MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Subjective evaluations of detectability of alert sound for electric and hybrid electric vehicle under actual environment

Yasui, Nozomiko[1]
Graduate School of Science and Engineering, Saitama University
255 Shimo-Okubo, Sakura-ku, Saitama City, 338-8570 Japan

ABSTRACT

The motor sound on electric and hybrid electric vehicle is quiet at low speeds. Thus, pedestrians have difficulty detecting those vehicles approaching them. Although those vehicles were designed to play an alert sound to solve this problem, it has not been solved yet. Our previous studies found that the fluctuation frequency, non-periodic fluctuation and amplitude envelope are effective to make them detect approaching vehicles. However, those studies were investigated under only an actual environment, weren't examined validity of detectability in those studies. Therefore, this paper investigate under some actual environment, examine the validity. Investigations were carried out by using synthesized complex sounds which were designed to have periodic and non-periodic amplitude fluctuations. Those complex sounds have characteristics of amplitude fluctuations in gasoline powered vehicle. Envelopes such as modulation wave in amplitude-modulated sound were set for deviations for time and amplitude, and amplitude-modulated complex sounds were synthesized using sine wave, sawtooth wave, and rectangle wave as modulation wave. Then, their effects on detectability by pedestrians were assessed in some actual environment. The results found that amplitude fluctuation enhances the ability with which people detect approaching electric and hybrid electric vehicles in case of some complex sound.

Keywords: Alert sound, Detectability, Amplitude fluctuation
I-INCE Classification of Subject Number: 79

1. INTRODUCTION

Hybrid electric (HEV) or electric vehicles (EV) are becoming common globally. Those vehicles are comparatively quieter than gasoline powered vehicles, especially when those vehicles are driven at low speeds. Although, relative quietness of those vehicles effected a solution to the problem for traffic noise, the safety for pedestrians is exposed to risk by those vehicles. They have trouble recognizing their approach in an urban sound environment because those vehicles are too quiet. This is not only of particular problem for the visually impaired people but also for any people who cannot see the approaching vehicle, for example in the situation that the vehicle comes from behind of them or an obstacle object.

The regulations have been developed in some governments to minimize the

[1] nyasui@mail.saitama-u.ac.jp

trouble posed by those vehicles. Those regulations are going to mandate equipping artificially generated sound that intends to enhance pedestrian's awareness. In 2010, the first guideline was taken in Japan[1]. Recently, the UN regulation No.138 on Quiet Road Transport Vehicles[2] was adopted and published in 2016. The regulation introduces the minimum sound level, spectrum, and frequency shift depending on the vehicle's speed. In the regulation, the system emitting artificially generated sound is named as "Acoustic Vehicle Alerting System (AVAS)". As following the publication of the regulation, Japanese Ministry of Land Infrastructure and Transportations have announced officially that the mandate for equipping the AVAS is enforced from March 2018. In Germany, all electric vehicles should emit an external sound from 2019[3]. Various studies[4-7] have been conducted on the survey and experimental examinations regarding the feasible design for the alert sounds. However, the alert sound that has satisfied the regulation has not yet been proposed. The regulation isn't defined about amplitude fluctuation.

In this work, pedestrians are assumed to be aware of approaching gasoline vehicles by hearing amplitude fluctuation on the exhaust sound. Then, we propose a possibility that they can be aware of approaching EV by hearing fluctuation sound. So, it is expected that an alert sound with large fluctuation makes it easier for pedestrians to be aware of approaching EVs than the sound with small fluctuation. Before publication of the regulation, previous study[8] found that the amplitude fluctuation is effective to enable people to notice the approaching vehicles. Those ones used the average fluctuation rate, deviations for Time (DT) and Amplitude (DA), and the shape of the amplitude envelope on a single sound comprised the fluctuation sound as characteristics that affect hearing fluctuation. Those deviations occur on periodic fluctuation, elicit non-periodic fluctuation. Another study[9] showed that the shape of envelope and the fluctuation frequency contribute to impression of alert sound. However, the alert sound designed in those previous studies hasn't satisfied the regulation. Also, the experimental examinations weren't conducted by simulation of realistic environment. Although another study[10] tried to examine detectability in realistic environment, the results of analysis have some problem.

Thus, detectability of various amplitude fluctuation sound from a realistic background sound is examined by subjective experiment, effect of amplitude fluctuation on detectability is investigated to propose the alert sound satisfied the regulation. Specifically, the adjusted acoustic sound level that pedestrians require to react to the auditory recognition of an approaching HEV or EV in a realistic environment sound is measured in this study.

2. SUBJECTIVE EVALUATION EXPERIMENT

2.1 Method

The aim of subjective evaluation experiment is to measure the adjusted acoustic sound level that pedestrians require to react to the auditory recognition of an approaching electric or hybrid vehicle in an environmental sound. In this study, those sound levels for various fluctuating sounds were measured in a soundproof room. A total of those subjects with an average of 20.0 years (19 to 20) took the experiment. 4 subjects were male and 1 subjects were female. A total of 84 sounds were used as stimuli.

This experiment were conducted by method of limits. The sound levels of stimuli were gradually increased in 1 dB steps until they were just detectible. The method was also run in reverse with a decrease in the intensity of stimuli until they could no longer be detected. The subjects gave a binary (YES/NO) response to indicate whether they could detect stimuli in situations in which an environmental sound was also presented. Three descents and three ascents were used in each stimulus.

The stimuli were presented to the listeners through a speakers (8030A, GENELEC Inc.) from behind subjects. Those subjects were allowed to adjust the acoustic sound level before the experiment to one that best enabled them to listen to the fluctuating sounds. The average level was about L_A = 65.0 dB.

2.2 Stimuli

A total of 84 sounds were used as stimuli. 3 of those stimuli were non-fluctuated complex sounds, 81 of those stimuli were amplitude-fluctuated complex sounds. The levels of acoustic power of those stimuli were equalized.

Those fluctuated sounds were synthesized using the procedure proposed in previous study[8], created in the under condition.

- Frequency characteristics of complex sound: 630 and 2000 or 3150 or 4000 Hz
- Fluctuation frequency: 8, 14 20 Hz
- Deviation patterns: No deviations, only DA, and DT&DA
- Envelopes on amplitude fluctuation: sine wave, square wave, sawtooth wave

Three kind of complex sounds were used. One is complex sound composed of a 630 Hz tone and 2000 Hz (CS_1), another is one composed of a 630Hz tone and 3150 Hz (CS_2), the other is one composed of a 630 Hz tone and 4000 Hz (CS_3). Those frequencies were decided based on UN regulation No. 138[2] and previous study[11]. In case of "No deviation", the stimulus doesn't have both DT and DA. In case of "only DA", the one has only DA. In case of "both DT and DA", the one has both DT and DA.

The environmental sound was used for masking. To obtain an environmental sound, acoustic recordings with a dummy head HATS was carried out near road in Fukuoka, Japan.

Stereo sounds perceived as if a car is approaching the subject and departing from the one were presented in this experiment. Each stimuli with taper was synthesized in the left channel, the stimuli with taper was synthesized 0.25 sec late from left channel in the right channel. The length of taper was 1 sec.

2.3 Result

A result of each complex sound that doesn't have amplitude fluctuation is given in Fig. 1. The vertical axis represents the average of adjusted acoustic sound level. As can be seen from Fig. 1, it's found that the level on CS_2 is the highest of the result. So, the analysis of variance (ANOVA) was conducted for the result. This ANOVA revealed an effect of kind of complex sound ($p < .05$). To further examining the effect, post hoc analysis were made using either Tukey's multiple comparisons test. Tukey's post hoc analysis showed that average of the level on CS_3 is the highest in all complex sounds ($p < .10$).

Results of each envelopes on amplitude fluctuation in case of no deviation are given in Fig. 2. The S_0 mean non-fluctuated complex sound and the $S_{f,dev,env}$ (f = 8, 14, 20, *dev* = non, DA, both; *env* = sin, squ, saw) mean fluctuating sounds. "non" means that the deviation pattern is no deviations, "DA" means that the one is only DA, and "both" means that the one is both DT and DA. "sin" means sine wave, "squ" means square wave and "saw" means sawtooth wave. As can be seen from Fig. 2, it's found that those level are close to the same among fluctuation frequencies. So, the ANOVA was conducted for each results. Those ANOVA revealed a main effect of kind of complex sound ($p < .01$). In case of square wave, a main effect of kind of fluctuation frequency was revealed ($p < .10$). To further examining the effect of kind of complex sound, post hoc analysis were made using either Tukey's multiple comparisons test. Tukey's post hoc analysis showed that average of the level on CS_3 is the highest in all complex sounds (p < .01).

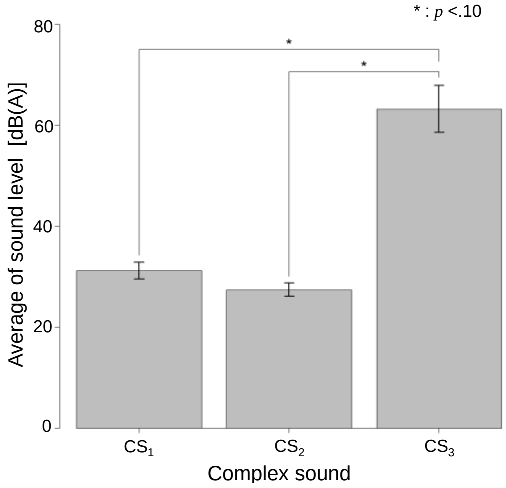
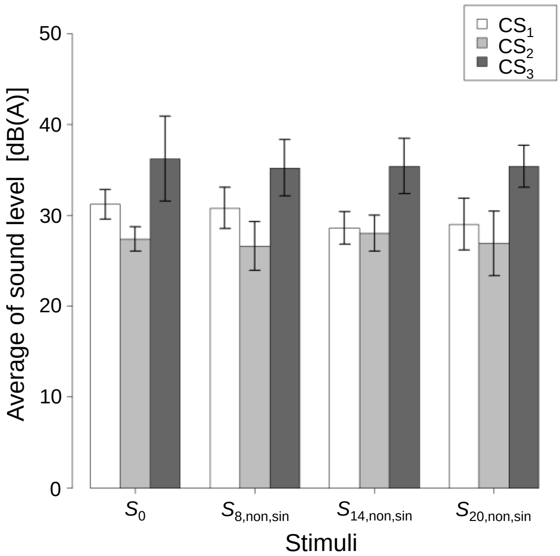
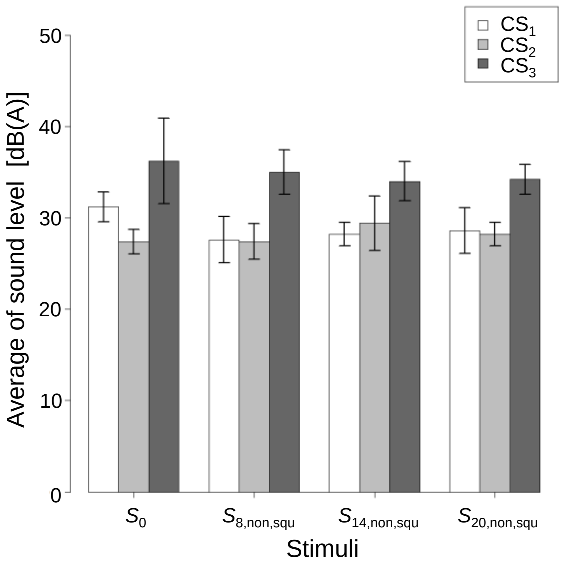


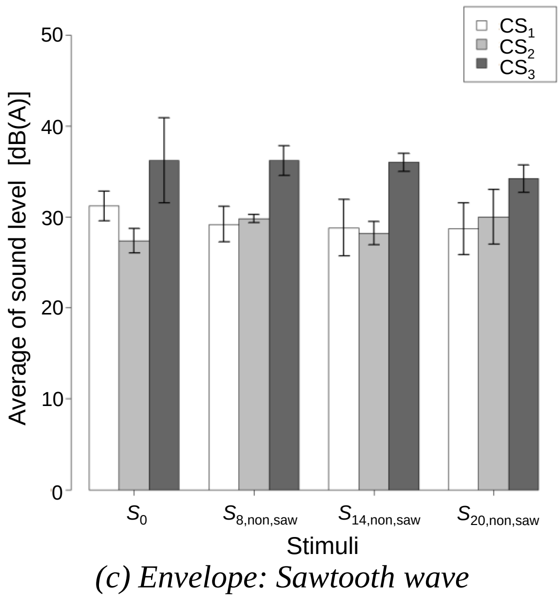
Fig. 1 – Results of experiment in each complex sound.



(a) Envelope: Sin wave



(b) Envelope: Square wave



(c) Envelope: Sawtooth wave

Fig. 2 – Results of experiment in case of no deviations.

Results of each complex sound are given in Fig. 3-5. As can be seen from Fig. 3-5, it’s found that there are kind of difference among deviation patterns. So, the ANOVA was conducted for each results. Those ANOVA revealed a main effect of kind of deviation pattern ($p < .001$). In case of CS$_1$, a main effect of kind of fluctuation frequency was revealed ($p < .05$). Also, a main effect of envelope was revealed in case of CS$_2$ ($p < .05$).

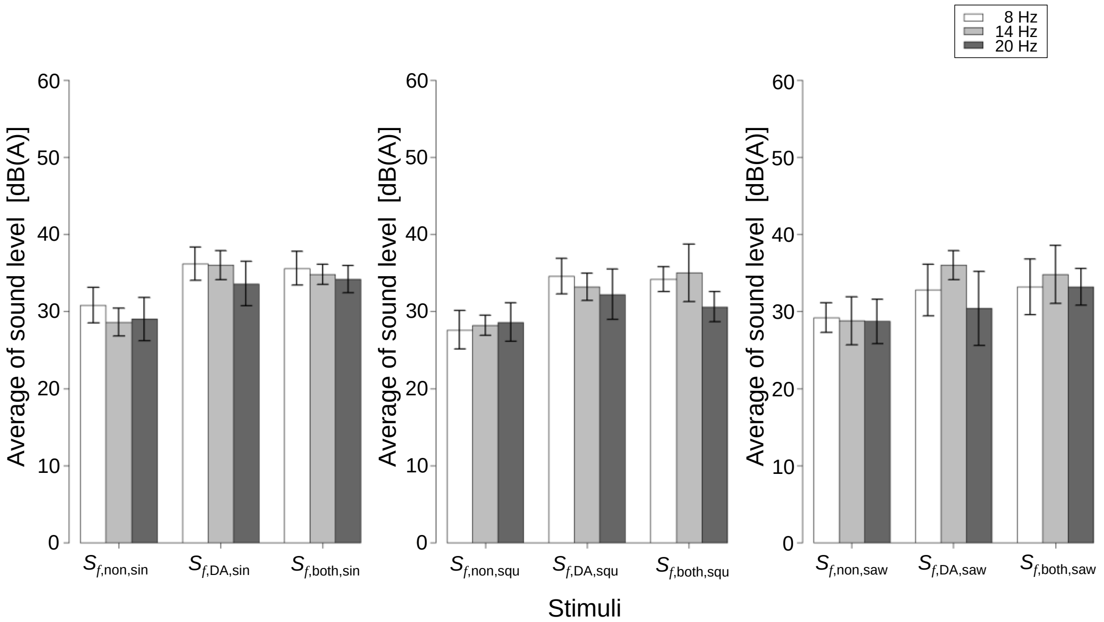


Fig. 3 – Results of experiment in case of CS$_1$.

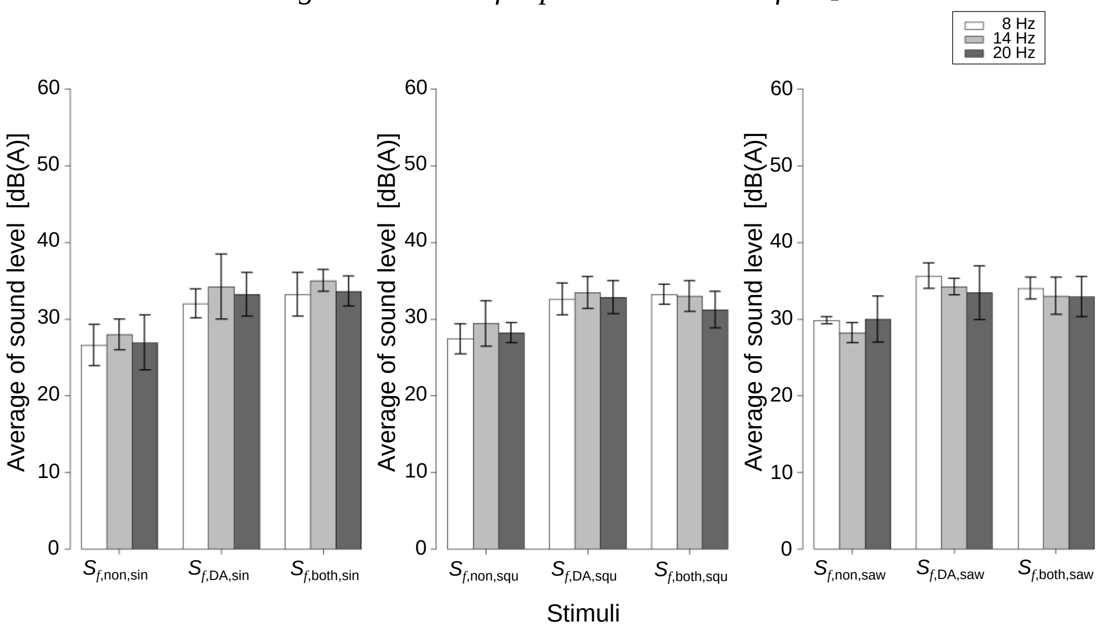


Fig. 4 – Results of experiment in case of CS$_2$.

3. DISUCUSSION

It was found from the Fig.1 that the sound designed by using CS$_3$ needs higher acoustic sound level to make pedestrians notice approaching HEV or EV because the average of the level on CS$_3$ is the highest in Fig. 1. It is thought that high acoustic sound level enhances the risk increasing traffic noise in urban area. Thus, the result show that the sound with 4000 Hz isn’t appropriate as the alert sound.

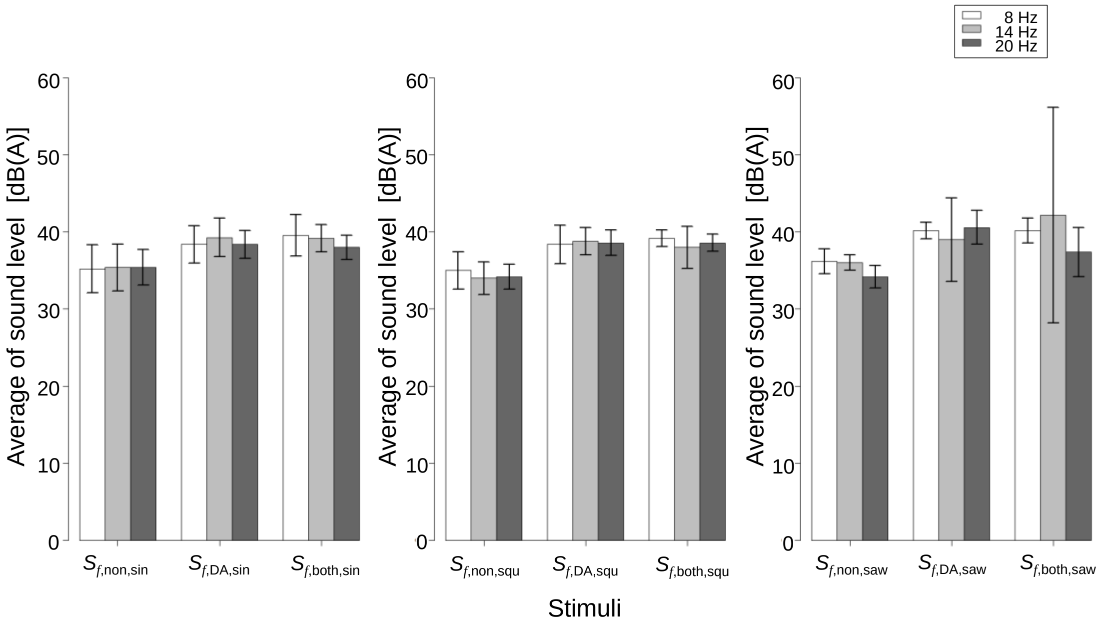


Fig. 5 – Results of experiment in case of CS_3.

It was observed from the Fig. 2 that the amplitude fluctuation is sort of effective depending on the shape of the amplitude envelope. The result show that frequency characteristics of complex sound have a more potent effect on detectability than the magnitude of amplitude fluctuation.

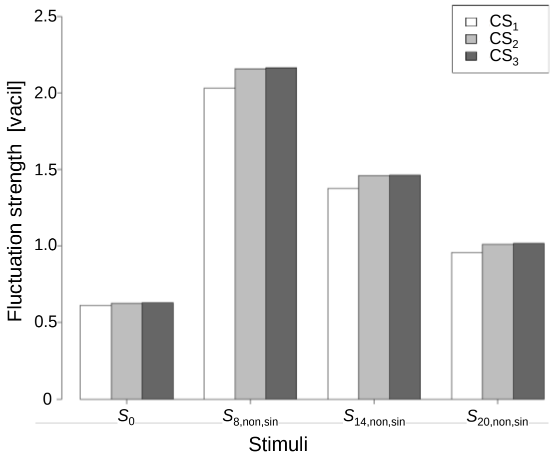
It was found from the Fig. 2 that there are little difference among fluctuation frequencies. To check the psychoacoustic magnitude of amplitude fluctuation on the stimuli, fluctuation strength was calculated by the software BK Connect produced by Brüel & Kjær. The calculated fluctuation strength are given in Fig. 6. As can be seen from the figure, it's found that there are difference among fluctuation frequencies. So, it is believed that something have strong influence on detectability.

Therefore, it was found that the frequency component of 4000 Hz isn't appropriate as the alert sound with high detectability. Also, it was shown that acoustic sound level increase by giving non-periodic fluctuation. So, it is thought that non-periodic fluctuation is not sort of effective. Although there was no significant difference between non-fluctuated sound and fluctuated, it was expected that the characteristics of amplitude fluctuation have sort of effect for detectability. However, the number of subjects was small. It needs to conduct the evaluation experiment increased the number of subjects.

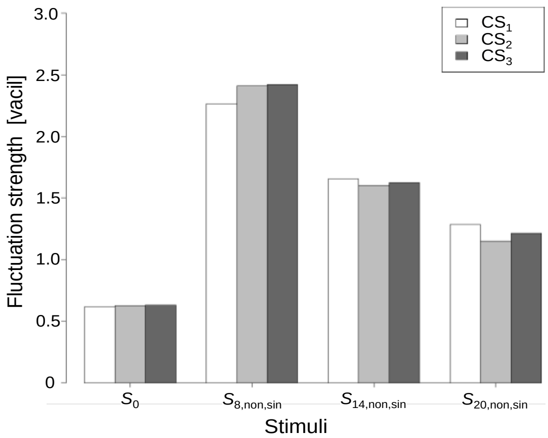
4. CONCLUSIONS

This study investigated effect of amplitude fluctuation on detectability of alert sound in an actual environment. Specifically, the acoustic sound level that pedestrians require to react to the auditory recognition of an approaching HEV or EV in a realistic sound is measured. The results revealed that the amplitude fluctuation has possibility for favorable effect in an actual environment. Also, it was shown that the frequency component of 4000 Hz isn't appropriate as the alert sound.

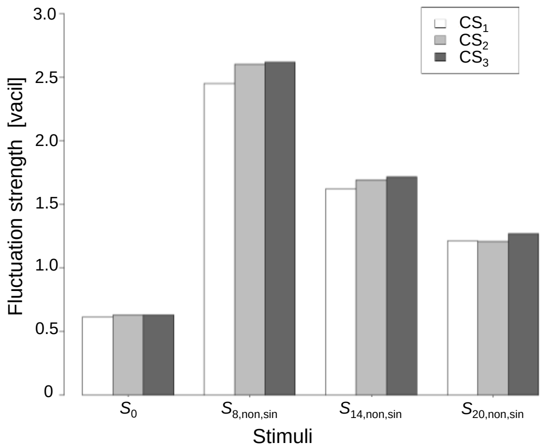
We plan to conduct the evaluation experiment increased the number of subjects, to conduct evaluation experiment simulated other real environment, to examine the detection time of the fluctuating sound in real environment, and to examine the combined effect of amplitude fluctuation and frequency shift.



(a) Envelope: Sin wave



(b) Envelope: Square wave



(c) Envelope: Sawtooth wave

Fig. 6 – Calculated fluctuation strength.

5. ACKNOWLEDGEMENTS

The author would like to thank K. Yamauchi for acoustic recordings of environmental sound. This study was partly supported by the Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (16H03021).

6. REFERENCES

1. Guideline for the Approaching Vehicle Audible System, Transport and Tourism (MLIT), (2010) (in Japanese)
2. United Nations, UN Regulation No. 138 on Quiet road Transport Vehicles, (2016)
3. ECE, UN. Proposal for a new Regulation concerning the approval of quiet road transport vehicles (QRTV). ECE/TRANS/WP/29/2016/26. Geneva, (2016)
4. K.Genuit, "Particular Importance of Psychoacoustics for Sound Design of Quiet Vehicles", Proc. of Inter-noise 2011, CD-ROM, Wed-8-10, (2011)
5. K. Wolff, G. Eisele, P. Genender, and G. Schürmann, "Acoustics of electric vehicles with range extender", Proc. of Inter-noise 2011, CD-ROM, Wed-8-11, (2011)
6. Van der H. Auweraer, K. Janssens, D. Sabbatini, E. Sana, and K. De Langhe, "Electric Vehicle Exterior Sound and Sound Source Design for Increased Safety", Proc. of Inter-noise 2011, CD-ROM, Wed-8-13, (2011)
7. Ming Une Jen and Ming-Hung Lu, "Warning sound of electric vehicle for pedestrian safety", Proc. of Inter-noise 2011, CD-ROM, Wed-8-15, (2011)

8. N .Yasui and M. Miura, “Relationship between fluctuation strength and detectability of alert sounds for hybrid and electric vehicle”, Proc. of Inter-noise 2017, 1943-1950, (2017)
9. N. Yasui, “Subjective evaluation of amplitude fluctuated sounds that warn of approaching quiet vehicle”, Proc. of Inter-noise 2015, CD-ROM, 742, (2015)
10. N. Yasui, “Effect of amplitude fluctuation on detectability of alert sound for electric and hybrid vehicle in an actual environment”, Proc. of Inter-noise 2018, in18_1619, (2018)
11. M. Suzuki, J. Yonemura, H. Matsuda, and N. Machida, “Study on perception of alert sound for quiet vehicles by difference in listening condition”, Reports of the 2017 autumn meeting the Acoustical Society of Japan, 1493-1494, (2017) (in Japanese)