Proposal of Automotive 8-directional Warning System That Makes Use of Tactile Apparent Movement

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Abstract. We proposed a tactile 8-directional warning system which informs drivers of hazardous traffic situations hidden in 8 directions via tactile apparent movement. The effectiveness of the proposed warning system was compared with that of a warning system by simultaneous two-point stimulation and a system without warning. As a result, the apparent lead to quick reaction and higher hit rate (higher accuracy of hazard perception and recognition) as compared with the simultaneous two-point stimulation. However, this was limited to the front and the rear hazard, and was not true for all directions. The vibrotactile warning system that can recognize hazards from all of eight directions should be developed in future research.

Keywords: warning system, traffic safety, apparent movement, simultaneous two-point stimulation, reaction time, hit rate.

1 Introduction

With the progress of by-wire and information technology, 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.

The potential application of tactile sense to the automotive warning system is paid more and more attention for enhancing driving safety [4]. Recently, the tendencies of cross-modal information processing [5-9] and design have emerged as major research topics in the design of automotive warning system. 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 a better application of this property to the automotive warning design. Ho et al. [6-8] showed the effectiveness of vibrotactile warning presentation in driving environment. In traffic situations, many hazards exist ubiquitously. Therefore, the effectiveness of automotive warning must be confirmed using a lot of locations where hazards potentially hide. However, few studies have examined the effectiveness of automotive warning system using

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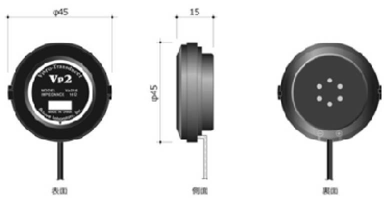

Fig. 1. Vibrotransduce Vp216 used as a vibrotactile stimulus

Table 1. Conditions for producing apparent movement

Duration of stimulation [ms]	125
Inter-stimulus interval [ms]	125
Inter-stimulus distance [mm]	100
Frequency [Hz]	66
Intensity [V]	10

more than two locations. Ho et al. [6-8] explored the effectiveness of tactile warning for front and rear locations. Murata et al. [10] examined how the tactile warning is effective for left and right locations. Moreover, few studies investigated the effectiveness of vibrotactile warning by apparent movement. It is expected that vibrotactile warning by apparent movement can more quickly transmit the directional cues than the simultaneous stimulation of two vibrotransducers or the single-point stimulation.

The aim of this study was to propose a tactile 8-directional warning system which informs drivers of hazardous traffic situations hidden in 8 directions via tactile apparent movement. The effectiveness of the proposed warning system was compared with that of a warning system by simultaneous two-point stimulation and a system without warning. The paper is organized as follows: Section 2 shows the experimental method to explore the effectiveness of tactile 8-directional warning system. Section 3 summarized the results, and Section 4 discussed how the proposed warning system should be utilized for enhancing driving safety.

2 Method

2.1 Participants

A total of five participants aged from 21 to 24 years old took part in the experiment. All had a driver's license. All were healthy, and had no neurological diseased. Informed consent on the participation to the experiment was obtained from all participants after explaining the contents of the experiment briefly.

2.2 Task

The experimental conditions were: warning presentation by apparent movement, simultaneous two-point stimulation, and no warning. The vibrotactile stimuli were presented to the participant via a vibrotranceducer (Vp216) shown in Fig.1. The vibrotranceducers were arrayed on the seat as shown in Fig.2. In a preliminary experiment, the conditions for producing apparent movement were determined as in Tab.1.

Two warning presentation method were used in the experiment. One was the simultaneous two-point stimulation (See Fig.3), and the other was the apparent movement (See Fig.4). In Fig.5, the sketch of experimental setting is depicted.

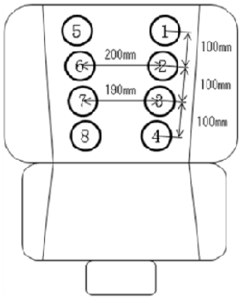

Fig. 2. Array of vibrotransducers on the automotive seat

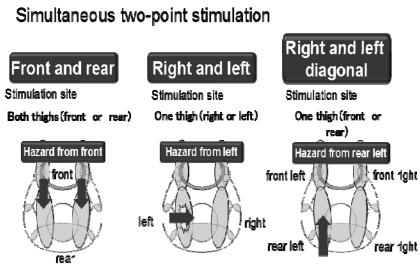

Fig. 3. Condition of simultaneous two-point stimulation

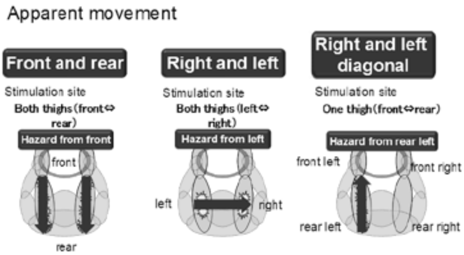

Fig. 4. Condition of apparent movement

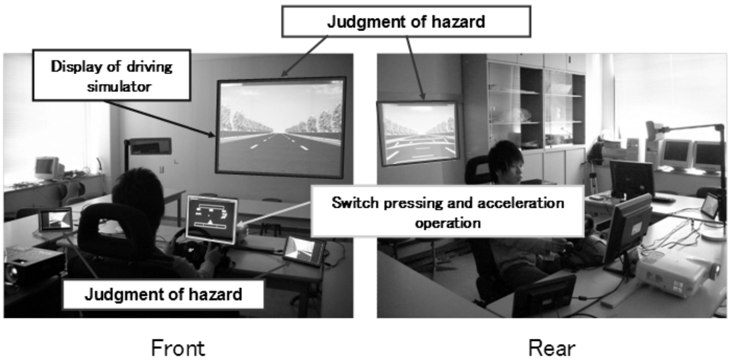

Fig. 5. Sketch of experimental setting

2.3 Design and Procedure

The participants were required to simultaneously carry out the following four tasks: (a) virtual driving task (main task), (b) switch pressing task (secondary task), (c) accelerator operation (secondary task), and (d) judgment of information randomly appearing at 8 directions (front, rear, left, right, front left, front right, rear left, and rear right) around drivers. Each task is explained from Fig.6 to Fig.9. The direction of hazard and how to avoid it are summarized in Fig.10 and Fig.11.

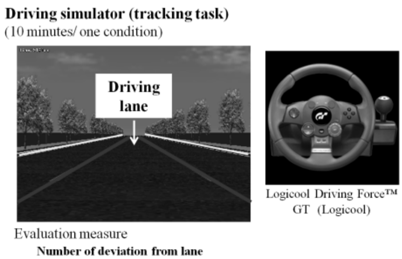

Fig. 6. Explanation of main task

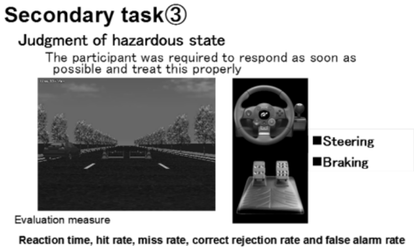

Fig. 7. Explanation of secondary task (judgment of hazardous state)

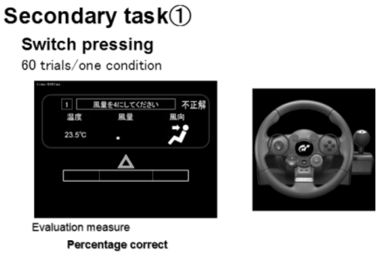

Fig. 8. Explanation of secondary task (switch pressing)

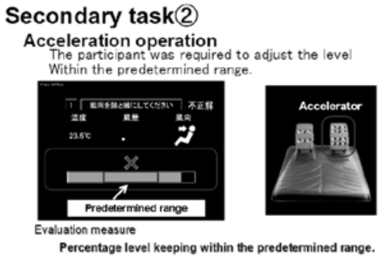

Fig. 9. Explanation of secondary task (acceleration operation)

2.4 Evaluation Measures

The following measures were used to evaluate the effectiveness of the proposed warning system: (1) frequency of lane deviations, (2) percentage correct in switch pressing, (3) accuracy of accelerator operation, and (4) response time (speed) and accuracy to the hazard. The experiment explored how the evaluation measures were affected by the method of warning presentation (no warning, warning by simultaneous two-point stimulation, and warning by apparent movement).

3 Results

3.1 Hit Rate and Miss Rate

In Fig.12, the hit rate in the judgment of information randomly appearing at 8 directions is plotted as a function of warning condition (apparent movement, simultaneous two-point stimulation, and no warning). The hit rate of the warning by apparent movement was higher than other warning conditions. In accordance with this, the miss rate of the warning by apparent movement was nearly the same with that of the simultaneous two-point vibrotactile stimulation (See Fig.13). In Fig.14, the hit rate to hazard is shown as a function of warning presentation method and direction of hazard

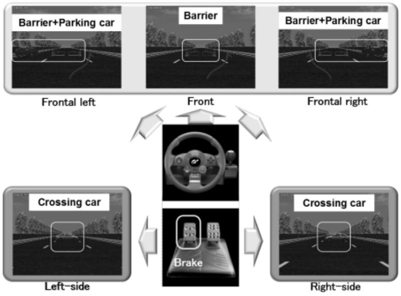

Fig. 10. Direction of hazard and its avoidance -1-

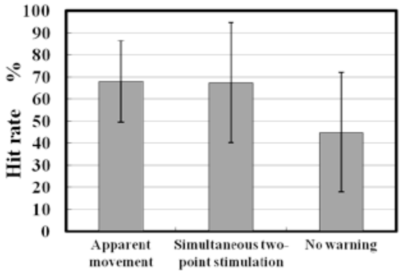

Fig. 11. Hit rate as a function of warning condition

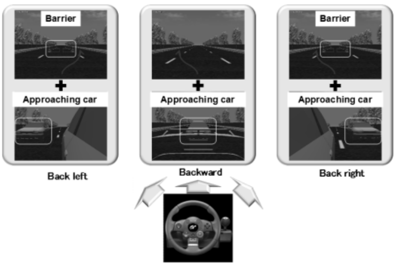

Fig. 12. Direction of hazard and its avoidance -2-

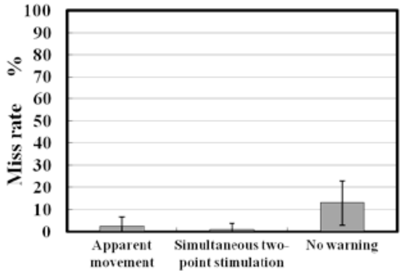

Fig. 13. Miss rate as a function of warning condition

(except for right and left directions). Fig.15 shows the hit rate as a function of warning presentation method and direction of hazard (right and left directions).

A one-way (warning presentation method) ANOVA carried out on the hit rate revealed a significant main effect ($F(2,18)=10.102$, $p<0.01$). Fisher's PLSD revealed a significant difference between apparent movement and no warning ($p<0.01$), and between simultaneous two-point stimulation and no warning ($p<0.01$).A similar one-way (warning presentation method) ANOVA carried out on the hit rate for the right and left directions revealed no significant main effect.

For each direction, Fisher's PLSD further revealed the following significant difference.

Front: Apparent movement and no warning ($p<0.01$)
Simultaneous two-point stimulation and no warning ($p<0.01$)
Front right: Simultaneous two-point stimulation and no warning ($p<0.01$)
Rear right: Apparent movement and no warning ($p<0.05$)
Simultaneous two-point stimulation and no warning ($p<0.01$)
Rear: Apparent movement and no warning ($p<0.05$)
Left: Apparent movement and no warning ($p<0.05$)

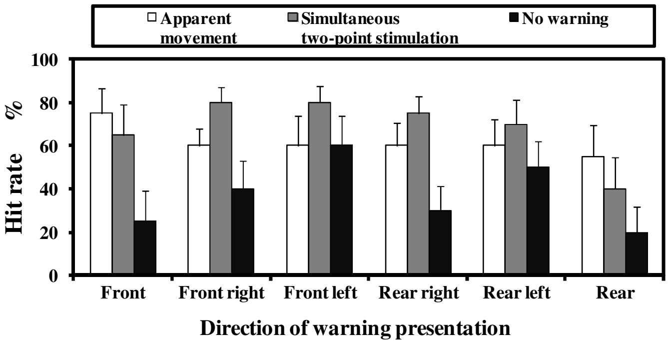

Fig. 14. Hit rate of hazard as a function warning method and direction of warning except for right and left directions

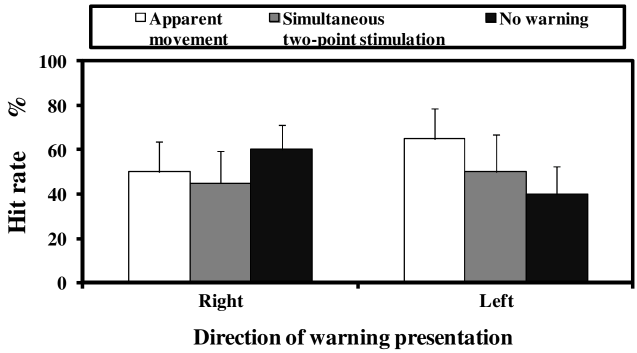

Fig. 15. Hit rate of hazard as a function warning method and direction of warning (right and left directions)

3.2 Reaction Time

The reaction time to a hazard is plotted as a function of warning presentation method and direction of hazard (except for right and left directions) in Fig.16. In Fig.17, The reaction time to a hazard is plotted as a function of warning presentation method and direction of hazard (right and left directions).

For direction of hazard presentation except for right and left directions, a one-way (warning presentation method) ANOVA was conducted on the reaction time to a hazard. A significant main effect of warning presentation method ($F(2,18)=4.438$, $p<0.05$) was detected. Fisher's PLSD revealed significant differences between apparent movement and no warning ($p<0.05$), and between simultaneous two-point stimulation ($p<0.05$).

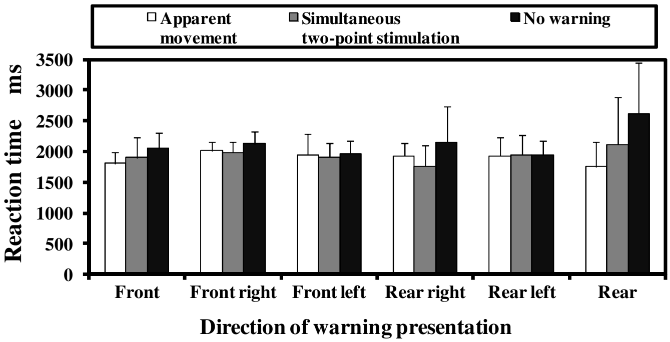

Fig. 16. Reaction time to hazard as a function warning method and direction of warning except for right and left directions

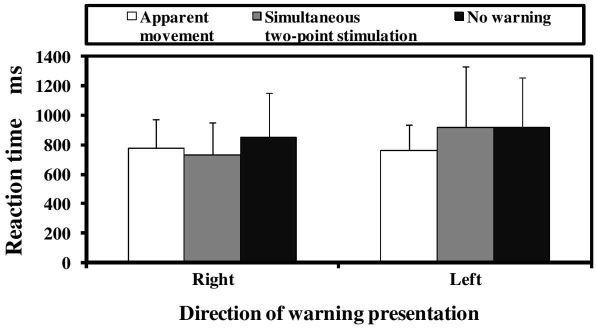

Fig. 17. Reaction time to hazard as a function warning method and direction of warning (right and left directions)

For each direction, Fisher's PLSD further revealed the following significant difference.

Front: Apparent movement and no warning (p<0.05)
Rear right: Simultaneous two-point stimulation and no warning (p<0.05)
Rear: Apparent movement and no warning (p<0.05)
Simultaneous two-point stimulation and no warning (p<0.05)

4 Discussion

4.1 Accuracy of Warning Perception

For both front and rear directions, it tended that the warning presentation by apparent movement led to higher hit rate, and was more effective than the warning presentation by simultaneous two-point stimulation as shown in Fig.14. As for other directions, the hit rate for the warning presentation by simultaneous two-point stimulation tended to be higher (See Figs.14 and 15). These results mean that warning presentation should be properly used according to the direction of hazard.

Table 2. Comparison between apparent movement and simultaneous two-point stimulation

Evaluation measure	Comparison between two stimulation methods
Number of deviation from lane	Apparent movement = Simultaneous two-point stimulation
Percentage correct of switch press	Apparent movement = Simultaneous two-point stimulation
Percentage level keeping within the predetermined range	Apparent movement = Simultaneous two-point stimulation
Reaction time	Apparent movement > Simultaneous two-point stimulation (Front, Back, Left) Apparent movement < Simultaneous two-point stimulation (Back right, Right)
Hit rate	Apparent movement > Simultaneous two-point stimulation (Front, Back, Right, Left) Apparent movement < Simultaneous two-point stimulation (Front right, Front left, Back right, Back left)
Miss rate	Apparent movement = Simultaneous two-point stimulation
False alarm late	Apparent movement = Simultaneous two-point stimulation
Correct rejection rate	Apparent movement = Simultaneous two-point stimulation

4.2 Speed of Warning Perception

For the front hazard, as shown in Fig.16, the warning presentation by apparent movement tended to lead to quick reaction. For the rear right hazard, the warning presentation by simultaneous two-point stimulation tended to lead to quick reaction (See Fig.17). This is also indicative of the proposal that whether warning should be presented via apparent movement or simultaneous two-point stimulation must be determined according to the direction of warning presentation.

4.3 Implication for Automotive Warning Design

The driving task corresponds to a multi-task situation [11] 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. [12-15], 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. As expected, it was indicated that the tactile warning system promoted a quick response to hazardous situations. The proposed 8-directional warning system by apparent movement led to higher hit rate. As the simultaneous two-point stimulation seems to have produced confusion among the directions of hazardous situations, this warning system led to slower response time.

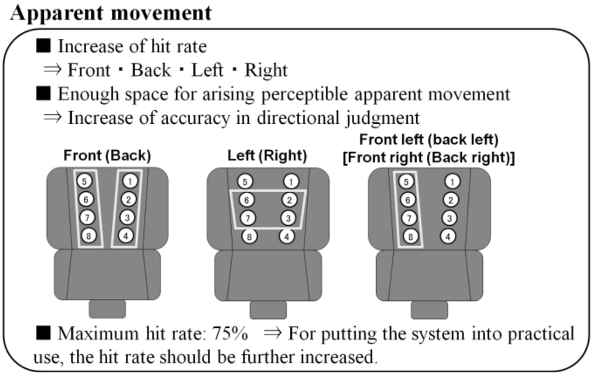

Fig. 18. Summary of results for warning presentation by apparent movement

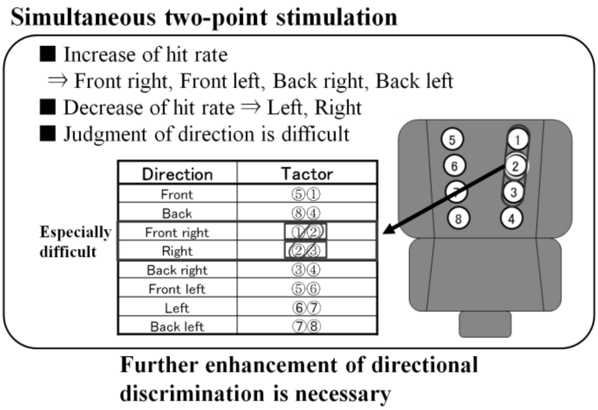

Fig. 19. Summary of results for warning presentation by simultaneous two-point stimulation

However, it must be noted that the hit rate for the warning by apparent movement was about 74%. The reason can be inferred as follows. In this experimental situation, the judgment of information randomly appearing at 8 directions includes (1) warning presentation, (2) appearance of hazardous scene, and (3) avoidance of hazard. In this process, the time to think how the hazard should be avoided is necessary. Even if the hazard was quickly recognized, it is insufficient unless the avoidance action of the hazard was also executed as soon as possible. Therefore, the warning system must be further improved so that the avoidance action after the hazard cognition will be executed fast.

In Table 2, the comparison of two warning presentation methods is listed. Except for the reaction time and the hit rate, no significant differences were detected between two warning presentation methods.

The results for warning presentation by apparent movement and simultaneous two-point stimulation are summarized in Fig.18 and Fig.19, respectively. In conclusion, the vibrotactile warning presentation was in a sense effective for preventing hazard from missing and was helpful to shorten the reaction to hazard (See Figs.12-15). It must also be noted that the following issued related to each warning presentation method must be overcome to put vibrotactile warning system into practical use. As for the warning by apparent movement, more accurate reaction should be attined in some way. Ambiguous perception of direction occurs frequently in the warning presentation by simultaneous two-point stimulation, and this induces delay of directional judgment. The increase of the number of vibrotranceducer installed to the cockpit might solve this problem.

Future work should overcome the issued identified in this experiment so that such a preventive safety driving system should be put into practical use.

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