Effect of Spatial Haptic Cues on Visual Attention in Driving

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ABSTRACT
We have developed a haptic cue-based navigation system that helps a driver find important traffic signs and obstacles in cognitive overload situations. We conducted a visual search experiment using a flicker paradigm to evaluate the effectiveness of the system. The two independent variables used in the experiment were cue validity (valid vs. invalid vs. no-cue) and level of cognitive load (high vs. low). A haptic facilitation effect was found for visual tasks; the response time was shorter when haptic cues were consistent with the location of visual targets (*valid cue*) than when haptic cues were not (*invalid cue*) or when no haptic cues were presented (*no-cue*). In addition, this crossmodal facilitation effect of haptic cues was found in both levels of cognitive load. This result strongly implies the development of a driving navigation system with spatial haptic cues for various cognitive load situations.

Categories and Subject Descriptors
H5.2. User Interfaces: Evaluation, Haptic I/O.

General Terms
Experimentation, Human Factors.

Keywords
Driving navigation system design, haptic interface, vibrotactile, cognitive load, flicker paradigm

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1. INTRODUCTION
Current navigation systems usually provide visual and auditory guidance. However, there are some visual and auditory obstacles that prevent a driver from acquiring driving related information from a navigation aid. Haptic cues as an alternative modality to this highly cognitive overloaded situation was considered in this study. Haptic cues can be helpful while driving because they do not interfere with other modalities. In addition, there is evidence of a crossmodal facilitation effect of spatial haptic cues on visual tasks [3, 5]. Therefore we designed a novel navigation aid which exploits vibrotactile cues to represent spatial locations in visual search tasks and evaluated the proposed system under various conditions.

2. SYSTEM DESIGN
We have developed a haptic cue-based navigation system using vibrotactile signals to present haptic spatial information during driving. The haptic interface was mounted on the back of a chair because torso is considered to be suitable for rendering spatial information [1].

The haptic navigation system in this study consisted of a tactor array, a controller board and a host computer. The tactor array included 5-by-5 vibration motors. Each vibration motor was located on the latex rubber which reduces the transmission of vibration from a tactor to others. Five tactors on the top and five tactors on the bottom of the tactor array were used to provide directional information for visual tasks: lower right, lower left, upper left and upper right. Tactors were vibrating one after another to indicate four different directions so that participants could easily perceive directional flows of vibration on their backs. The host computer transmitted information about the direction and timing of haptic cues to the controller board, and the controller board drove the tactor array based on the received information.

3. SYSTEM EVALUATION

We conducted a visual search experiment using a flicker paradigm to evaluate the usefulness of the system.

Participants. Sixteen university students (Males: 7, Females: 9) volunteered to participate. Their mean age was 22.4 (SD= 1.7). They did not have any visual or haptic health problems.

Design. The two independent variables used in the experiment were validity (valid vs. invalid vs. no-cue) and cognitive load (high vs. low). As to the validity factor, a vibrotactile cue was defined as *valid* if the directional flow of the vibrating tactor indicated the quadrant where the changing object was presented; a vibrotactile cue was defined as *invalid* otherwise; *no cue* was without any vibrotactile cues presented. The occurrence ratio between the valid haptic cues and invalid haptic cues was 3 to 1 throughout the entire experiment. The visual cognitive load factor had the two levels of depending on visual complexity. Visual scenes with highly dense objects were defined as a *high* overload condition, because visual search tasks with those scenes were expected to be difficult [4]. Visual scenes were otherwise defined as a *low* level of cognition overload condition. The level of cognitive load of each visual scene was examined in the pilot test. The occurrence ratio between the high and low cognitive load conditions was the same throughout the experiment.

Procedure. First, they conducted a practice session where they could become aware of vibrations and clearly identify the direction of vibrations presented on their back. The visual change-detection task consisting of two blocks of 28 trials conducted after the practice session. For each trial, a fixation point was presented in the center of the screen at the beginning, and then a vibrotactile cue was rendered. After a short pause, the visual change-detection task began. During the task, an original photograph and a modified photograph which contained only one different object were repeatedly alternated and presented to participants. We asked participants to find and locate changing objects on the host computer's screen as quickly as possible, and their response times were recorded for analysis. Visual stimuli were presented until participants found changing element.

4. RESULT

Response times for each condition were recorded during the experiment and used as dependent variables in analysis. A two-way repeated-measure ANOVA with validity (valid vs. invalid vs. no-cue) and cognitive load (high vs. low) as within-subjects factors was carried out.

The analysis showed that the main effect of validity was statistically significant ($F(2,30)=42.54$, $p<0.001$). The result indicated the usefulness of the vibrotactile cue for the visual search task. The main effect of cognitive load was also significant ($F(1,15)=90.20198$, $p<0.001$). Response times were significantly shorter in the low cognitive load condition than in the high cognitive load condition. There was no significant interaction effect between validity and cognitive load.

Pairwise comparisons for validity showed that the response times in the valid cue condition was significantly shorter than in the invalid cue condition and also in the no-cue condition ($p<0.001$). The analysis also showed that the vibrotactile cues for conveying spatial information were useful for both levels of visual cognitive loads.

5. CONCLUSION

In this research, we designed and evaluated the haptic cue-based driving navigation system which uses vibrotactile cues to present spatial locations in the visual task. The result showed the efficiency of haptic cues in a visual search task while driving.

Valid haptic cues facilitated the participants' performance, elicited shorter response times in visual search tasks than invalid and no haptic cues. This crossmodal facilitation was found in both high and low cognitive load conditions. In other words, the vibrotactile cues for spatial information were efficient for any level of visual cognitive loads in the driving situation. The result of this research implies the development of haptic cue-based driving navigation system.

For future work, more research on the crossmodal facilitation of haptic cues under various visual tasks is necessary. In addition, the crossmodal interaction of haptic and auditory or haptic, visual and auditory should be dealt to provide a guidance in designing of future navigation systems.

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