press the space key on a normal keyboard as soon as they detect the test car. They were further told that this car could only appear when a green arrow was shown on left side of the screen. Between the trials no arrow was shown, and if the participant missed a car a red arrow was shown on the right side of the screen.

The reaction time for detection of the test car was measured between the onset of the test car sound and the time the participant pressed the space key on the keyboard. If no response was given, the trial was counted as a miss. When the participant pressed the key the trial ended and a new trial started.

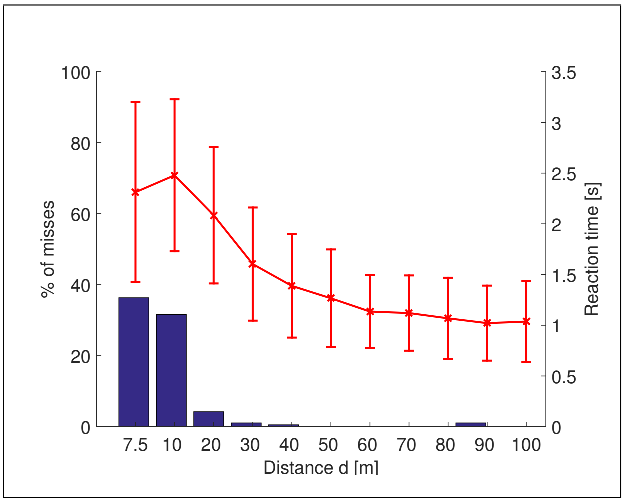

Figure 2. The figure shows the average reaction time and standard deviation over the distances d (as defined in figure 1). The boxplot shows the relative amount of misses for the different background signals.

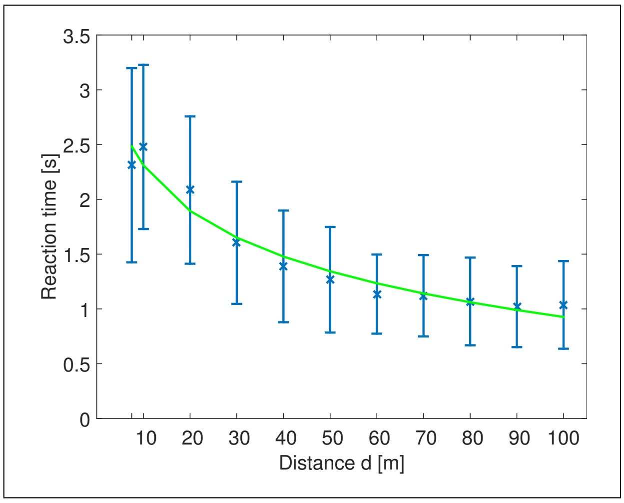

Figure 3. Average reaction time and standard deviations of the reaction times over the distances d (as defined in figure 1) and the fitted line from the regression analysis (green).

For each trial in the experiment a background signal was presented at random from the 66 different background noises. With a random delay the test car was presented during the playback after the onset of the background signal. The delay varied between 0.3 and 5 seconds. To avoid accidental keyboard operations reaction times were only registered 0.1 seconds after the onset of the test car. The test car needed 3 seconds to reach the frontal position to the listener. The Intertrial interval was 1 second containing silence. Each participant conducted 2 session of the 66 background signals with a short break in between. To ensure that the participant actually responded to when they heard a signal one trial of each condition only contained the background signal (a false positive test).

3. Results

Due to an error in the computer program 3 participants had to be removed from the analysis of the results. Furthermore 1 participant had not understood the task and was therefore removed. Removal was further done in 2 steps. Reaction times extending 3 times the standard deviation from the average response at an individual level were considered as outliers. No outliers were found in the responses.

Participants making a false positive response (i.e., responded to hearing a car even when there was no car present) in more than 15% of the cases were further removed. The two nearest conditions (7.5 m and 10 m) had a higher risk of leading to a false positive responses and were not included in the 15% limit. This resulted in another 3 participants being removed from the analysis, since their responses were not seen to be consistent enough. For the remaining participants the false positive responses varied between 0 and 11% ($M = 3.7\%$). In total 18 participants were included in the further analysis.

The maximum latency was decided to 3000 milliseconds after the onset of the test car, latencies longer than this was replaced by 3000 milliseconds. In figure 2 the average response time for the different distances are presented together with the percentage of misses. A repeated measure analysis of variance (ANOVA) with distance as main factor determine that there was a main effect of distance ($F(10, 170) = 111.04$, $p < .001$). Bonferroni post-hoc tests revealed that when the background sounds were presented at >50 meters there was no significant difference between the adjacent distances and that there was no significant difference between the 7.5 meters and the 10 m distance. To determine the reaction time of detecting a car as a function of the distance from the background a regression analysis was conducted. This resulted in a logarithmic regression that explained a significant proportion of the variance in reaction time ($b = 601.3, t(9) = -13.77, p < .001$, $R^2 = .96, F(1, 9) = 189.67, p < .001$) as is illustrated in 3.

Since the change in SNR for the different cases is expected to have a strong effect on the reaction time, a regression analysis using reaction time as function of the SNR was done. The SNR significantly predicted the reaction time ($b = .084, t(9) = -14.66, p < .001$). The SNR also explained a significant proportion of variance in the RT ($R^2 = .96, F(1, 9) = 214.77$, $p < .001$). This is illustrated in figure 4 where the regression and the average reaction time is plotted over the SNR between the L_{eq} of the test signal and the L_{eq} of the background noise for the 11 distances.

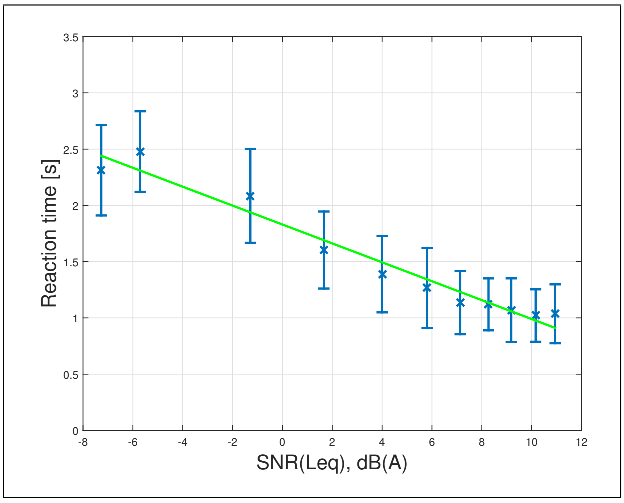

Figure 4. Average reaction time and standard deviations of the reaction times over the SNR between test signal and background noise for the 11 cases.

4. Discussion and future work

The aim of the present study was to investigate the ability of a listener to detect a car in the presence of background noise due to traffic. The varied parameter in the study is distance between the the listener and the road with high traffic flow responsible for the background noise background noise. In contrary to most of the published work simulated sound files for both the test vehicle an the background noise were used. The results showed that there is a logarithmic relation between the response times and the distance d between listener and the road with high traffic flow. The logarithmic relation indicates that the sound pressure levels or better the SNR governs the reaction time as expected. This is confirmed by a second regression analysis, relating the reaction time to the SNR. The SNR has a linear relation to the reaction time (figure 4). The regression analysis predicts the reaction time with statistical significant agreement. Thus the change in reaction time with distance is mainly explained by the change in SNR.

The results also show that the method of using simulated data instead of recorded data seems to be a feasible approach as it is demonstrated here. The study by Grosse [3] indicates detections of cars in background noise from traffic with reaction times of 1 sec before the pass-by until 1.5 seconds after the pass-by for different cars with combustion engines. The background noise was recorded for a road 50 meters away from the road where the car is assumed to pass-by. The results are in agreement with the findings of the presented study, where the reaction time was around 1 second before the pass by for $50m$ distance. In the presented study only one car with combustion engine was studied.

The demonstrated approach will be utilized further to investigate the influence of e.g. separate components such as rolling noise or engine noise on the reaction time. This will hopefully give a better insight into the situation where additional measured are need for a better detection of e.g. electric vehicles and the the possibilities to improve such a detection in ordinary traffic situations.

References

[1] National Highway Traffic Safety Administration (NHTSA): Incidence of pedestrian and bicyclist crashes by hybrid electric passenger cars, 2009

[2] Pedestrian Safety Enhancement Act of 2010, USA, 2010.

[3] J. Grosse, R. Weber, S. Van De Par: Comparison of detection threshold measurements and modeling for approaching electric cars and conventional cars presented in traffic and pink noise, Proceedings of Meetings on Acoustics, 2013, Vol.19.

[4] E. Altinsoy: The detectability of conventional, hybrid and electric vehicle sounds by sighted, visually impaired and blind pedestrians, 42nd International Congress and Exposition on Noise Control Engineering 2013, INTER-NOISE 2013: Noise Control for Quality of Life, 2013, Vol.7, 5385-5389.

[5] W. Kropp, K. Larsson, F. Wullens, P. Andersson, F.X. Bécot: The generation of tyre/road noise - Mechanisms and models, Proceedings of the Tenth International Congress on Sound and Vibration, 2003, 4289-4301.

[6] J. Forssén, T. Kaczmarek, J. Alvarsson, P. Lunden, M.E. Nilsson: Auralization of traffic noise within the LISTEN project - Preliminary results for passenger car pass-by, 8th European Conference on Noise Control 2009, EURONOISE 2009, Vol. 31.

[7] A. Hoffmann, J. Forssén, W. Kropp: Auralization of tyre/road noise based on the SPERoN prediction tool, Proceedings AIA-DAGA Euroregio, Conference on Acoustics, Merano, Italy, 2013.

[8] A. Hoffmann, J. Forssén, W. Kropp: Extended Auralization of tyre/road noise based on the SPERoN prediction tool [Optimierung der Auralisierung von Reifengeräuschen basierend auf dem Modellierungs-Tool SPERoN], Proceedings DAGA, Conference on Acoustics, Oldenburg, Germany, 2014.

[9] T. Beckenbauer, P. Spiegler, G.van Blokland, A. Kuijpers, F. Reinink, S. Huschek, T. Stütze, J. Heerkens: Effect of pavement texture on tyre/pavement noise [Einfluss der Fahrbahntextur auf das Reifen-Fahrbahn-Geräusch], German Federal Ministry of Transport, FE-Nr. 03.293/1995/MRB, 2002.

[10] B. Gardner, K. Martin: HRTF Measurements of a KEMAR Dummy-Head Microphone, MIT Media Lab, Machine Listening Group, 1994 .