Effectiveness of Automotive Warning System Presented with Multiple Sensory Modalities

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Abstract. Although it is very important to drive safely by drivers themselves, it is impossible to find drivers who do not make mistakes during driving. Therefore, vehicles should be equipped with a system that automatically detect hazardous state and warn if of drivers so that such a preventive safety can contribute to the reduction of traffic accidents due to the oversight of important information necessary for safety driving. This study paid attention to the preventive safety technology, and discussed how the warning should be presented to drivers. It was explored whether simultaneously presenting warning to multiple sensory organs such as visual and auditory systems can promote (quicken) the perception of warning even under the situation, where interference between information of the same sensory modality occurs. The auditory-tactile warning was found to lead to quicker and more accurate reaction to a hazardous scene during a simulated driving.

Keywords: automotive warning, multiple sensory modality, auditory-tactile warning, reaction time, hit rate.

1 Introduction

With the growth of intelligent transportation systems (ITS), such as car navigation systems or hands-free cellular phones, driving is becoming more and more complex. As much of the information provided contains texts and images, drivers are apt to become distracted and inattentive. Driving a car places a characteristically heavy workload on visual perception, cognitive information processing, and manual responses. Drivers often simultaneously perform two or more tasks; for example, they adjust the volume of a radio or CD player and control the air conditioner to adjust the temperature while driving. Such sharing of attention may lead to dangerous situations.

Thus, in driving environment, the visual and cognitive driving workload increases, and the driver-vehicle interaction is getting more and more complicated [1,2]. Consequently, drivers tend to be distracted by a variety of secondary task such as the operation of switches for CD or air conditioner other than driving [3], which increases the risk of inattentive driving.

As the display and control systems of automobile is becoming more and more complex, it is predicted that older drivers are distracted by these systems and cannot cope with such situations. Jones et al.[4] reviewed the utilization of sense of touch as

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a medium for information representation. They concluded that sense of touch represents a promising means for communication in human-vehicle system. Driver et al. [5], Spence et al. [6,7] and Ho et al.[8-10] showed that the presentation of spatially predictive vibrotactile warning signal can facilitate drivers response to driving event seen through the windscreen or rear mirror. However, in these studies, the presentation of vibrotactile warning signal was to prevent front-to-rear-end collision in a driving simulator. They did not discuss the presentation of tactile signal to warn drivers of right and left dangers. Moreover, they did not compare the effectiveness as a warning signal between auditory and vibrotactile presentations. In driving environment, most information is presented via a visual or auditory stimulus. If the warning signal is presented via a visual or auditory stimulus, the auditory or visual interference with other information might arise. On the other hand, if a vibtotactile warning, that is, tactile interface is used, the possibility of such interference would be sure to reduce. Moreover, although older adults exhibit deficits in various cognitive-motor tasks, older adults' decline of tactile sense seems to be less as compared with visual or auditory sense. On the basis of the discussion above, it is expected that a vibrotactile signal would be very promising as a warning signal especially for older adults.

Recently, the tendencies of multimodal information processing [11,12] and design have emerged as major research topics in complex real-world domains such as military, air traffic operation, or automobile. Presenting information via multiple modalities such as vision, audition, and touch has been expected to be a promising means to reduce transmission errors and enhance safety. A better understanding of cross-modal spatial and temporal links is essential to ensure better application of this property to the automotive warning design. Murata [13] showed the effectiveness of tactile interface for warning presentation in driving environment. However, design technologies of automotive warning system using a principle of cross-modal link have not been established. It is expected that such a cross-modal link between different modalities further enhances the effectiveness of automotive warning system.

The aim of this study was to promote the perception of warning even under the situation, where interference between information of the same sensory modality occurs, by simultaneously presenting warning to multiple sensory organs such as visual and auditory systems. In order to clarify the most suitable method for presenting warning using a cross-modal link between different sensory modalities, the following seven conditions were used in the experiment: (1) visual cue, (2) auditory cue, (3) tactile cue, (4) combination of visual and auditory cues, (5) combination of visual and tactile cues, (6) combination of auditory and tactile cues, and (7) no warning (cue). The aim and hypothesis of the study are summarized in Fig.1. It has been hypothesized that multimodal warning presentation with different modalities is more effective for quickening the reaction to a hazard than unimodal warning presentation.

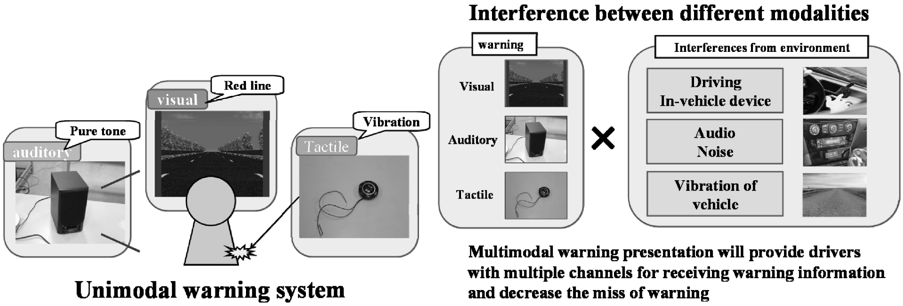

Fig. 1. Aim and hypothesis of the study

The paper is organized as follows: Section 2 shows the experimental method to explore the effectiveness of automotive warning system with multiple sensory modalities. Section 3 summarized the results, and Section 4 discussed the results, and Section 5 considered how the proposed warning system should be utilized for enhancing driving safety.

2 Method

2.1 Participant

Ten participants aged from 21 to 24 years took part in the experiment. All had held a driver's license for 3-4 years. The visual acuity of the participants in both young and older groups was matched and more than 20/20. They had no orthopedic or neurological diseases. All signed the informed consent after receiving a brief explanation on the aim and the contents of the experiment.

2.2 Apparatus

Using a driving simulator system shown in Fig.2, the participants were required to simultaneously carry out a simulated driving task (main task) and the following three secondary tasks: switch pressing, accelerator maneuvering, and judgment of information which is randomly presented on one of the four locations (front, back mirror, right monitor, and left monitor). The experimental front and rear scenes are shown in Fig.3.

2.3 Task

The displays of main task, secondary switch pressing task, accelerator maneuvering, and judgment task of hazard are depicted in Fig.4, Fig.5, Fig.6, and Fig.7, respectively. The displays of eight types of hazard directions are shown in Fig.8-Fig.11.

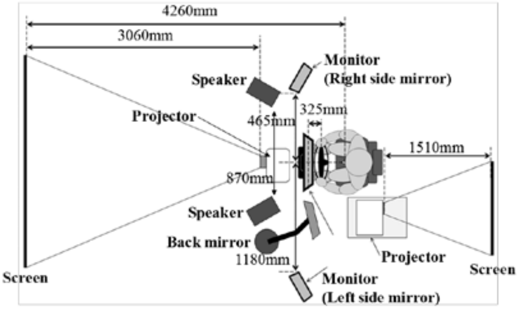

Fig. 2. Explanation of experimental setting

Fig. 3. Scene of experiment (front and rear screen)

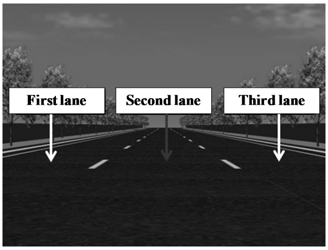

Fig. 4. Display of main task

In the main task, the participant was required to minimize the deviation from the predetermined line and keep the lane location by maneuvering a steering wheel. The switching task requires the participant to carry out a secondary task such as the adjustment the audio volume using the steering switch. In the accelerator maneuvering, the participant was required to keep the control within the predetermined range using the accelerator. In the judgment task of hazard, the participant was required to react to a visual hazard using an accelerator or a steering switch. In this task, the warning was presented to the participant using the following warning (cue) presentation method: (1) visual cue, (2) auditory cue, (3) tactile cue, (4) combination of visual and auditory cues, (5) combination of visual and tactile cues, (6) combination of auditory and tactile cues, and (7) no warning (cue).

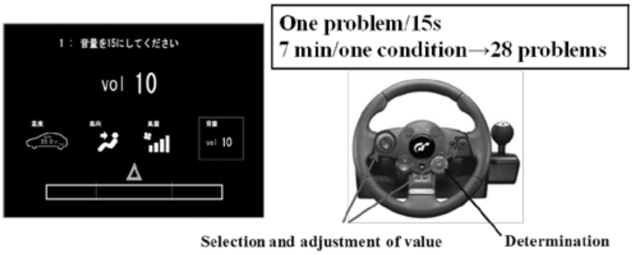

Fig. 5. Display of secondary switch pressing task

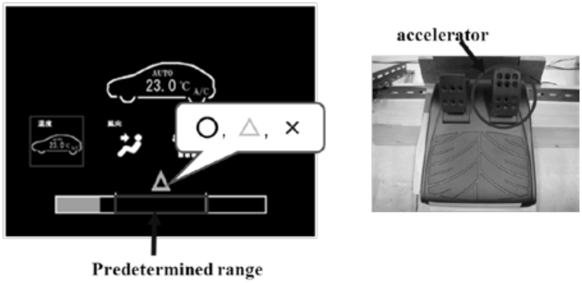

Fig. 6. Display of secondary accelerator operation task

Fig. 7. Display of secondary judgment task of hazard

2.4 Design and Procedure

The experimental condition is summarized in Table 1. The experimental variables were warning presentation method (seven levels). The participant was required to simultaneously carry out a main driving simulator task, a secondary switch pressing task, accelerator maneuvering, and judgment task of hazardous scene displayed either of the front, the back mirror, the right monitor, and the left monitor.

The following measures were used to evaluate the effectiveness of the seven warning condition above: (A) percentage correct in switch pressing, (B) frequency of deviation from the pre-specified range in acceleration maneuvering, and (C) reaction time and accuracy (percentage correct reaction) to the warning cue by steering or braking operation. Hypothesizing that multimodal warning presentation will provide drivers with multiple channels for receiving warning information and decrease the miss of warning, this was experimentally verified.

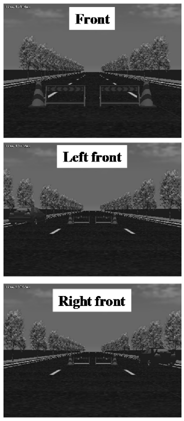

Fig. 8. Display of front hazard, left front hazard, and right front hazard

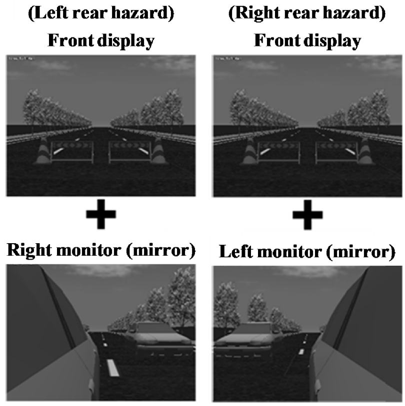

Fig. 9. Display of left rear and right rear hazards

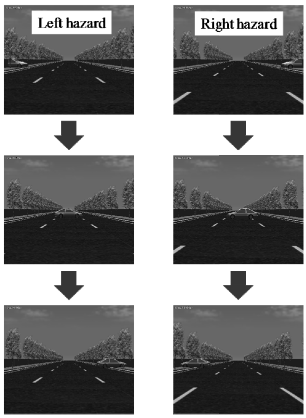

Fig. 10. Display of left and right hazards

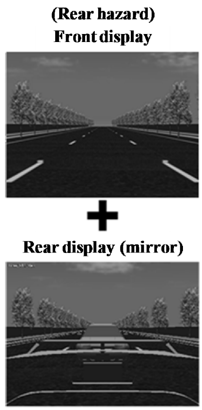

Fig. 11. Display of rear hazard

Table 1. Experimental condition

Condition	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Warning method	Nothing	Warning presentation method					
		Visual	Auditory	Tactile	Visual & Auditory	Visual & Tactile	Auditory & Tactile
Blocking sound	Noise of moving car						
Location of stimulus				Leg		Leg	Leg

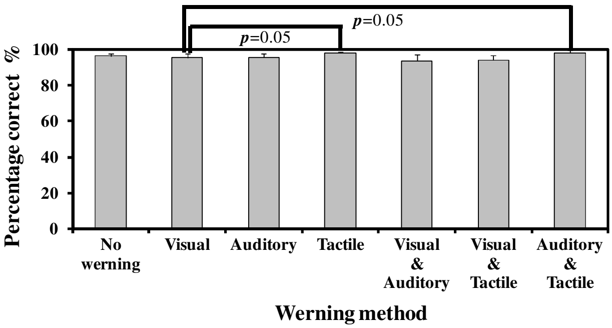

Fig. 12. Percentage correct in switch pressing task compared among seven warning conditions

3 Results

The percentage correct in the switch pressing task is plotted as a function of seven warning presentation condition ((1) visual cue, (2) auditory cue, (3) tactile cue, (4) combination of visual and auditory cues, (5) combination of visual and tactile cues, (6) combination of auditory and tactile cues, and (7) no warning (cue)) in Fig.12. As shown in Fig.13, the reaction time in the braking operation tended to be prolonged for the single-modality condition (visual only, and auditory only) and the visual-auditory combination. In Fig.14, the hit rate of hazardous scenes is plotted as a function of warning presentation condition. Fig.15 compares the miss rate of hazardous scene compared among seven warning presentation conditions above.

A one-way (warning presentation method) ANOVA conducted on the percentage correct in the switch pressing task revealed no significant main effect. A multiple comparison by Fisher's PLSD revealed marginally significant differences between tactile and auditory-tactile presentations, and between visual-tactile and auditory-tactile presentations (p=0.0584).

A one-way (warning presentation method) ANOVA conducted on the number of deviation from the lane in the accelerator maneuvering task revealed no significant main effect. A multiple comparison by Fisher's PLSD revealed marginally significant differences between visual and auditory presentations ($p<0.05$).

A one-way (warning presentation method) ANOVA conducted on the reaction time to a hazard revealed a significant main effect of warning presentation method ($F(6,54)=3.873$, $p<0.01$). A multiple comparison by Fisher's PLSD revealed the following significant differences: (no warning, visual) ($p<0.01$), (no warning, auditory) ($p<0.05$), (no warning, visual-auditory) ($p<0.05$), (visual, tactile) ($p<0.01$), (visual, visual-tactile) ($p<0.01$), (visual, auditory-tactile)

($p<0.05$), (visual, auditory-tactile) ($p<0.05$), (auditory, tactile) ($p<0.01$), (auditory, visual-tactile) ($p<0.05$), (tactile, visual-tactile)($p<0.01$).

A one-way (warning presentation method) ANOVA conducted on the reaction time to a hazard revealed no significant difference. A multiple comparison by Fisher's PLSD revealed the following significant differences: (visual, tactile) ($p<0.05$), (visual, visual-tactile) ($p<0.05$), and (visual, auditory-tactile) ($p<0.05$).

Table 2. Summary of the results

Measure	Proper condition
Accuracy in switch pressing	Tactile & auditory-tactile warnings led to higher accuracy.
Reaction time to hazard	Visual, auditory visual-auditory warnings led to slower reaction.
Hit rate	Tactile, visual-auditory, and auditory-tactile warnings led to higher hit rate.
Miss rate	Auditory, tactile, and auditory-tactile warnings led to lower miss rate.

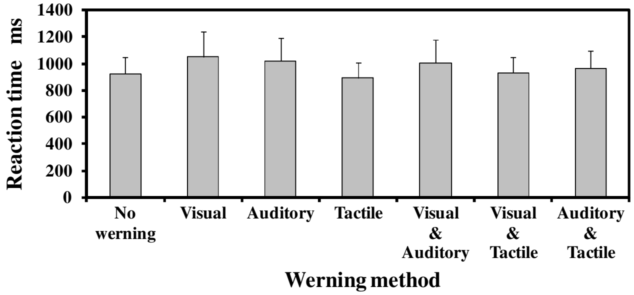

Fig. 13. Reaction time of braking operation compared among seven warning conditions

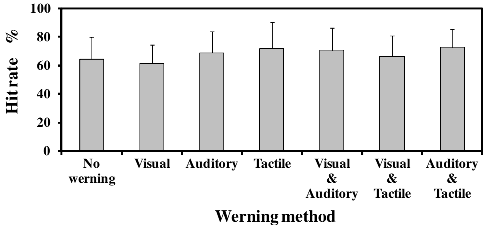

Fig. 14. Hit rate of hazardous scene compared among seven warning conditions

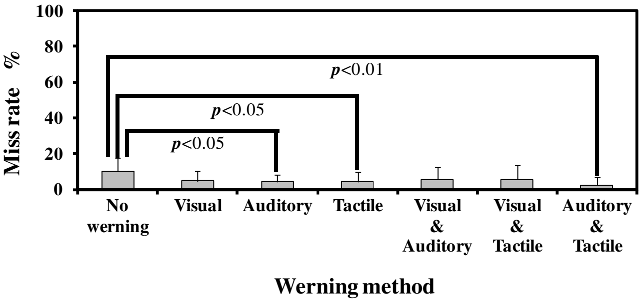

Fig. 15. Miss rate of hazardous scene compared among seven warning conditions

4 Discussion

The braking reaction time for the tactile, and the tactile-auditory combination tended to be shorter (See Fig.8). It tended that the hit rate of tactile only and the auditory-tactile combination was higher (See Fig.9). The auditory-tactile warning led to faster and more accurate reaction to a hazard. The tactile and the tactile-auditory combination improved the accuracy and the speed of the warning perception and the following operation. It might be inferred that the tactile-auditory superiority over other modality combination appeared in this experiment as pointed out by Fujisaki et al. [2].

As a whole, the performance measure such as the reaction time and the hit rate was improved for the cueing condition of tactile only and the auditory-tactile combination. In such a way, the effectiveness of the tactile cue and the combination of auditory and tactile cues was indicated.

5 Implications for Designing Automotive Warning System

The driving task corresponds to a multi-task situation [14] where a main driving task and secondary tasks such as operating an air conditioner or a digital audio system are carried out simultaneously. As pointed out by Wickens at al. [15-18], the interference of perceptual stimuli degraded the cognitive information processing. In almost all of driving environments, drivers receive almost all of information via visual or auditory stimulus. Under such a situation, it was predicted that the presentation of warning via tactile sense would accelerate the processing of stimulus.

The effectiveness of multimodal warning presentation should be explored when directional judgment is added to the hazard judgment. The presentation condition of warning of each modality was determined using the results of unimodal warning experiment. The optimal presentation of each warning must be determined using an experimental setting of multimodal warning. Moreover, as pointed out by Jones [4], the warning condition differs by the attachment location or the number of tactors. Therefore, the optimal warning condition should be determined adaptively according to the experimental setting.

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