PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Relationship between acoustic characteristics and impression for warning sounds on electric vehicles

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ABSTRACT

The motor sound on 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. When the sound is designed, it should be concerned not only detectability of approaching quiet vehicles but also impression of the sound. For pedestrians, it's important to make it easier to recognize quiet vehicle. Also, warning sounds shouldn't contribute to traffic noise annoyance. Our previous studies found that acoustic characteristics of amplitude fluctuation are effective to make them detect approaching vehicles. Here, this study evaluates impressions of those fluctuated sound, investigates relationship between the impression and those characteristics. The impressions of synthesized warning sounds that have periodic and non-periodic amplitude fluctuations were measured by semantic differential method. The obtained data were analyzed by factor analysis. The results revealed that characteristic of amplitude fluctuation influences the factors of "alerting", "clarity" and "familiarity".

Keywords: warning sound, amplitude fluctuation, Impression

1. INTRODUCTION

Hybrid electric (HEV) or electric vehicles (EV) are becoming common globally. These vehicles are comparatively quieter than gasoline powered vehicles, especially when those vehicles are driven at low speeds. It has been a matter of concern that the quietness of quiet vehicles may create dangerous situations for pedestrians, because sometimes, they have trouble recognizing their approach in an urban sound environment(1). This is not only 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. Thus, a warning sound should be played to solve this problem. When the sound is designed, it should be concerned not only detectability of approaching quiet vehicles but also impression of the sound. For pedestrians, it's important to make it easier to recognize quiet vehicle. Also, warning sounds should not contribute to traffic noise annoyance. The previous study(2) found that the amplitude fluctuated sound is effective to enable people to notice the approaching vehicles. Here, we evaluated impressions of those fluctuated sound, investigated relationship between impression and characteristics of amplitude fluctuation.

2. EXPERIMENT

2.1 Method

To evaluate impressions of those fluctuated sound, we conducted a semantic-differential-rating experiment with 5 subjects in a soundproof room. All subjects reported to have normal hearing abilities. A total of those subjects with an average of 26.0 years (21 to 34) took the experiment. 3 subjects were male and 2 subjects were female.

A total of 84 sounds were used as stimuli. The order of stimuli was determined randomly for each subject. After listening to each stimulus, the subjects were requested to rate the impressions. The impressions of the stimuli were measured by 10 bipolar, 5-step, Semantic Differential(SD) scales. The 10 pairs of adjectives shown in Table 1 were used to create the SD scales. These scales were selected from the previous study[*]. Numbers 1 to 5 were given for each of the five categories on the SD scales.

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The stimuli were presented to the subjects through a speakers (GX500Hd, ONKYO Inc.). Those subjects were allowed to adjust the acoustic sound level before the experiment to one that best enabled them to listen to the stimulus. The average level was about L_A = 54.4 dB.

Table 1 –Factor loadings of each factor on each adjective scale

Pair of adjectives			Factor 1(Alerting)	Factor 2(Clarity)	Factor 3(Familiarity)
Familiar	-	Unfamiliar	0.040	0.040	0.843
Safe	-	Dangerous	0.538	0.296	-0.549
Comfortable	-	Uncomfortable	-0.004	-0.162	-0.680
Calm	-	Restless	0.927	-0.452	0.018
Approaching	-	Receding	-0.009	0.693	-0.029
Alerting	-	Non alerting	0.770	0.328	0.010
Vehicle-like	-	Non vehicle-like	-0.064	0.354	0.167
Distinct	-	Vague	0.005	0.710	-0.018
Informing	-	Non informing	0.663	0.387	0.221
Advancing	-	Backing	0.179	0.193	0.044

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(*), 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. 1382 and previous study(*). In case of “No deviation”, the stimulus doesn’t have both DT and DA. In case of “DA”, the one has only DA. In case of “DT & DA”, the one has both DT and DA.

2.3 Result

The rating values were averaged for each scale and for each sound. Next, a factor analysis was performed for the averaged values with maximum likelihood method and promax rotation. The results of the analysis showed that these impressions were accounted for by the orthogonal three-factor solution. Table 1 shows the resulting factor loading. The first factor is interpreted as the alarm factor because adjective pairs such as ‘‘alerting/non alerting’’, “calm/ restless” and ‘‘informing/non informing’’ have high loadings for the first factor. The second factor is interpreted as the clarity factor because adjective pairs such as ‘‘distinct/vague’’ and ‘‘approaching/receding’’ have high factor loadings. The third factor is interpreted as the familiarity factor because the adjective pairs ‘‘familiar/unfamiliar’’ and ‘‘comfortable/uncomfortable’’ have high factor loadings. Then, those three factors were labeled “alerting”, “clarity” and “familiarity”, respectively, from the scales showing high loading on the dimensions.

In order to investigate the features of the stimuli with regard to the factors, factor scores for each stimulus for each factor were also calculated. As a result, it’s found that there are little difference among each frequency characteristics and deviation patterns.

3. DISCUSSION

The factor scores of stimuli for each factors are given in Fig. 1 and 2. In Fig. 1 and 2, each stimulus

are described on each two-dimensional space spanned by the “alerting”, “clarity” and “familiarity”. In Fig. 1, each stimulus are plotted for each fluctuation frequency. In Fig. 2, each ones are plotted for each envelopes. “non” in fig. 1 and 2 means non-fluctuated complex sound.

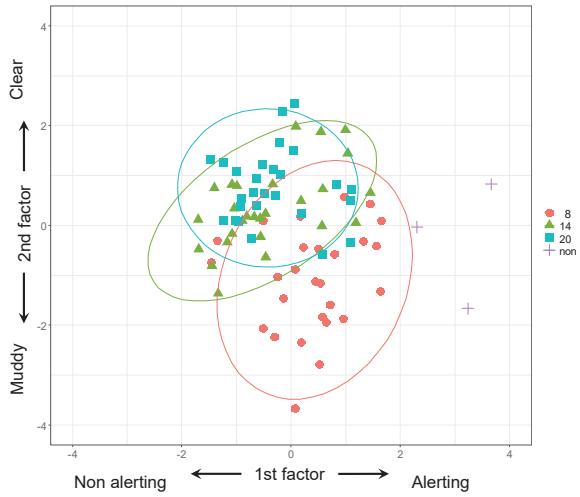
As can be seen from Fig. 1, it’s found that fluctuation frequency contribute to both factors of “clarity” and “familiarity”. Fluctuating sounds with high frequency are relatively high “familiarity” while those with low frequency are relatively low “familiarity”. This implies that the impression of familiarity increased, as fluctuation frequency increased. Moreover, it’s observed that non-fluctuated complex sounds have strong alerting and high familiarity. The reason is thought that those sounds are often used as alert or warning sound in many places.

As seen in Fig. 2, it’s that observed that that fluctuation frequency contribute to factor of “alerting”. Fluctuating sounds with sine wave are relatively high “alerting” while those with square and sawtooth wave are relatively low “alerting”.

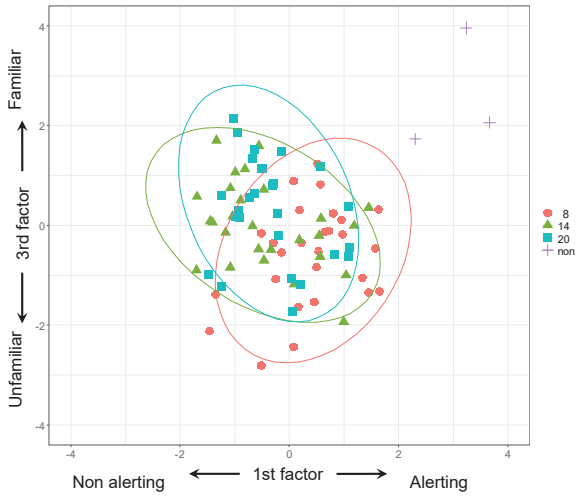
Those results showed that fluctuating sound for detecting approaching quiet vehicles should be designed by considering fluctuation frequency or envelope not to contribute to traffic noise annoyance.

4. CONCLUSIONS

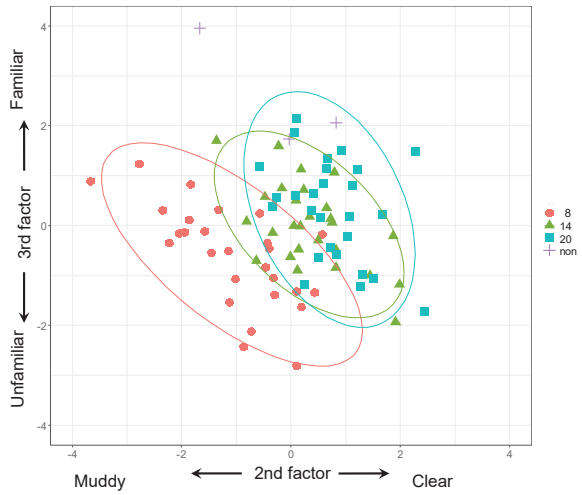
This study evaluated impressions of amplitude fluctuated sound, investigated relationship between



(a) The 1st factor (“Alerting” factor) and the 2ns factor (“Clarity” factor)

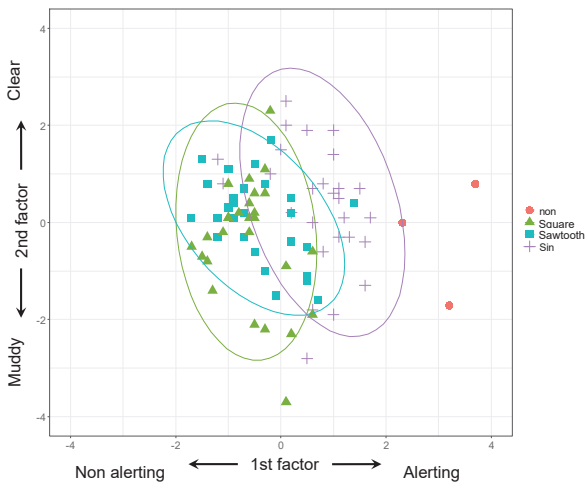


(b) The 1st factor and the 3rd factor (“Familiarity’ factor)

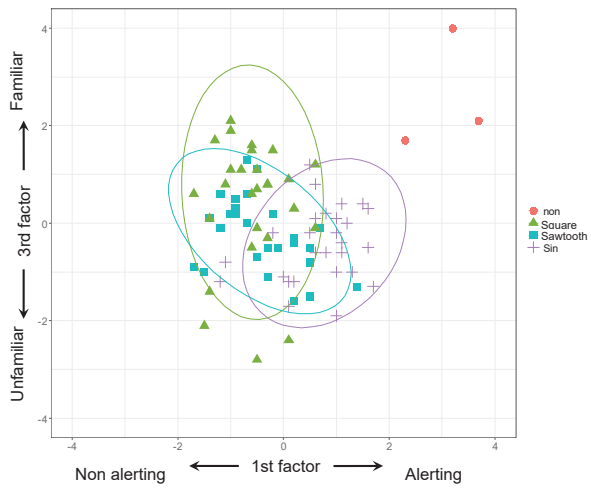


(c) The 2nd factor and the 3rd factor

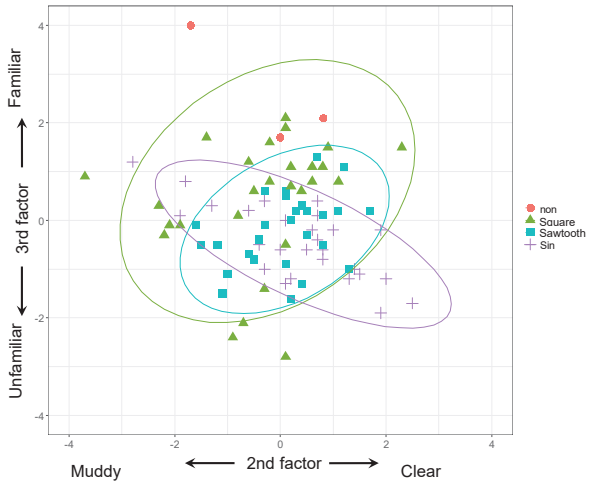
Figure 1 – Factor scores of sound for each fluctuation frequency



(a) The 1st factor and the 2ns factor



(b) The 1st factor and the 3rd factor



(c) The 2nd factor and the 3rd factor

Figure 2 – Factor scores of sound for each envelope

the impression and characteristics of amplitude fluctuation. As a result of factor analysis, the factors of "alerting", "clarity" and "familiarity" are obtained. Our results revealed that characteristic of fluctuation frequency influences the factors of "clarity" and "familiarity". Moreover, our results found that shapes of envelope contribute to factor of "alerting".

In future work, this study plan to investigate the combined effect of characteristics of amplitude fluctuation, to conduct the evaluation experiment increased the number of subjects and to examine relationship between impression of fluctuating motor sound and detectability of approaching quiet vehicle.

ACKNOWLEDGEMENTS

This study was partly supported by the Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (16H03021, 19K20613).

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