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Cognition improvement of warning system by complex stimuli in vehicle interior

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ABSTRACT

These days, various safety sensors in vehicles are widespread. And, for warning sounds such as for the trapping prevention of the power slide door of the vehicle, the importance of the warning system for senior citizens, whose audibility characteristic at high frequencies decreases, increases because the warning sound around 4,000Hz is about 25dB different in audibility characteristic between a person in their twenties and in their sixties. Moreover, another issue is that the cognition of direction of the warning sound might be made difficult by the influence of the inside and outside environmental noise, or by the influence of the refraction or the diffraction of sound in the vehicle. In this study, the new methods for the cognition improvement of the warning system and of the specific direction by using the complex stimuli with the auditory sense of sound and the tactile sense of vibration, and by using the complex stimuli with the auditory sense of sound and the visual sense of light are examined. First, the effect of the complex stimuli, using sound and vibration, is evaluated by the paired comparison method of subjective evaluation. Next, the suitable excitation point, frequency and the stimulation time of vibration are examined. Then, the effect of the complex stimuli, using sound and light, is evaluated. Then, the suitable color and the stimulation time of light are examined. Moreover, it is examined if the cognition rate of direction where is different from the sound source position in the vehicle can be improved by using the complex stimuli, using sound and vibration, and using sound and light. As a result, it is found that the cognition of the warning system is improved in the case when the complex stimuli are used compared to when only the simple stimulus with sound is used at the driver's position. Moreover, it is verified that the cognition rate of direction where is different from the sound source position in the vehicle can be improved by adding the stimulus with the tactile sense of vibration or by adding the stimulus with the visual sense of light.

INTRODUCTION

These days, various safety systems in vehicles using the warning sounds such as for the trapping prevention of the power slide door and for lane deviation are widespread.

However, there are some issues with the warning system. One of the issues is that the audibility is different between young persons and aged persons, consequently it is difficult for aged persons to cognize the warning sound. As a result, the importance of the warning system for senior citizens, whose audibility characteristic at high frequencies decreases, increases. Another issue is that the cognition of direction of the warning sound might be made difficult by the influence of the inside and outside environmental noise in the vehicle, or by the influence of the refraction or the diffraction of sound in the vehicle.

To improve the cognition rate of the warning sound, the sound quality evaluation is carried out by subjective evaluation or objective evaluation. The examples of subjective sound quality evaluation method are the paired comparison method and the Semantic Differential (SD) method [1-3]. On the other hand, objective sound quality evaluation method by using physiological reaction has also been studied [4-6].

In addition, lately the effect of the complex stimuli with the auditory sense of sound and the visual sense of view, and with the auditory sense of operational sound and tactile sense of operational feeling have been studied as well as simple stimulus with sound. Additionally, the effect of the complex stimuli is examined by subjective evaluation such as the paired comparison method and the SD method and by objective evaluation by using physiological reaction [7].

In this study, to improve the cognition of warning system and of the specific direction of the warning sound, we focus on the methods by using the complex stimuli with the auditory sense of sound and the tactile sense of vibration, and by using the complex stimuli with the auditory sense of sound and the visual sense of light. The effect of the complex stimuli is evaluated by the paired comparison method of subjective evaluation. Additionally, the suitable excitation point, frequency and the stimulation time of vibration for the cognition improvement are examined. Then, the suitable color and the stimulation time of light for the cognition improvement are examined. Moreover, it is examined if the cognition rate of direction where is different from the sound source position in the vehicle can be improved by using the complex stimuli with the auditory sense of sound and the tactile sense of vibration, and by using the complex stimuli with the auditory sense of sound and the visual sense of light.

COGNITION EVALUATION OF WARNING SOUND BY USING AGING HEARING-IMPAIRED FILTER

The cognition evaluation of the warning sound by using aging hearing-impaired filter is carried out.

Figure 1 shows the audiogram whose vertical axis indicates the audibility characteristics of each frequency sound, and horizontal axis indicates ages. The frequency of the warning sound of the vehicle is usually used at 4,000 Hz. Consequently, the frequency of the warning sound examined in this study is 4,000 Hz. Figure 1 indicates that the audibility characteristic of 4,000 Hz of 60-year-olds is decreased by 25 dB compared to 20-year-olds.

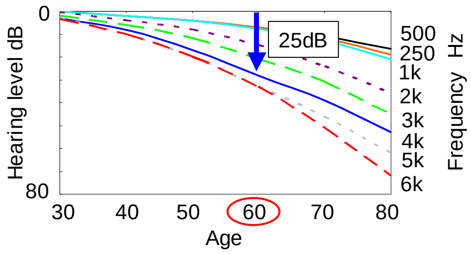


Figure 1. Audiogram

Accordingly, to examine the effect of change of the audibility characteristic by age experimentally, the cognition evaluation of the warning sound by using aging hearing-impaired filter is carried out. Figure 2 shows the time history of the evaluation sound consisting of Sound 1 (S1) and Sound 2 (S2). Duty ratio is defined as equation (1).

$$\text{Duty ratio (\%)} = A / (A+B) \times 100 \quad (1)$$

The frequency of the evaluation sounds is shown in Table 1. Five sounds, which are the sound A that is 4,000 Hz, the sound B that is mixed with 1,000 Hz and 4,000 Hz, the sound C that is mixed with 2,000 Hz and 4,000 Hz, the sound D that consisting of 1,000 Hz and 4,000 Hz alternately and the sound E that consisting of 2,000 Hz and 4,000 Hz alternately, are prepared.

Sixteen Japanese males aged between 21 and 25 participate in the cognition evaluation of the warning sound with aging hearing-impaired filter, and the evaluation is carried out by using the paired comparison method.

Figure 3 (a) shows the result of the evaluation without aging hearing-impaired filter and figure 3 (b) shows the result of the evaluation with aging hearing-impaired filter. Figure 3 indicates that the cognition of the sound A whose frequency is 4,000 Hz with aging hearing-impaired filter is extremely decreased compared to the sound A without aging hearing-impaired filter. Therefore, it is stated that the present warning sound whose frequency is 4,000 Hz is difficult for aged persons to cognize. Figure 3 also indicates that it is easer for aged persons to cognize the warning sounds mixed low frequency to the 4,000 Hz (Sound B, Sound C) or the sounds consisting of 4,000 Hz and lower frequency alternately (Sound D, Sound E) compared to the simple 4,000 Hz sound (Sound A).

There are some sounds whose frequencies are lower than 4,000 Hz such as winker sound and music sound in the vehicle, as a result, in this study, to improve the cognition rate of the warning sound, we don't use the warning sounds mixed low frequency to the 4,000 Hz or the warning sounds consisting of 4,000 Hz and lower frequency alternately, and we focus on the methods by using the complex stimuli with sound and vibration, and by using the complex stimuli with sound and light.

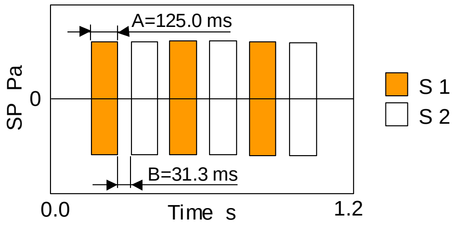


Figure 2. Time history of the evaluation sounds to examine the effect of the changed sound and of the aging hearing-impaired filter

Table 1. Evaluation sounds to examine the effect of the changed sound and of the aging hearing-impaired filter

Sounds	S1 Frequency Hz	S2 Frequency Hz	Duty ratio %	A ms	B ms
A	4,000	4,000	80	125.0	31.3
B	1,000 + 4,000	1,000 + 4,000			
C	2,000 + 4,000	2,000 + 4,000			
D	1,000	4,000			
E	2,000	4,000			

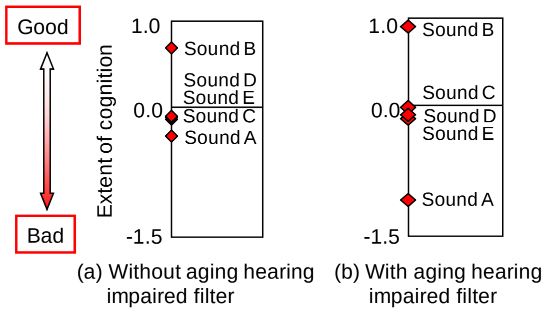


Figure 3. Evaluation result of the effect of hearing-impaired filter

COGNITION IMPROVEMENT OF WARNING SOUND BY COMPLEX STIMLI WITH SOUND AND VIBRATION

Evaluation of effectivity of complex stimuli with sound and vibration

The evaluation to examine the effect of the methods by using the complex stimuli with the auditory sense of sound and the tactile sense of vibration for the cognition improvement of the warning system is carried out.

Figure 4 shows the evaluation setup to examine the effect of the complex stimuli with sound by speaker and vibration by shaker. A seat and a speaker are placed in anechoic chamber. The positions of the seat and the speaker are in the same positions as the driver seat and the warning sound source respectively in the vehicle. The stimulus of vibration is presented from the back of the seat and sounds are presented from the speaker. The time histories of the stimuli are shown in figure 5. The timings of presenting each sound and presenting each vibration are synchronized. Two kinds of levels of vibration are prepared. Three kinds of stimuli for the evaluation, which are the single stimulus with sound, the single stimulus with vibration and the complex stimuli with sound and vibration, are prepared as shown in Table 2. The frequency of sounds is 4,000 Hz and that of vibration is 20 Hz, the duty ratio of sound is 80 % and that of vibration is 25 %.

Sixteen Japanese males aged between 21 and 25 participate in the cognition evaluation of the effectivity of the complex stimuli with sound and vibration, and the evaluation is carried out by using the paired comparison method.

Figure 6 shows the result of the evaluation whose vertical axis indicates the extent of the cognition that is scored by the paired comparison method, and horizontal axis indicates the kinds of the stimulus. The extent of the cognition of the single stimulus with sound is defined as 0 as a standard value. Figure 6 shows that the extent of the cognition of the complex stimuli with sound and vibration is higher than the single stimulus with sound and single stimulus with vibration. Moreover, when the complex stimuli with sound and small power of vibration is presented, the difference of the extent of the cognition from the case of sound is 1.0, on the other hand, when the big power of vibration is presented, the difference is 3.1. It is clear that the extent of the cognition and the power of vibration are the same tendency. This experimental result indicates that the extent of the cognition of the warning sound can be improved by adding the stimulus of tactile sense of vibration.

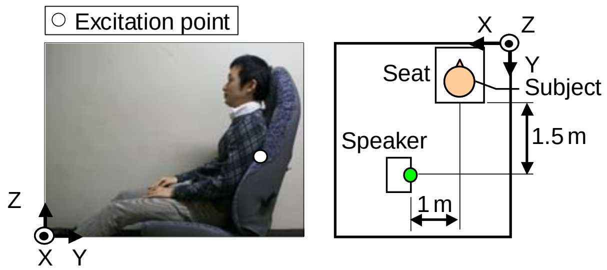


Figure 4. Evaluation setup to examine the effect of the complex stimuli with sound and vibration.

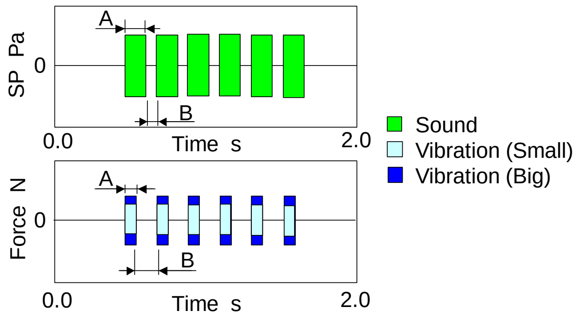


Figure 5. Time history of the evaluation stimuli to examine the effect of the complex stimuli with sound and vibration

Table 2. Evaluation stimuli to examine the effect of the complex stimuli with sound and vibration

Stimulus	Frequency Hz	Duty ratio %	A ms	B ms
Sound	4,000	80	125.0	31.3
Vibration	20	25	39.3	117.0
Sound + Vibration	4,000	80	125.0	31.3
	20	25	39.3	117.0

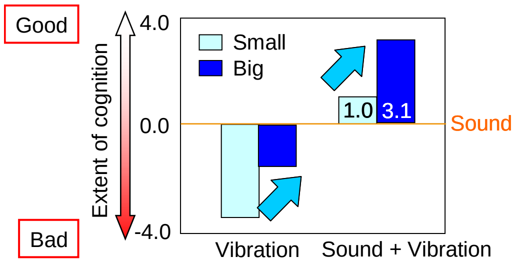


Figure 6. Evaluation result of the effect of the complex stimuli with sound and vibration

Examination of parameters of vibration for cognition improvement of the warning system

Next the evaluation to examine the suitable parameters of the complex stimuli with sound and vibration for the cognition improvement of the warning system is carried out.

Seventeen Japanese males aged between 21 and 25 participate in the cognition evaluation to examine the suitable parameters, and the evaluation is carried out by using the paired comparison method.

First the evaluation to examine the suitable excitation point of vibration for the cognition improvement of the warning system is carried out. The excitation points of the evaluation are at the steering, top, middle and bottom of the seat as shown in figure 7. The frequency of vibration is 20 Hz, the duty ratio is 25 % as shown in table 3.

Figure 8 shows the result of the evaluation whose vertical axis indicates the extent of the cognition that is scored by the paired comparison method. Figure 8 indicates that the extent of the cognition of the excitation point at the top of the seat is the highest compared to other points. The reason of this phenomenon is that the body's sensitivity to the stimulus with vibration at the top of the seat is the highest, since the flesh of the body touching the top of the seat is thin.

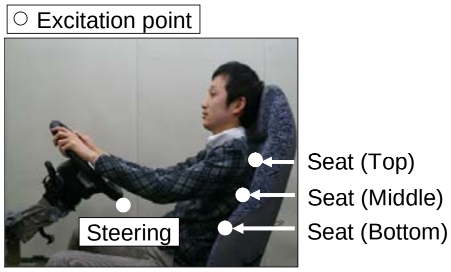


Figure 7. Evaluation setup to examine the suitable excitation point of vibration

Table 3. Stimulus of the evaluation to examine the suitable excitation point of vibration

Excitation point	Frequency Hz	Duty ratio %	A ms	B ms
Steering	20	25	39.3	117.0
Seat (Bottom)				
Seat (Middle)				
Seat (Top)				

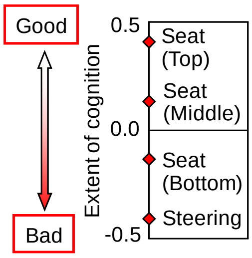


Figure 8. Evaluation result of the suitable excitation point of vibration

Next the evaluation to examine the suitable frequency and duty ratio of vibration for the cognition improvement of the warning system is carried out.

The stimuli of the evaluation are shown in Table 4. The excitation point is at the top of the seat where is verified as suitable point for the cognition improvement, and the frequencies are 20 Hz, 100 Hz and 200 Hz, the duty ratios are 25 % and 50 %. In this evaluation, sound is not presented.

Figure 9 shows the result of the evaluation whose vertical axis indicates the extent of the cognition that is scored by the paired comparison method. Figure 9 indicates that the extent of the cognition of vibration whose frequency is 100 Hz is the highest compared to other frequencies, and the extent of the cognition of vibration whose duty ratio is 50 % is higher compared to the case of 25 %. As a result, it is clear that the suitable frequency of vibration is 100 Hz, the duty ratio is 50 % for the cognition improvement.

Table 4. Stimuli of the evaluation to examine the suitable frequency and duty ratio of vibration

Stimulus of vibration	excitation position	Frequency Hz	Duty ratio %	A ms	B ms
A	Seat (Top)	20	25	39.3	117.0
B			50	78.0	78.0
C		100	25	39.3	117.0
D			50	78.0	78.0
E		200	25	39.3	117.0
F			50	78.0	78.0

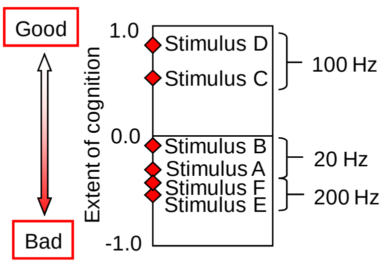


Figure 9. Evaluation result of the suitable frequency and duty ratio of vibration

Next the suitable stimulation time of each vibration of the complex stimuli with sound and vibration is examined. The presenting sound whose frequency is 4,000 Hz and whose duty cycle is 80 % is the same as sound shown in table 2. The presenting vibration is shown in figure 10 and table 5. Four kinds of the stimuli, whose ratio of the presenting number of sound to that of vibration is changed by editing the stimulation time of vibration, are prepared.

Figure 11 shows the result of the evaluation whose vertical axis indicates the extent of the cognition that is scored by the paired comparison method. Figure 11 indicates that the extent of the cognition of the stimuli, whose ratio of the presenting number of sound to that of vibration is 1, is the highest compared to other stimuli. This result shows that the number of the presenting vibration is more effective compared to the presenting time of each vibration.

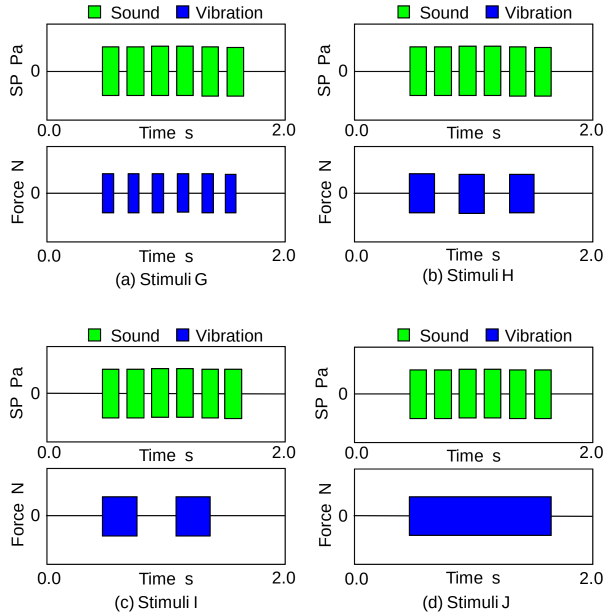


Figure 10. Time history of the stimuli of the evaluation to examine the suitable stimulation time of vibration

Table 5. Stimuli of the evaluation to examine the suitable stimulation time of vibration

Stimulus of vibration	Frequency Hz	Duty ratio %	A ms	B ms	Ratio of presenting number (Sound / Vibration)
G	100	50	78.2	78.2	1
H			156.0	156.0	2
I			235.0	235.0	3
J		100			—

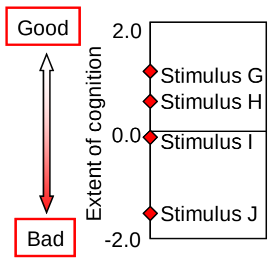


Figure 11. Evaluation result of the suitable stimulation time of vibration

COGNITION IMPROVEMENT OF WARNING SOUND BY COMPLEX STIMLI WITH SOUND AND LIGHT

Evaluation of efficiency of complex stimuli with sound and light

The evaluation to examine the effect of the methods by using the complex stimuli with the auditory sense of sound and the visual sense of light for the cognition improvement of the warning system is carried out.

Figure 12 shows the evaluation setup to examine the effect of the complex stimuli with sound and light. A 20-inch display which is virtual display of the car navigation system, a chair and a speaker are placed in anechoic chamber. The positions of the display, the chair and the speaker are in the same positions as the display of the car navigation system, the driver seat and the warning sound source respectively in the vehicle. The stimulus of light, which is yellow circle whose diameter is 10 mm, is presented in the center of display whose background color is black, and sounds are presented from the speaker. The timing of the presenting each light is synchronized to the presenting sound. Three kinds of stimuli for the evaluation, which are the single stimulus with sound, the single stimulus with light and the complex stimuli with sound and light, are shown in Table 6. The frequency of sounds is 4,000 Hz and the duty ratio of sound is 80 % and that of light is 50 %.

Sixteen Japanese males aged between 21 and 25 participate in the cognition evaluation of the effectivity of the complex stimuli with sound and light, and the evaluation is carried out by using the paired comparison method.

Figure 14 shows the result of the evaluation whose vertical axis indicates the extent of the cognition that is scored by the paired comparison method and horizontal axis indicates the kind of stimulus. Figure 14 indicates that the cognition of the complex stimuli with sound and light is higher compared to the single stimulus with sound and single stimulus with light. This experimental result indicates that the extent of the cognition of the warning sound can be improved by adding the stimulus of visual sense of light.

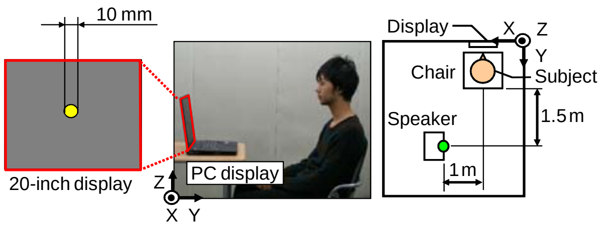


Figure 12. Evaluation setup to examine the effect of the complex stimuli with sound and light.

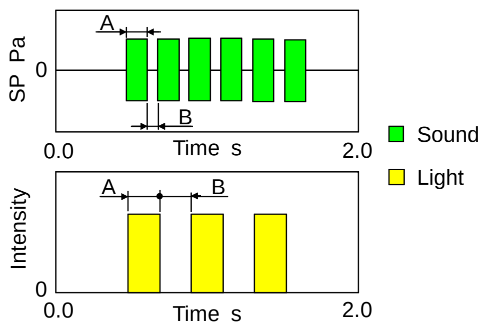


Figure 13. Time history of the evaluation stimuli to examine the effect of the complex stimuli with sound and light

Table 6. Evaluation stimuli to examine the effect of the complex stimuli with sound and light

Stimulus	Frequency Hz	Duty ratio %	A ms	B ms
Sound	4000	80	125.0	31.3
Light		50	156.0	156.0
Sound + Light	4000	80	125.0	31.3
		50	156.0	156.0

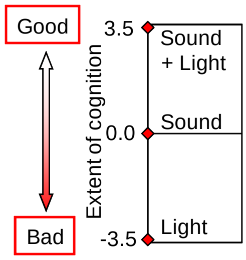


Figure 14. Evaluation result of the suitable stimulation time of light

Examination of parameters of light for cognition improvement of the warning system

Next the evaluation to examine the suitable parameters of the complex stimuli with sound and light for the cognition improvement of the warning system is carried out.

Seventeen Japanese males aged between 21 and 25 participate in the cognition evaluation to examine the suitable parameters, and the evaluation is carried out by using the paired comparison method.

First the evaluation to examine the suitable color of light for the cognition improvement of the warning system is carried out. The evaluation setup is shown in figure 15. The evaluation colors which are red, blue, green, yellow and white are flashed on the display whose background color is black, and the subjects sit on the chair in front of the display and evaluate the colors for the cognition improvement. The duty ratio of light is 50 %, whose parameter is the same as the parameter as shown in table 6. In this evaluation, sound is not presented.

Figure 16 shows the result of the evaluation whose vertical axis indicates the extent of the cognition that is scored by the paired comparison method. Figure 16 indicates that yellow is the suitable color for the cognition improvement.

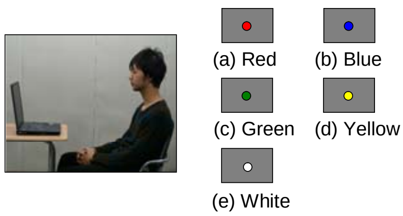


Figure 15. Evaluation setup to examine the suitable color

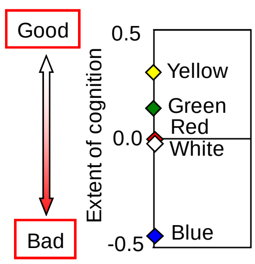


Figure 16. Evaluation result of the suitable color

Next the suitable stimulation time of each vibration of the complex stimuli with sound and vibration is examined. The presenting sound whose frequency is 4,000 Hz and whose duty cycle is 80 % is the same as sound as shown in table 2. The presenting light is shown in figure 17 and table 7. Four kinds of the stimuli, whose ratio of the presenting number of sound to that of light is changed by editing the stimulation time of light, are prepared.

Figure 18 shows the result of the evaluation whose vertical axis indicates the extent of the cognition that is scored by the paired comparison method. Figure 18 indicates that the extent of the cognition of the stimuli, whose ratio of the presenting number of sound to that of light is 1 and whose duty cycle is 50%, is the highest compared to other stimuli. The result also indicates that when the presentation time of light is too short, the extent of the cognition is low because the stimulus is too low when the presentation time of light is too short. Simultaneously, the presentation time of light is longer, the extent of the cognition is lower. It is considered that this phenomenon is caused by the habituation of the stimulus with light.

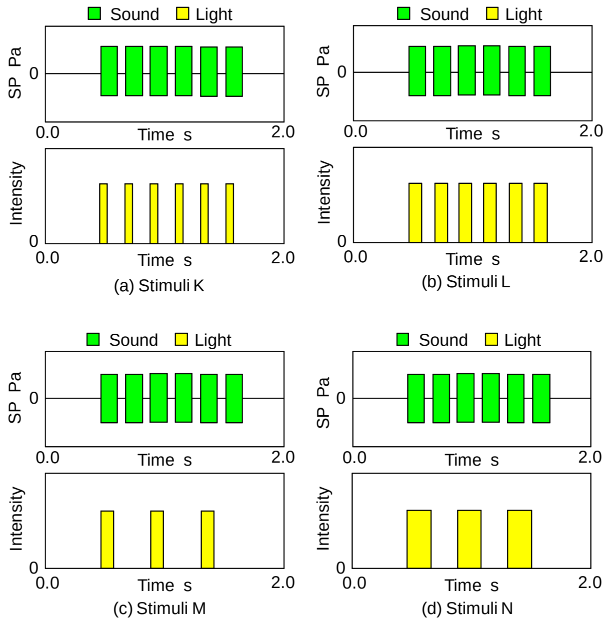


Figure 17. Time history of the stimuli of the evaluation to examine the suitable stimulation time of light

Table 7. Stimuli of the evaluation to examine the suitable stimulation time of light

Stimulus of light	Duty ratio %	A ms	B ms	Ratio of presenting number (Sound / Light)
K	25	39.3	117.0	1
L	50	78.2	78.2	
M	25	78.6	234.0	2
N	50	156.0	156.0	

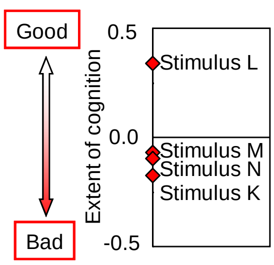


Figure 18. Evaluation result of the suitable stimulation time of light

IMPROVEMENT OF COGNITION OF SPECIFIC DIRECTION OF WARNING SYSTEM BY USING COMPLEX STIMLI WITH SOUND AND VIBRATION IN VEHICLE INTERIOR

There is an issue that the cognition of direction of the warning sound might be made difficult by the influence of the inside and outside environmental noise in the vehicle, or by the influence of the refraction or the diffraction of sound in the vehicle. To resolve the issue, the new warning system by using the complex stimuli is examined. In this examination, it is assumed that the improvement of the cognition rate of the specific direction in the vehicle is needed, consequently the evaluation is carried out in the vehicle.

First the effectivity of the complex stimuli with sound and vibration for the improvement of the cognition rate of the specific direction is examined. Figure 19 shows evaluation setup to examine the effect of the complex stimuli with sound and vibration. The warning sound source is placed at C or E, and the target direction of the improvement of the cognition rate is at B or F where is different from the sound source. In this evaluation, the simple stimulus with sound and the complex stimuli with sound and vibration are presented. The excitation point of vibration is at the top of the seat, and the distance from the center of the seat is 150 mm as shown in figure 19. The parameters of vibration determined by the evaluation above are used.

Sixteen Japanese males aged between 21 and 25 participate in the cognition evaluation. Subjects answer the direction where is the highest cognition among 6 directions from A to F in the vehicle.

The result of the evaluation is shown in figure 20. Figure 20 (a) is the case that the sound source is placed at E and the target direction of the improvement is F, and figure 20 (b) is the case that the sound source is placed at C and the target direction of the improvement is B. Figure 20 (a) of the improvement direction at F shows that the cognition rate of the simple stimulus with sound is 7 % and the rate of the complex stimuli with sound and vibration is 47 %. Figure 20 (b) of the improvement direction at B shows that the cognition rate of the simple stimulus with sound is 0 % and the cognition rate of the complex stimuli with sound and vibration is 53 %. It is clear that the cognition rate of the specific direction is improved in the case when the complex stimuli with sound and vibration are used, compared to when only the simple stimulus with sound is used at the driver's position. Consequently, it is verified that the cognition rate of the specific direction where is different from the sound source position in the vehicle can be improved by adding the stimulus with the tactile sense of vibration.

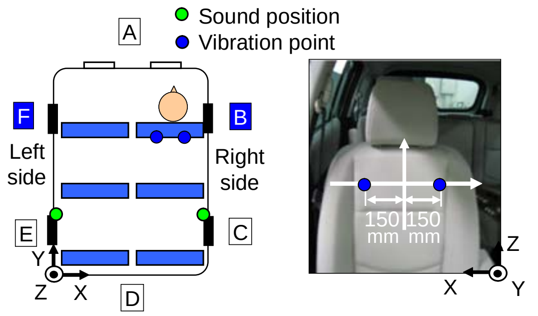
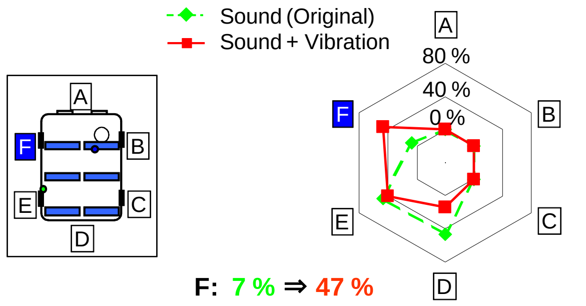
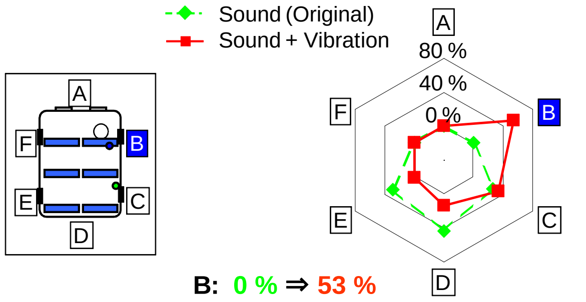


Figure 19. Evaluation setup to examine the effect of the complex stimuli with sound and vibration to improve the cognition rate of the specific direction



(a) Left side



(b) Right side

Figure 20. Evaluation result of the examination of the effect of the complex stimuli with sound and vibration to improve the cognition rate of the specific direction

IMPROVEMENT OF COGNITION OF SPECIFIC DIRECTION OF WARNING SYSTEM BY USING COMPLEX STIMLI WITH SOUND AND LIGHT IN VEHICLE INTERIOR

Then the effectivity of the complex stimuli with sound and light for the improvement of the cognition rate of the specific direction is examined. Figure 21 shows the evaluation setup to examine the effect of the complex stimuli with sound and light. The warning sound source is placed at C or E, and the target direction of the improvement of the cognition rate is at B or F where is different from the sound source. In this evaluation, the simple stimulus with sound and the complex stimuli with sound and light are presented. The distance between two light positions on the 20-inch display is 350 mm as shown in figure 21. The parameters of light determined by evaluation above are used.

Sixteen Japanese males aged between 21 and 25 participate in the cognition evaluation. Subjects answer the direction where is the highest cognition among 6 directions from A to F in the vehicle.

The result of the evaluation is shown in figure 22. Figure 22 (a) is the case that the sound source is placed at E and the target direction of the improvement is F, and figure 22 (b) is the case that the sound source is placed at C and the target direction of the improvement is B. Figure 22 (a) of the improvement direction at F shows that the cognition rate of the simple stimulus with sound is 7 % and the rate of the complex stimuli with sound and light is 47 %. Figure 22 (b) of the improvement direction at B shows that the cognition rate of the simple stimulus with sound is 0 % and the cognition rate of the complex stimuli with sound and light is 60 %. It is clear that the cognition rate of the specific direction is improved in the case when the complex stimuli with sound and light are used, compared to when only the simple stimulus with sound is used at the driver's position. Consequently, it is verified that the cognition rate of the specific direction where is different from the sound source position in the vehicle can be improved by adding the stimulus with the visual sense of light.

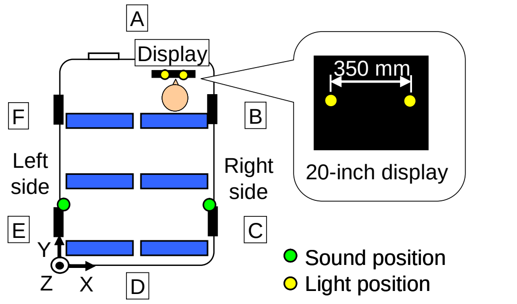
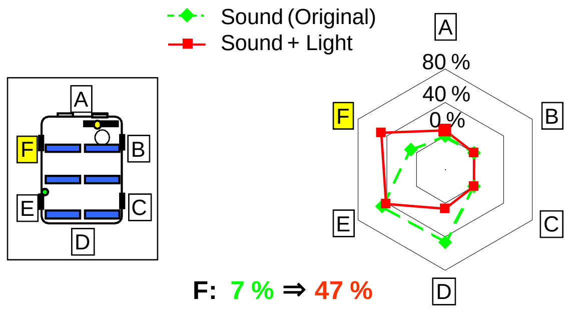
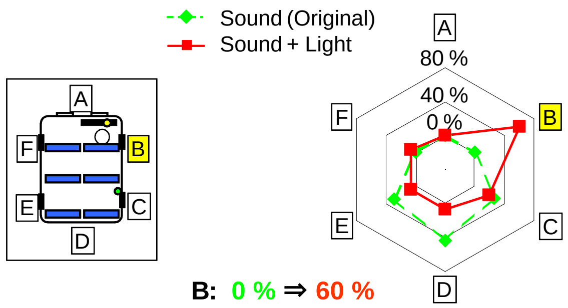


Figure 21. Evaluation setup to examine the effect of the complex stimuli with sound and light to improve the cognition rate of the specific direction



(a) Left side



(b) Right side

Figure 22. Evaluation result of the examination of the effect of the complex stimuli with sound and light to improve the cognition rate of the specific direction

SUMMERY

In this study, the new methods for the cognition improvement of the warning system and of the specific direction of the warning system by using the complex stimuli with the auditory sense of sound and the tactile sense of vibration, and by using the complex stimuli with the auditory sense of sound and the visual sense of light were examined. First, the effect of the complex stimuli, using sound and vibration, was evaluated by the paired comparison method of subjective evaluation. Next, the suitable excitation point, frequency and the stimulation time of vibration were examined. Then, the effect of the complex stimuli, using sound and light, was evaluated. Then, the suitable color and the stimulation time of light were examined. Moreover, it was examined if the cognition rate of direction where is different from the sound source position in the vehicle can be improved by using the complex stimuli, using sound and vibration, and using sound and light. As a result, it is found that the cognition of the warning system is higher in the case when the complex stimuli are used compared to when only the simple stimulus with sound is used at the driver's position. Moreover, it is verified that the cognition rate of direction where is different from the sound source position in the vehicle can be improved by adding the stimulus with the tactile sense of vibration or by adding the stimulus with the visual sense of light.

Furthermore, we plan in the near future to examine the possibility of the objective and quantitative evaluation methods by using physiological reaction for the evaluation of the cognition of the warning system.

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