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Basic study on effectiveness of tactile interface for warning presentation in driving environment

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Abstract— **The aim of this study was to get insight into the development of tactile interface for automobile warning system. In other words, it was investigated whether the important driving information in the right and left peripheral visual fields can be recognized faster using tactile warning system as compared with auditory warning system. The participants were required to simultaneously carry out a tracking task (main task), a switch pressing task such as selection of light-on function, and a judgment task of important information which randomly appeared to the right or left peripheral visual field. The tracking error, the number of lane deviation, the percentage correct of switch pressing, and the response time to right and left peripheral stimulus were measured. It was examined how age, the modality of alarm presentation (no alarm, auditory, and tactile), the addition of direction in alarm presentation, and the existence of disturbance sound, and the location of tactile sensor (steering or foot) affected the measures above. The young adults performed better than older adults. The response time was not affected by the modality of alarm presentation, and the disturbance sound. The addition of direction of alarm presentation affected the performance. The tactile sensor attached to the foot led to faster response than that attached to the steering wheel.**

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[1]. 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[2]. 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.

Previous research in the area of displays and controls for secondary devices in automobiles is notable for the lack of reported work on compatibility. Most research discusses design of the display or the control, but not the way in which they are to operate together, which includes effects of compatibility.

Lambel, Kauranen, Laakso, and Summala and Lambel, Laakso, and Summala discussed the relationship between display location and performance in car driving situations[3], [4]. Lambel, Laakso, and Summala reported that the driver's ability to detect the approach of a decelerating car ahead was affected by the display location[4]. Waller and Green[5] examined switch type and its location, and pointed out a lack of consensus as to where the control should be located. Proper control (switch) location must be one of the important factors to assure fast responses of drivers.

Makiguchi et al.[6] demonstrated that steering wheel mounted controls were more effective than controls on the instrumental panel. However, they did not examine the effectiveness of steering wheel-mounted switches by taking the display location factor into account. Although Wierwille[7] stated that in-car controls and displays should be designed by taking visual and manual demands into account, he did not give guidelines for where the displays and controls should be located. Murata and Moriwaka[8] investigated how the number and arrangement of steering wheel mounted switches interactively affected performance. They found that the cross-type arrangement with three switches provided best performance.

These studies did not take the memory factors into account to the design of display with layered structures. The display design also should consider the findings on eye movement characteristics that horizontal eye movement is faster and easier than vertical eye movement. Although Murata and Moriwaka[8] investigated how the control should be designed without taking the display factors into account, the interaction between display and control factors must be investigated in order to obtain a more proper design guideline.

Older adults may have more difficulty in operating a vehicle than younger adults. There are many reports suggesting that older adults exhibit deficits in various cognitive-motor tasks[9]-[11]. These authors reviewed the literature in movement control and discussed the effects of age on cognitive-motor capabilities in driving, from the viewpoint of movement science. Imbeau et al. [12] discussed how the aging factor affected display design and driving performance. They made an attempt to provide designers with integrated performance data that helped them answer design questions and evaluate design alternatives. They presented a model that can predict performance (glance time of the display) using age, character size of the display, and contrast of the display. However, they did not discuss the effects of controls. Smith et al.[13] reviewed the current databases applicable to automobile design. They pointed out that design approaches and data used in automobile design are mostly for a young population. The design approach and data suitable for an older population has not been provided. They did however review data on the characteristics and problems of older drivers, including physical and motor, sensory and cognitive changes. It is pointed out that working memory of older adults is inferior to that of young adults.

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.[14] reviewed the utilization of sense of touch as a medium for information representation. They concluded that sense of touch represents a promising means for communication in human-vehicle system. Ho et al.[15]-[17] 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[9]-[11], 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.

The aim of this study was to acquire basics for the development of tactile (vibrotactile) interface for automobile warning system. It was investigated whether the important driving information presented to the right and left peripheral visual fields can be recognized faster using tactile (vibrotactile) warning system as compared with auditory warning system.

2. Method

2.1 Participants

Twenty participants took part in the experiment. Ten were male adults aged from 65 to 76 years. All had held a driver's license for 30 to 40 years. Ten were male undergraduate students aged from 21 to 24 years and licensed to drive from 1 to 3 years. Stature of participants ranged from 160 to 185 cm. 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.

2.2. Apparatus

The experimental system for the tracking task and the switch press task is the same with than used in Murata et al.[18]. The main components were (i) a pursuit tracking system (a personal computer with an I/O board, rotary encoder, and steering wheel). This PC was connected to a projector to display a tracking task in front of the participant.), (ii) a personal computer that was used to display speedometer and operational information, (iii) a personal computer equipped with an I/O card and used to enable the participant to operate switches. The CRT was in front of the participant.

In order to reflect the dynamic images to be placed at the location of left and right side mirrors, two personal computers (ASUS, Eee PC) were used. A speaker system (Edifier, Multimedia Speaker R800TC) was used to present an auditory stimulus. A tactor was used for the presentation of vibrotactile warning. The PCI interface board (Interface, PCI-2431) was used to control a tactor.

The installation of tactors on the steering wheel is

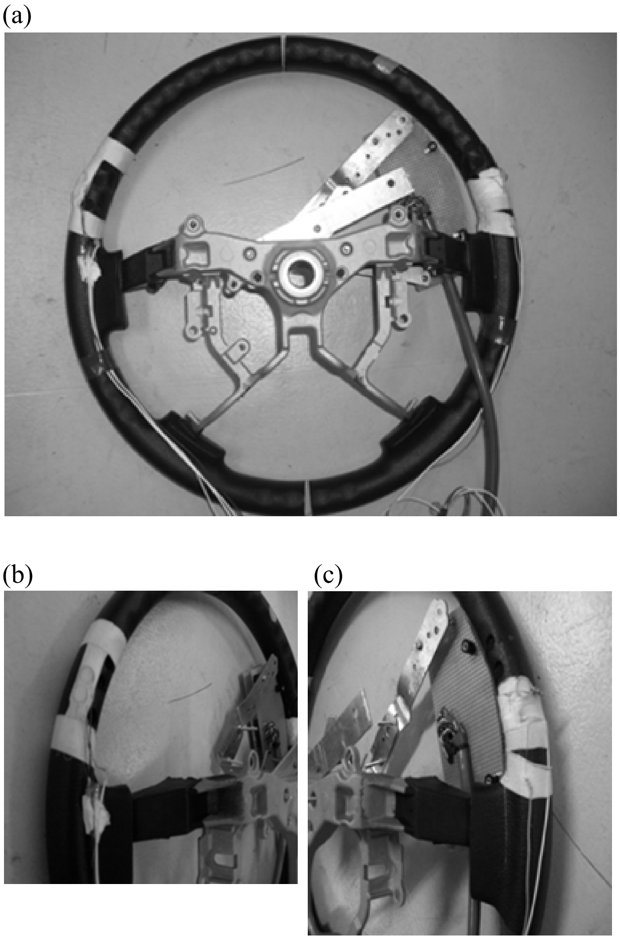

Photo1. Arrangement of tactor. (a) Back of the steering wheel, (b) back and right-side, (c) back and left-side.

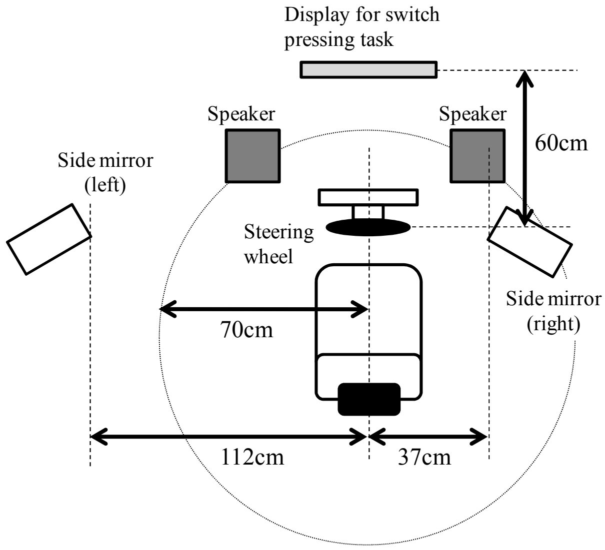

Fig1. Arrangement of experimental system.

depicted in Photo.1. The installation location of apparatuses is summarized in Fig.1.

<u>*2.3 Task*</u>

The participants were required to simultaneously carry out a tracking task (main task), a switch pressing task such as selection of light-on function, and a judgment task of important information which randomly appeared to the right or left peripheral visual field.

The outline of a tracking task is summarized in Fig.2. The participant was required to keep the filled target within the two lines by a steering wheel. When the target went outside of two lines, the background color of the whole display changed to red.

In the switch pressing task, the participant was required to select one of the following items using a switch (control) placed around the left side on the steering wheel. The sample of display is the same with that of Murata[18].

The participant was also required to carry out a judgment task of important information which randomly appeared to the right or left peripheral visual field. Ten kinds of dynamic images were presented to either right of left peripheral visual field via a personal computer (ASUS, Eee PC). Each dynamic image was presented two times to the participant randomly. This was presented to both right and left personal computers. A total of 40 judgments must be carried out by the participant for each experimental condition. Four kinds of dynamic images were predetermined, and the participant was required to respond as quickly and accurately as possible with a foot switch as soon as the participant noticed the predetermined dynamic image. The condition of this task was as follows:

(a) type of warning signal
- no warning
- auditory warning (The pure tone of 1 kHz with 80dB(A) was used.)
- vibrotactile warning (The tactors were driven with a 280 Hz sinusoidal signal.)

(b) presence of directional cue

With cue: When the predetermined image appears on the left (right) peripheral visual field, the warning was presented to the same direction using a tactor placed on the left (right)-side of a steering wheel, or a speaker placed on the left (right).

Without cue: When the predetermined image appears on the left (right) peripheral visual field, the warning was presented using two tactors placed on the both sides of a steering wheel, or speakers placed on the left and right.

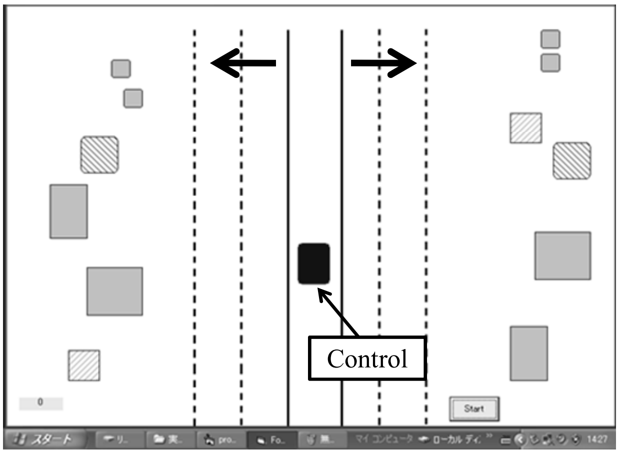

Fig.2 Display of tracking task.


Photo2. Outline of experimental situation.

2.4 Design and procedure

The experimental factors were participant age (young and older adults), the type of warning signal (no warning, auditory warning, vibrotactile warning), and the directional cue (without cue and with cue). Age was a between-subject factor; the type of warning signals and the directional cue were within- subject factors.

The participant was asked to adjust his seat so that the task could be comfortably performed and the left-side console switches and the foot switch could be pressed by reaching his hand or food naturally. Before the experimental tasks, the contents of the primary driving simulator task and secondary tasks (switch pressing task and judgment task) were thoroughly explained to each participant.

Participants were allowed to practice before performing experimental tasks. When the experimenter judged that the participant clearly understood how to perform the experimental task, the experiment was started. The order of five combinations of experimental condition (no warning, auditory warning without directional cue, auditory warning with directional cue, tactile warning without directional cue, and tactile warning with directional cue) was counterbalanced across the participants. The participants were required to keep the primary task stable and also to perform the secondary switch pressing and judgment tasks as fast and accurately as possible. The outline of experimental situation is summarized in Photo.2.

The following evaluation measures were used.

(1) Tracking performance: mean deviation between the center of two tracking lines and the center of controlled target.

(2) Number of deviation from normal lane

(3) Percentage correct switch pressing

(4) Reaction time to a predetermined dynamic image

(5) Percentage correct reaction to a predetermined dynamic image

3. Results

3.1 Tracking error

In Fig.3, the tracking error is plotted as a function of age, type of warning signal, and presence or absence of directional cue. As a result of a two-way (age by type of warning) ANOVA conducted on the tracking error, significant main effect of age ($F(1,18)=5.403$, $p<0.05$) and type of warning ($F(2,36)=5.922$, $p<0.01$) were detected. A two-way (age by directional cue) ANOVA conducted on the tracking error revealed only a significant main effect of age ($F(1,18)=5.321$, $p<0.05$). The main effect of directional cue was not statistically significant.

3.2 Number of deviation from normal lane

In Fig.4, the number of deviation from normal lane is shown as a function of age, type of warning, and presence or absence of directional cue. As a result of a two-way (age by type of warning) ANOVA conducted on the tracking error, only a significant main effect of age was detected ($F(1,18)=8.321$, $p<0.01$). A two-way (age by directional cue) ANOVA conducted on the tracking error revealed only a significant main effect of age ($F(1,18)=9.521$, $p<0.01$). It seems that this measure was not affected by the type of warning and the directional cue.

3.3 Percentage correct switch pressing

In Fig.5, the Percentage correct switch pressing is shown as a function of age, type of warning, and presence or absence of directional cue. As a result of a two-way (age by type of warning) ANOVA conducted on

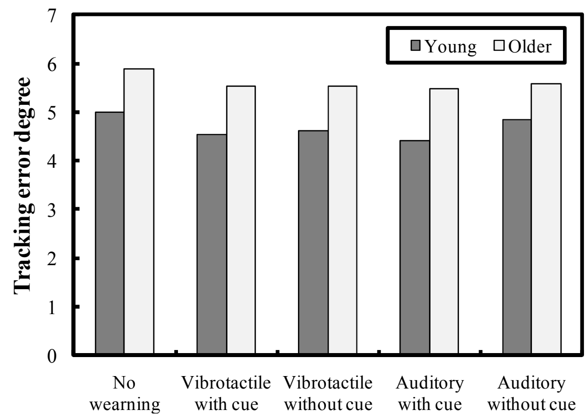

Fig.3 Tracking error as a function of age, type of warning, and presence or absence of directional cue.

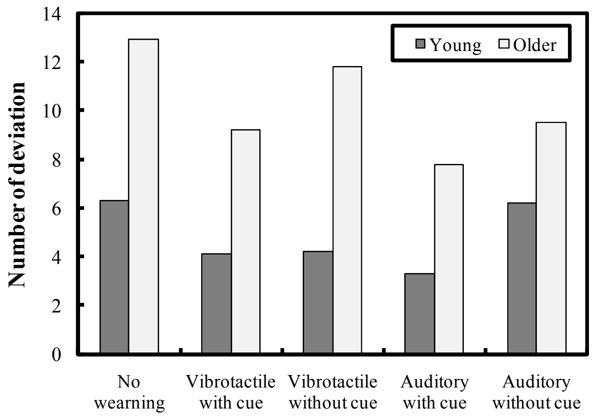

Fig.4 Number of deviation as a function of age, type of warning, and presence or absence of directional cue.

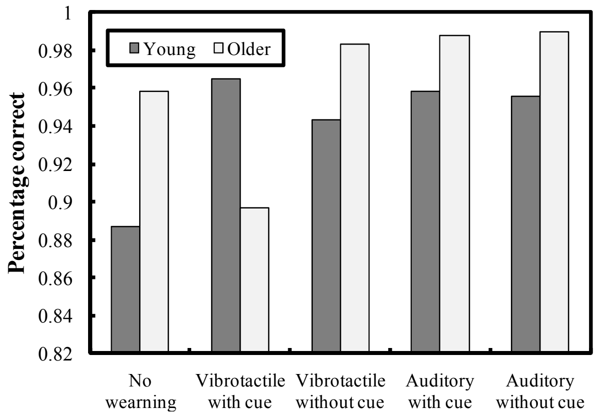

Fig.5 Percentage correct as a function of age, type of warning, and presence or absence of directional cue.

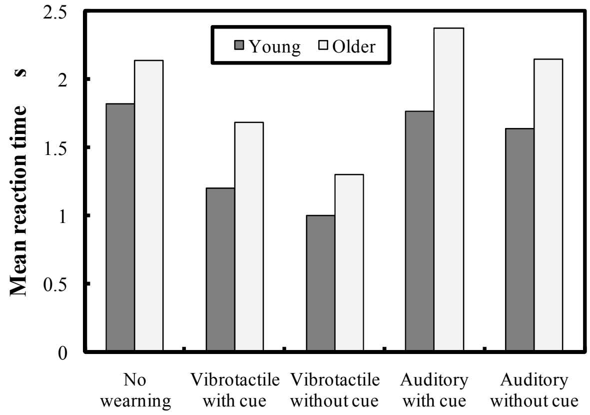

Fig.6 Mean reaction time as a function of age, type of warning, and presence or absence of directional cue.

the tracking error, only a significant main effect of age was detected ($\boldsymbol{F}(1,18)=5.015$ $\boldsymbol{p}<0.05$). A two-way (age by directional cue) ANOVA conducted on the tracking error revealed only a significant main effect of age ($\boldsymbol{F}(1,18)=6.146$, $\boldsymbol{p}<0.05$). Fisher's PLSD (Protected Least Significant Difference) multiple comparisons revealed significant differences between no warning and auditory warning, and between no warning and vibrotactile warning.

<u>*3.4 Performance of judgment task*</u>

The correct response (hit rate and correct rejection rate) to the predetermined dynamic image did not differ between two age groups, among three warning types, and between directional cue conditions.

In Fig.6, the response time to the stimulus is plotted as a function of age, type of warning, and presence or absence of directional cue. The vibrotactile warning with directional cue seems to assure faster response than the auditory warning signal with directional cue. As a result of a two-way (age by type of warning) ANOVA conducted on the response time, significant main effect of age ($\boldsymbol{F}(1,18)=17.808$, $\boldsymbol{p}<0.01$) and type of warning ($\boldsymbol{F}(2,36)=28.428$, $\boldsymbol{p}<0.01$) were detected. Fisher's PLSD (Protected Least Significant Difference) multiple comparisons revealed significant differences even between tactile and auditory stimulus with directional cue.

4. Discussion

As shown in Fig.3-Fig.6, the performance of older adults seem be inferior to that of young adults. The declined perceptual, cognitive and motor functions of older adults [9]-[13] are clearly reflected in these results.
The effectiveness of warning signal does not necessarily appear as shown in Fig.6. For both age groups, the response time of the tactile warning with directional cue was the shortest. In particular, older adults seem to obtain benefits if the tactile warning is used properly. In order to make warning signal effective, as pointed by Ho et al.[15]-[17], the directional cue was found to play an important role.

Although the tactors were driven with a 280 Hz sinusoidal signal, it must be identified in more detail the frequency, the duration and the intensity of tactors as pointed out by Jones[14]. As Scmidt[19] shows the communication capacity of auditory and tactile senses are approximately 105 and 106, respectively. We assumed that tactile interfaces are promising in automotive warning system, based on the rationale that most information is presented via a visual or auditory stimulus. Moreover, the tactile warning system has an advantage in that it has the following advantage to reduce the interference of sensory modalities. 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. Such an assumption has been verified in the range of this experiment. Therefore, more efforts would be necessary to put tactile warning system into practical use in automotive driving environment.

Only the right and left warnings were used in this study. The dangerous warning does not necessary appear from these directions only. According to the dangerous situations, a variety of ways to realize a vibrotactile sensor-based warning system must be proposed to enhance safety on the basis of tactile-interface based warning system. Future research should be carried out to identify appropriate frequencies and intensity of vibration of a tactor for a variety of body parts so that we can obtain a useful data or basis for designing a tactile interface-based warning system. Scmidt[19] pointed out that the motor preparation characteristics of tactile sense. The motor preparation characteristics mean that the faster the response becomes faster, the nearer the tactile stimulus is placed to effectors. The characteristics should be explored in future research.

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