In this paper, the impression of various kinds of auditory signals currently used in automobiles and a comprehensive evaluation were measured by a semantic differential method. The desirable acoustic characteristic was examined for each type of auditory signal. Sharp sounds with dominant high-frequency components were not suitable for auditory signals in automobiles. This trend is expedient for the aged whose auditory sensitivity in the high frequency region is lower. When intermittent sounds were used, a longer OFF time was suitable. Generally, “dull (not sharp)” and “calm” sounds were appropriate for auditory signals. Furthermore, the comparison between the frequency spectrum of interior noise in automobiles and that of suitable sounds for various auditory signals indicates that the suitable sounds are not easily masked. The suitable auditory signals for various purposes is a good solution from the viewpoint of universal design.

**Keywords:** auditory signal, automobile, universal design, semantic differential (SD) method, factor analysis

**Introduction**

Various auditory signals with important functional roles such as “danger alarm”, “operation feedback”, “malfunction warning”, etc., have been provided in automobiles. When drivers cannot pay attention to or concentrate on visual information, auditory signals are very important for the drivers to notify various information. It is expected that the amount and types of these signals would be increased with the technology development, such as Intelligent Transport Systems (ITS). Actually, the application of the auditory warning for “not wearing a seat belt wearing” is obligated in a new law of Japan.

We have investigated auditory signals not only in the automobiles. A study on auditory signals which were actually utilized in various products in everyday life, which clarified the relationship between the functional imagery of auditory signals and their acoustical properties for wider types of auditory signals (Yamauchi et al., 2000; 2003).

In this paper, the rating experiment was conducted for various kinds of auditory signals currently used in automobiles to examine the desirable acoustic characteristic for each function.

Furthermore, the auditory signals must be certainly easy to recognize and understand for any people. It is very important to discuss the results in connection to the auditory properties for the aged and disabilities. In the final section, we will consider this matter.

**Methods**

The auditory signals currently used in automobiles were used as stimuli. The 207 stimuli were classified into 56 “reverse gear information sounds”, 58 “light switch warning sounds”, 58 “key leaving warning sounds” and 45 “blinker sounds”.

The “reverse gear information sounds” are the signals which sound when the drivers put their gear in reverse. The “key leaving warning sounds” and the “light switch warning sounds” are the signals which sound to inform that the key is still in the keyhole or the light switch is still on when the door is open. All stimuli were recorded from cars which were sold by Japanese, Korean, German and Swedish automobile manufacturers.

The impression associated with each stimulus was measured by a semantic differential (SD) method. In this experiment, 14 pairs of adjectives as impression rating scales shown in Table 1 and two pairs of adjectives as comprehensive evaluation scales were used as the SD scales. The comprehensive evaluation scales were “desirable-undesirable” and “suitable-unsuitable”. Each SD scale had 5 step categories (from 1 to 5).

Each stimulus was presented to the participants from a computer via headphones in a sound proof room. The equivalent continuous A-weighted sound pressure level ($L_{eq}$) of each stimulus at the headphone was set to the recording
level; from 43 to 67dB (A). The length of each stimulus was between about 5 and 8s.

Thirteen students (11 males and 2 females) aged between 22 and 31 with normal hearing and driving experience participated in the experiment. They were instructed to rate each type auditory signal on impression rating scales and comprehensive evaluation scales as if they were driving a car imaginarily.

### Results

The rating values for the 14 SD scales were averaged for each scale. The averaged values were applied to a factor analysis. The scales were taken as variables. The three-factor solution was chosen. The factor loadings are shown in Table 1.

The first factor was interpreted as the “calmness factor” because the adjective scales such as calm–hurried and slow–speedy had high loadings on this factor. The second factor was interpreted as the “brightness factor” because the adjective scales such as bright–dark and clear–muddy had high loadings on this factor. The third factor was interpreted as the “potency factor” because the adjective scales such as strong–weak and small–big had high loadings on this factor.

The factor scores for each stimulus of each factor were obtained to investigate the relationship between the general impressions and the comprehensive evaluation scales.

The correlation coefficients between factor scores of each factor and the averaged rating values of comprehensive evaluation scales for each type of the auditory signal are shown in Table 2.

For all types of auditory signals, evaluation ratings highly correlated with factor 1 (calmness factor) scores. In general, the sounds with calm and slow impressions were suitable and desirable for all auditory signals in this experiment. The “key leaving warning sounds” had negative correlation with factor 2 (brightness factor). The “light switch warning sounds” also had a negative correlation with factors 2 and 3 (brightness and potency factor). The clear and bright sounds are suitable for key leaving and light switch warning sounds. The strong sounds are also desirable for light switch warning sounds.

To consider the relationship between the comprehensive evaluation and the physical properties of auditory signals in each function, we selected the stimuli which had the five highest and lowest rating scores on the “suitable–unsuitable” scale in each function. In the following section, the acoustic properties of these stimuli are examined in each function.

1. **Reverse gear information sound**

   All reverse gear information sounds in this experiment were composed of a single sequence of intermittent sounds with constant ON times and OFF times. Each sound within a sequence was identical.

   The ON time of the top five stimuli on the suitability ranged from 325 to 375 ms. The OFF time was from 625 to 675 ms. The ON time of the bottom five stimuli ranged from 300 to 460 ms. The OFF time was from 200 to 240 ms. The OFF time affected the calmness factor score. Referring to Table 2, the rating values of comprehensive evaluation highly correlated with factor 1 (calmness factor) scores. The shorter the OFF time, the more hurried the impression of sound. The intermittent pattern with relatively short OFF time aroused a hurried impression and was not suitable for reverse gear information sound.

   To discuss the frequency spectrum of suitable sound for reverse gear information sound, the power spectra of the top five sitimli were compared with that of the bottom five stimuli. When the fundamental frequency was over 2kHz and the frequency of dominant components was over 4kHz, the sounds were evaluated as unsuitable for reverse gear information sound. The brightness factor scores of these sounds were relatively high. The average value of Bismarck’s sharpness (von Bismarck, 1974) was 1.31 acum for the top five stimuli and 2.25 acum for the bottom five stimuli. The difference of these average values was statistically significant ($t=3.18$, $df=8$, $p=0.013$).

   We also obtained the introspection of the participants by means of a post-experiment written report. Some participants described that the long OFF time evoked a slow and calm
impression and a suitable and desirable feeling for reverse gear information. They felt impatience from fast intermittent patterns. Some participants indicated the effect of the frequency spectrum. They thought sharp sounds were not suitable for reverse gear information. Furthermore, a high-pitched sound may be difficult to recognize for the aged, because their auditory sensitivity to high-frequency sound is lower. Calm and not-sharp sounds are suitable for reverse gear information sound.

2. Light switch warning sound

The light switch warning sounds were long steady sounds or regularly intermittent sounds. Four of the bottom five stimuli on the suitability rating scale were long steady sounds. Four of the top five stimuli on the suitability scale were intermittent sounds whose period of repetition was 1000 ms.

Frequency analysis of the top five stimuli and the bottom five stimuli showed that the suitable stimuli had the dominant spectral energy in the frequency range from 1 kHz to 4 kHz and unsuitable stimuli had the dominant spectral energy in the frequency range from 2 kHz to 8 kHz. The average value of Bismarck’s sharpness was 1.33 acum for the suitable five stimuli and was 2.30 acum for the unsuitable five stimuli. The difference between these average values was statistically significant ($t=3.53$, $df=8$, $p=0.008$).

This trend was affected by the brightness factor. Referring to Table 2, the correlation coefficients between the brightness factor scores and the rating values of comprehensive evaluation scales were slightly high. Steady sounds with dominant high-frequency energy were not suitable for light switch warning.

The comprehensive evaluation ratings also correlated with potency factor scores (Table 2). Loud sounds were not suitable. The average value of $L_{eq}$ was 58.3 dB (A) for the top five stimuli and was 66.6 dB (A) for the bottom five stimuli. The difference between these average values was statistically significant ($t=2.64$, $df=8$, $p=0.030$).

Participants indicated that sharp sounds were unpleasant and soft sounds were suitable for light switch warning, and these feelings did not depend on whether the stimuli were steady sounds or intermittent sounds.

3. Key leaving warning sound

The key leaving warning sounds were intermittent sounds except one long steady sound. The top five stimuli on the suitability scale were intermittent sounds whose period of repetition was from 700 to 940 ms. Their fundamental frequency was around 2 kHz, and their harmonics reached 5 kHz. The average value of Bismarck’s sharpness of the suitable five stimuli was 1.24 acum and that of the unsuitable five stimuli was 1.99 acum. The difference between these average values was statistically significant ($t=3.53$, $df=8$, $p=0.008$).

Some participants reported that they associated the repetition of four short sounds with the sound of an alarm clock, and it gave a “cheap” and “disagreeable” impression. This introspection suggested that these patterns of sounds might cause misunderstanding of the function of the auditory signals.

4. Blinker sound

All blinker sounds were the repetition of a pair of clicks. The two clicks in a pair were always different. In Japan, Japanese Industrial Standard (JIS, 1998) also regulated these intervals. This standard is based on ISO 7588. In the JIS, it is regulated that the period of flashing is shorter than 1.5 s. A blinker sound is required, however its properties are not regulated.

A typical waveform is shown in Fig. 2. The inter onset interval between the first and second click (IOI-1) and another inter onset interval between the second click and the first click of the next repetition (IOI-2) are shown.

The IOI-1 of the top five stimuli on the suitability rating ranged from 360 to 400 ms. Their IOI-2 was from 330 to
400 ms. The IOI-1 of the bottom five stimuli on the suitability rating ranged from 310 to 340 ms. Their IOI-2 was from 310 to 380 ms.

Some comments were given from participants, such as, “The sounds with a calm impression were desirable because they were associated with the imagery of luxury cars” and, “If there is too much difference between the timbre of the two clicks, it annoys me”.

Conclusion

We conducted rating experiments on the perception on auditory signals in automobiles to clarify the desirable acoustical properties for each auditory signal. Sharp sounds with dominant high-frequency components were not generally suitable for auditory signals in automobiles. This trend is expedient for the aged whose auditory sensitivity in the high frequency region is lower. When intermittent sounds were used, a longer OFF time was suitable. Generally, “dull (not sharp)” and “calm” sounds were appropriate for auditory signals.

The hearing level of the aged shows a particular decreasing in high frequency region above 2 kHz. The dominant spectral range of the sounds rated as “suitable” in this experiment was around from 1 kHz to 2 kHz. That of the sounds rated as “unsuitable” was more than 2 kHz. Furthermore, the comparison of the frequency spectrum of interior noise in automobiles and that of suitable sounds for various auditory signals indicates that the suitable sounds are not easily masked. The suitable auditory signal properties indicated in this study is a good solution from the viewpoint of the universal design.

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