On the Effect of Second Task for Detection of Alerting Sound of Electric Vehicles

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ABSTRACT

Relative quietness of electric or hybrid electric vehicles is a matter of safety concern, because they are potentially dangerous to pedestrians when the approach of them becomes inaudible under urban noise. Hence, regulations regarding additional alerting sounds for the quiet vehicles (Acoustic Vehicle Alerting System; AVAS) have been developed in Japan as well as in global. Several studies have been conducted in different institutions to examine the feasible sound design for the AVAS to be detected in urban noise environment. In this paper, a cross-cutting perspective on the detectability of the AVAS sound compared to the background noise levels is provided. The acoustic power level of the vehicle sound, that means total acoustic power including mechanical and the alerting sound, was calculated from the sound level based on semi-free field assumption. Then the A-weighted sound pressure level al the point of the participants were estimated from the distance data in the literatures. The result suggests the effect of second task of the pedestrians. The paper also provides a pilot study on such effect through a laboratory experiment.

Keywords: Electric Vehicle, Acoustic Vehicle Alerting System (AVAS), Second Task, Traffic Noise
I-INCE Classification of Subject Number: 68, 79, 81

1. INTRODUCTION

During the last decade, the vehicles that are propelled in whole or in part by electric motors, such as Electric vehicles (EV) and hybrid-electric vehicles (HEV), are becoming common in urban fleets, and the number of production is rapidly increasing. By the end of 2018, the number of registered EV, plug-in HEV, and HEV in Japan[1] has reached 7.5 million, which is 12.3% of all registered passenger vehicles (see Fig. 1).

These vehicles are regarded as environmental friendly due to their fuel efficiency and low-carbon emission. In addition, these vehicles emit lesser noise than the conventional internal combustion engine vehicles (ICEV) particularly when they are travelling at lower speed. This quietness is certainly beneficial for environmental noise reduction. The sound level limits emitted by running vehicles have been reduced for last

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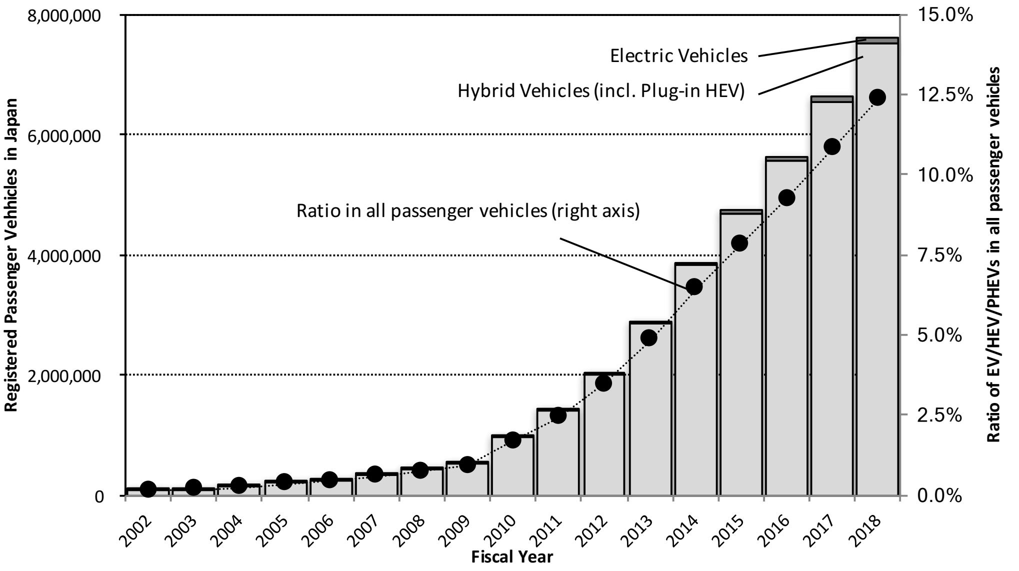


Fig. 1 – Number of registered EV and HEV and their ratio in total number of registered passenger vehicles in Japan (data was obtained from [1])

some decades, which intend to reduce road traffic noise pollution. The quiet vehicle is one of the goals for the noise reduction drive.

On the other hand, the quietness of such vehicles has also been regarded as a matter of concern, because they are potentially dangerous to pedestrians when the approach of them becomes inaudible under urban noise. This is of particular concern to the blind community. Hence, the regulations to minimize the risk posed by quiet vehicles have been developed in some governments, using additional sound-emitting devices to enhance pedestrians' awareness without creating a disturbing level of noise. Effectiveness of the additional warning sounds for pedestrians is discussed in this paper.

2. LEGISLATION TRENDS

The first measure was taken in Japan. In 2010 the ministry of land infrastructure and transportations (MLIT) published the guideline for the measure against the quietness problem of hybrid vehicles[2]. This Japanese guideline was arranged to be the international guideline[3] that was published from UNECE World Forum for Internationalization of Vehicle Regulation (UNECE/WP29). The WP29 established an informal group for quiet road transport vehicles, and have been discussed on the development of the regulation. Finally, in March 2016, the UN Regulation No.138 (R.138) on Quiet Road Transport Vehicles, QRTV, with regard to their reduced audibility[4] was published. In Japan, as following the publication of the UN regulation, MLIT have announced officially that the mandatory for installing the system will be enforced from March 2018.

In these guidelines and regulations, the system, which is named as "Acoustic Vehicle Alerting System (AVAS)," is defined to create artificial noise in the speed range from 0 to 20 km/h. The R.138 introduces the minimum sound level, spectral characteristic, and frequency shift depending on the vehicle's speed. The minimum levels are given for constant speed tests, 10 km/h and 20 km/h, and reversing test. The test condition is described in the Annex of the regulation, which is similar to the ISO-16254 "Measurement of sound emitted by road vehicles of category M and N at standstill and low speed operation"[5]. The minimum level of overall A-weighted sound level is

Table 1 – Minimum sound level requirements regulated in R.138[4]

		Minimum Sound Level Requirements (A-weighted) [dB]		
		Constant Speed Test (10 km/h)	Constant Speed Test (20 km/h)	Reversing Test
Overall		50	56	47
1/3rd Octave Bands [Hz]	160	45	50	
	200	44	49	
	250	43	48	
	315	44	49	
	400	45	50	
	500	45	50	
	630	46	51	
	800	46	51	
	1k	46	51	
	1.25k	46	51	
	1.6k	44	49	
	2k	42	47	
	2.5k	39	44	
	3.15k	36	41	
	4k	34	39	
	5k	31	36	

regulated to be 50 dB at 10 km/h, 56 dB at 20 km/h, and 47 dB for reversing. The spectral characteristic is regulated by minimum levels for each 1/3 octave band from 160 Hz to 5 kHz (see Table 1).

3. EXAMINATIONS ON FEASIBLE SOUND LEVELS OF AVAS

In this section, some reviews on the survey and experimental examinations regarding the feasible design for the alerting sounds are provided. Many studies have been conducted on the issue, how to design the sounds if those were utilized. After such works, the quality discussion on feasibility would be realized.

3.1 Social Survey on AVAS

One of the outcome from a questionnaire survey[6] was that the sound should not a simple imitation of conventional engine. The survey was conducted from December 2010 to January 2011 in Fukuoka (Japan) and Munich (Germany) to examine cross-cultural differences. The questionnaire consisted of some chapters; questions about the experience as a pedestrian, questions about the experience as a driver, questions about the opinion to the measure to quiet vehicles. After five years from the previous survey, in

2016, another questionnaire survey was carried in Japan[7]. The responses to the questions on respondents' experience of unaware vehicle approaching showed that approximately 45% experienced feeling dangerous or unsatisfaction as a driver, while approximately 70% experienced that as a pedestrian. According to the subquestions asking the detailed situation, usage of headphone audio was one of the highlighted factor of such experiences. The responses to the questions on the encountering experience with EV/HEVs revealed that majority of them have such experience and have the impression that EV/HEVs are quiet. The result also showed that approximately half of people know the equipment of AVAS, however half of them don't know the sound of that. Moreover, it was revealed that more than 60% agree with the effectiveness of AVAS but non-negligible number of respondents indicated the necessity of modification of the present AVAS sound.

3.2 Feasible Sound Level for AVAS

On the other viewpoint, feasible sound levels and detectability for the alerting sounds in the urban noise environment have been examined by several institutions. Based on some of these studies and simultaneous masking theory, the minimum requirement sound levels were determined for the regulations. However, detectability sometimes varies among experimental conditions.

Yamauchi et al. [8–10] conducted a series of examinations on feasible sound level of AVAS. In these examination, the feasible levels were discussed in the reliable level and in the minimum level. The alerting sounds were presented to the subjects over a background noise via headphone, which were recorded on sidewalk in Japan. Input voltage to the headphones was measured, so that the playback level could be calibrated taking into account the headphones' sensitivity. The subjects were asked to adjust the level of the alerting sounds for two scenarios; one was that reliably detected if they were not concentrate in listening to their environment (reliable level), the other one was that just audible in the background (minimum level). The result showed that the adjusted levels were affected by background noise level for both criteria. The results showed that the adjusted levels were strongly affected by the background noise and lower for quieter noise environment. The reliable levels were 10 to 15 dB higher than the minimum levels, and the levels were varied among the alerting sounds with different characteristics. Similar experiments ware conducted using different conditions of test sounds, background noise, and subjects' age[9, 10]. Although the background stimuli and alerting sounds were varied, the results of minimum level examination were always lower than that of reliable levels, and the levels correlated with the background level.

For further discussion, some literatures should be referred. There are some examinations on detection distance using test vehicles on test courses. Gläser et al.[11] examined the detection distance on their test site. They used three vehicles; an EV, a luxury ICEV, and an old diesel car; and blind and sighted subjects. The test vehicles were driven in constant speed from far away to the participant, and the participants were asked to react when they hear the approaching vehicle. Similar examinations have been conducted in Japan using an EV installed additional alerting sounds[12, 13]. In the latest examination, the subject asked to read news articles as a second task, which was designed to examine the effect on detection performance[13]. The other group of examinations on detection distance used the pass-by simulation in laboratory. Parizet et al.[14] used a recorded pass-by sound of a HEV and simulated alerting sounds were added to that. Altinsoy[15] conducted the examination with wide variety of stimuli. Poveda-Martinez et al.[16] also conducted similar examination, but in the condition of passing-by at 30 km/h.

The main data from all these examinations were distance or reaction time among the conditions of the sound pressure level of the vehicle with or without the alerting sound. In this paper, the detected sound level of the alerting sound under the environmental noise is focused. Once all the data were converted in sound power level. The sound power level of the vehicle sound, that means total acoustic power including natural mechanical sound from the vehicle itself and the additional alerting sound, was calculated from the sound level based on omnidirectional point source and hemi-free field assumption. Then, the A-weighted sound pressure level at the point of the participants were estimated from the distance data in the literatures above.

Fig. 1 shows the comparison of detection levels from varied background conditions obtained from several studies[8–13]. The vertical axis is A-weighted sound pressure level of the alerting sound that was just detected in each background noise condition. The horizontal axis indicates equivalent A-weighted sound pressure level of the background noise in the experiment. The symbols represent each different examination. The overall A-weighted sound levels for 10 and 20 km/h indicated in R.138 (see Table 1) were indicated in the figure as the horizontal dashed lines.

The detection level correlated with the background level. However, the correlation is not clear. Even for similar background noise level condition, the value on vertical axis varies widely. Among the authors' examinations, such as by Yamauchi 2015[8], Yamauchi 2014[9], and Yamauchi 2013[10], the minimum levels are below the lines, while the reliable levels are above the lines particularly in the environment in 60 dB or louder. Moreover, it is interested that the distribution might be divided into two clusters. Some of examination, such as by Parizet 2014[14] and Gläser 2012[11], are distributed in lower than the lines and similar to the minimum levels. The others, such as by Poveda-Martinez 2017[16] and Altinsoy 2013[15], show the similarity to the reliable levels. Although it is difficult to compare among the experiments without considering the time-domain fluctuation of alerting and background noise, it is suggested that the instruction and/or tasks for the participants may affect on the detection.

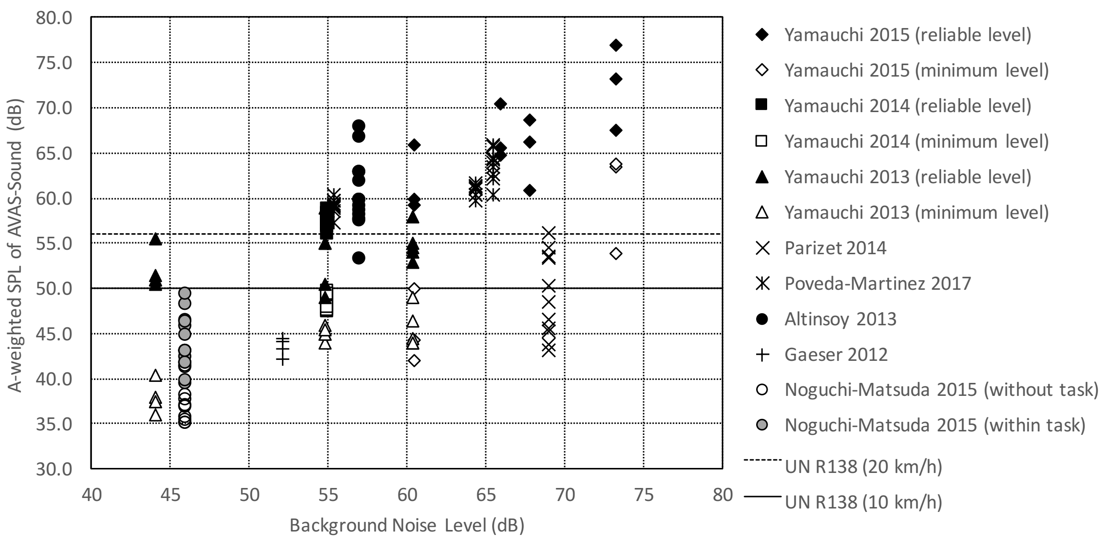


Fig. 1 – Comparison of detection levels obtained from the literatures

4. EXPERIMENTAL EXAMINATION OF SECONDARY TASK ON DETECTION LEVEL OF AVAS

In the previous attempt, cross-cutting comparison of detection level in the literatures, the influence of participants' tasks on the detectability was suggested. With regard to the issue, an experimental examination of secondary task was designed.

4.1 Method

The test AVAS stimuli were presented randomly via headphone to the participants who were listening to the background environmental noise and playing game application on a touchpad device. The experiment was designed by the method of constant stimuli. The participants were asked to answerer when they detect the AVAS stimulus.

4.1.1 Stimuli

The test stimulus was an AVAS sound commercially available. The sound was recorded close to the device on a hybrid vehicle (TOYOTA/ Prius), then played via loudspeaker and recorded by a head-and-torso-simulator (HATS, Brüel & Kjær/ type 4100) in an anechoic room. The loudspeaker located 2.0 m forward to the HATS. The relative height from loudspeaker level to the ear position of the HATS was 0.6 m. The duration of 2.0 s was extracted from re-recorded sound.

The background environmental noise was recorded with the HATS on sidewalk in Japanese shopping street, which was also used in the previous experiment[10]. The equivalent contentious A-weighted sound pressure level (L_{Aeq}) via headphone was configured to be equal to the recorded site, which was 60.3 dB.

4.1.2 Secondary Task (game application)

Two kind of game application as secondary task were used in the experiment. Both are free and available in the application distributing service (Apple/ AppStore). The first one (hereafter "Game 1") was Touch the Number by Riana Uchima. Forty-nine blocks with numbers are shown on the screen, which the user can tap sequentially from 1 to 49. If the user taped the block with the smallest number, the block is disappeared. The user tries to tap all blocks as faster as possible. The elapsed time until

The other one ("Game 2") was PokoSwitch by Ken Okamura. There are many nubs on the screen, which can be collapsed by tapping. When the all nubs were collapsed, the other nubs appeared.

In the experiment, the participants were asked to clear the games as many as possible during the test trial. The participants were asked to play only with dominant hand.

The Game 1 required the participants to concentrate more to search the numbers, while the Game 2 was easy and could be regarded as a time-killing application. In the analysis, it was assumed that the secondary task condition with Game 1 was higher concentrating condition than the other.

4.1.3 Procedure

The participants were asked to response on the keyboard when they hear the AVAS stimulus. The stimuli were repeatedly presented to the participants, where the presentation intervals were randomly selected from 7 to 12 s. The A-weighted sound pressure level via headphones (Sennheiser/ HD650) were 30, 35, 40, 45, 50, or 55 dB. The presentation level was calibrated before the experiment by using artificial ear (Brüel & Kjær/ type 4153), pressure field microphone (Brüel & Kjær/ type 4192), and sound level meter (Brüel & Kjær/ type 2250).

Fig. 2 – Experiment conducting in the anechoic room.

The experiment was conducted in an anechoic room in Kyushu University (Fig. 2). Six kind of stimuli, with different presentation levels, were presented 8 times for each, then in total 48 stimuli were presented in one test trial. The duration of each test trial was around 10 minutes. During the test trials, the background stimulus was played continuously and the participants were asked to keep playing game application on the device (Apple, iPad 9.7 inch) by their dominant hand. When they hear the AVAS stimulus, they had to press the space bar of the keyboard placed next to the touchpad device.

The participants alternated two secondary task conditions and took 8 trials in total (4 trials for each). The first conditions were counter-balanced among the participants. The participants' behavior were recorded by a video camera.

4.1.4 Participants

Twenty students, 10 females and 10males, aged between 20 and 25 participated in the experiment. None of them reported any auditory abnormality.

4.2 Result and Discussion

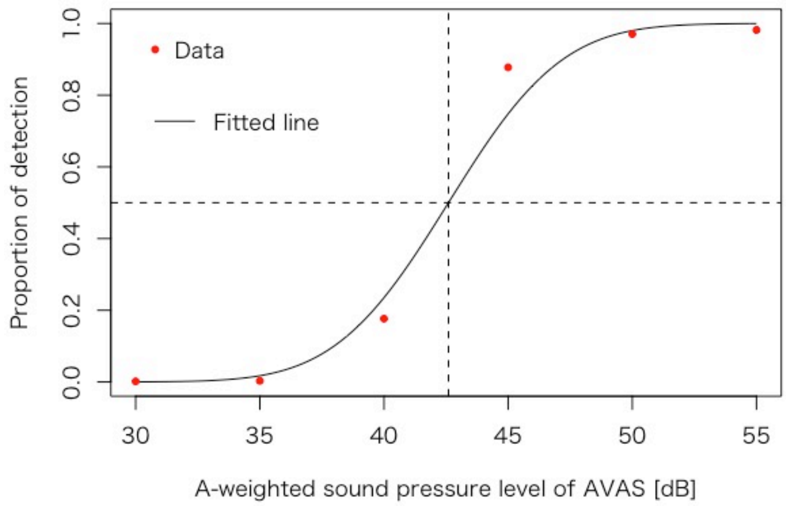
To ensure the higher concentrating condition, the playing time to clear was measured for the Game 1. The outliers were excluded from the analysis by the Smirnov-Grubbs test for each participant.

The participants' reactions, pressing the keyboard, within 2.0 s after the AVAS stimuli presentation were counted as the detection. The detection probability for each presentation level was calculated, then the cumulative normal distribution curve was estimated by probit regression analysis. Figure 3 shows the probability and the regression for each secondary task condition. The A-weighted sound pressure level that shows the detection probability of 0.5 was 42.6 dB with 3.6 dB standard deviation for Game 1 condition, while that was 43.1 dB and 3.7 dB for Game 2. The detection levels were not significantly different between two secondary task conditions with different concentration.

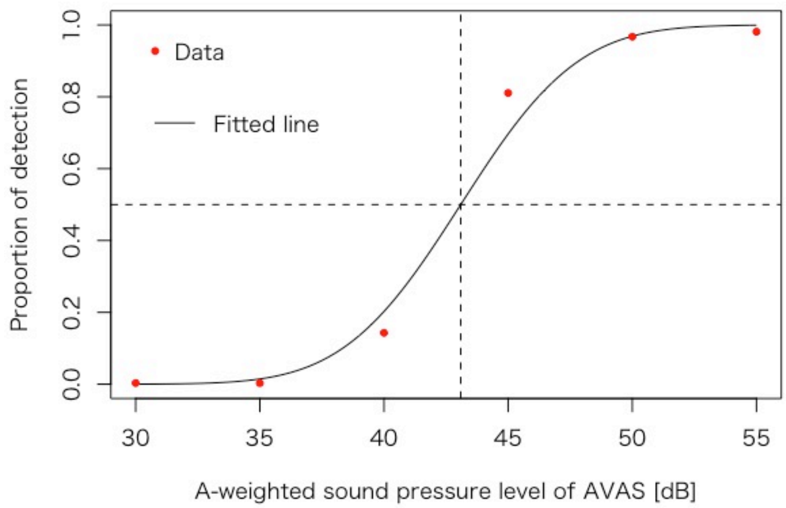
To examine the effect of the secondary task itself, similar experiment without any secondary task was conducted; i.e. without taking game application, just simply react to the AVAS stimulus under background noise. Five students, 1 female and 4 males, aged between 21 and 24 participated in the additional experiment. One of them also participated in the first experiment. The detection level was 41.2 dB with 3.2 dB standard deviation. The differences from the first results were 1 to 2 dB. In the previous study[14], the secondary task showed significant effect on the detection distance of the vehicle approaching from behind the participants. The alerting sound was rose up quickly and irregularly in the present experiment, while the sound was continuous and gradually rose in the previous. It is suggested that the secondary task would not affect on the detection of the alerting sound when the vehicle was just departing.

The detection levels were 42 to 43 dB, which were 17 to 18 dB lower than the background and clearly below the minimum requirement in R138[4] at 10 km/h (50 dB).

According to the questionnaire after the experiment, 8 of them had known the AVAS sound used in the experiment. The detection levels were compared between the participants who had known (group A) the stimuli and those had not (group B). The detection thresholds for each groups are shown in Table 2. The differences were 0.1 dB. It was suggested that the experience and knowledge on AVAS sound did not affect the detection performance.



(a) Game 1



(b) Game 2

Fig. 2 – Detection probability and probit regression for each secondary task condition.

Table 2 – Detection level difference between groups of AVAS listening experience.

	Detection level [dB]	
	Group A	Group B
Game A	42.5	42.6
Game B	43.0	43.1

4. CONCLUSIONS

Some reviews are provided in this report on the survey and experimental examinations regarding the feasible sound design for the alerting sounds (AVAS). After such works, the quality discussion on feasibility would be realized.

The questionnaire survey showed that the louder conventional engine vehicle sounds were still problematic to be sufficiently realized by pedestrians under urban noise environment. From the cross-cutting analysis among detectability examinations from several institutions, the alerting sounds may not be reliably detected by pedestrians, particularly in louder environments, even if they fulfill the requirements of UN Regulation. Moreover, it was suggested that the instruction and/or tasks for the participants may affect on the detection.

The paper also provides a pilot study on such effect through a laboratory experiment. The detection levels were not significantly different between two secondary task conditions with different concentration. Similar experiment without any secondary task was conducted to examine the effect of the secondary task itself, however, The differences from the first results were negligibly small. It was suggested that the secondary task would not affect on the detection of the alerting sound quickly rose up, which are similar to the AVAS from the vehicle was just departing. Moreover, it was suggested that the experience and knowledge on AVAS sound did not affect the detection performance.

5. ACKNOWLEDGEMENTS

The author would like to thank Marie Masuda for her efforts in the laboratory research on the effect of secondary task. This work was supported by the Japanese Society for the Promotion of Science (JSPS), Grant-in-Aid for Scientific Research (B), Grant Number 16H03021.

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