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Haptic Seat Interfaces for Driver Information and Warning Systems

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The implementation of haptic interfaces in vehicles has important safety and flexibility implications for lessening visual and auditory overload during driving. The present study aims to design and evaluate haptic interfaces with vehicle seats. Three experiments were conducted by testing a haptic seat in a simulator with a total of 20 participants. The first experiment measured reaction time, subjective satisfaction, and subject workloads of the haptic, visual, and auditory displays for the four signals primarily used by vehicle navigation systems. The second experiment measured reaction time, subjective satisfaction, and subjective workloads of the haptic, auditory, and multimodal (haptic + auditory) displays for the ringing signal used by in-vehicle Bluetooth hands-free systems. The third experiment measured drivers’ subjective awareness, urgency, usefulness, and disturbance levels at various vibration intensities and positions for a haptic warning signal used by a driver drowsiness warning system. The results indicated that haptic seat interfaces performed better than visual and auditory interfaces, but the unfamiliarity of the haptic interface caused a lower subjective satisfaction for some criteria. Generally, participants showed high subjective satisfaction levels and low subjective workloads toward haptic seat interfaces. This study provided guidance for implementing haptic seat interfaces and identified the possible benefits of their use. It is expected that haptic seats implemented in vehicles will improve safety and the interaction between driver and vehicle.

1. INTRODUCTION

The development of in-vehicle information systems (IVIS) has led to increasing complexity of interactions between drivers and systems. However, existing visual- and auditory-based interactions require drivers to concentrate on visual and auditory channels and cause problems such as decreased driving performance or interference with driver concentration (Ji & Jin, 2010; Tijerina, Johnston, Parmer, Winterbottom, & Goodman, 2000; Van Erp & Van Veen, 2004). As a result, the use of haptic interfaces in vehicles has emerged as an important alternative. Haptic
interfaces usually present tactile and kinesthetic cues to users, and users can perceive the haptic stimuli by all possible skins around the body (Ji, Lee, & Hwang, 2011). Compared with existing visual and auditory interfaces, haptic interfaces rapidly and simultaneously deliver a great deal of information. Therefore, the importance of haptic interfaces is being emphasized and the scope of these studies is becoming more diverse (Robles-De-La-Torre, 2008).

Vibrotactile haptic interfaces have the advantage of being safer to use than electrotactile or force-feedback systems (Alahakone & Senanayake, 2009). Vibrotactile haptic interfaces have been applied in diverse fields, and there have been studies of their use as warning systems and to deliver information in automobiles. A vibrotactile display usually delivers information through the arrangement of several vibrating elements. Some studies have been conducted on providing directional information such as location and sequence (Tan, Gray, Young, & Traylor, 2003), and especially on providing directional information from a vehicle navigation system. Van Erp and Van Veen (2001) presented navigational signals such as left turn, right turn, and go straight to a driver by offering a visual display and a tactile seat display. The result confirmed a lower subjective workload and better reaction time for the tactile navigation display than the visual display. Van Erp and Van Veen (2004) also provided a tactile seat display and a visual display in the navigation system. They measured driver subjective workload and reaction time by dividing situations into high and low subjective workloads. Although the workload increased, performance did not decrease in the tactile and multimodal displays, whereas a decrease in performance was observed while using the visual display. Kim, Seo, Lee, Ryu, and Lee (2006) presented a vibrotactile system at the driver's foot to deliver 12 different signals for navigation, lane warning, and obstacle warning. Their user studies with the vibrotactile device on the top of the foot showed high level of recognition rate for alphabet characteristics.

Several studies have applied haptic interactions in vehicles for warning purposes such as lane departure warnings or collision warnings. Lee, Hoffman, and Hayes (2004) measured driver reaction time and attitude during collision warnings to provide a visual modality for auditory or haptic systems. They observed fast reaction times and enhanced concentration when using a combination of visual signals and haptic signals generated by a seat. Ho, Tan, and Spence (2005) conducted an experiment to warn drivers of front and rear-end collisions by installing a tactor at the driver's front and back. They found that a combination of visual and vibrotactile information helps to improve driving safety. Kozak et al. (2006) conducted warnings using a head-up display and auditory signals and through the steering wheel with vibration or torque to prevent drowsy driving, and they measured reaction time during a lane departure. The steering wheel vibration resulted in the best performance. De Rosario et al. (2010) pointed out that there were many recently developed concepts for driver warning systems using auditory or haptic modalities to help improve safety by lessoning the visual load. They designed a haptic pedal for frontal collision warning and found that haptic stimuli were more effective than visual signals.

However, existing studies on haptic interfaces have focused mostly on effects of the system itself, such as the division of channels for delivering information, decreased workload, or the lower reaction time with the haptic interface than with
a visual or auditory interface. Some studies have detected negative aspects of the haptic interface. Although there have been studies to define cognitive limitations when sensing vibration (Morioka & Griffin, 2008) or the possibility of vibration causing discomfort for some individuals (Lieberman & Breazeal, 2007), they did not truly explore the negative aspects of haptic interfaces that are actually felt by drivers. Therefore, we designed a haptic interface for a vehicle seat and evaluated it with more subjective point of view.

We conducted three experiments using vehicle navigation systems, Bluetooth hands-free systems, and driver drowsiness warning systems used primarily for IVIS, and we evaluated their subjective effects. The safety of mobile phoning while driving has become an issue (Esbjörnsson, Juhlin, & Weilenmann, 2007). The vehicle Bluetooth hands-free system provides phone information to the driver by automatically linking with the vehicle IVIS. However, because it delivers information mostly through an auditory modality, it may interfere with other sounds and possibly cause carelessness, so the delivery of information by haptic seat interface is a reasonable alternative.

The first experiment measured reaction time, subjective satisfaction, and subjective workload for haptic, visual, and auditory displays of four signals (go straight, turn left, turn right, speed limit) used by the vehicle navigation system. The second experiment measured reaction time, subjective satisfaction, and subjective workload for haptic, auditory, and multimodal (haptic + auditory) displays of the ringing signal used by the vehicle Bluetooth hands-free system. The third experiment measured the driver’s subjective awareness, urgency, usefulness, and disturbance levels for various vibration intensities and positions for a haptic warning signal used by a driver drowsiness warning system.

2. METHOD

2.1. Participants and Apparatus

Twenty drivers (9 female, 11 male) participated in the study. Their ages ranged from 22 to 58 years ($M = 37.8, SD = 12.3$), the average weight was 65.4 kg, and the average height was 167.3 cm. All participants had a driver’s license and, on average, 8 years of driving experience. The participants worked in a broad range of careers.

The experiments were conducted using a driving simulator. The simulator was equipped with a vibration generator system, including the seat and vibrotactile system used by Ji et al. (2011). Six vibrators were placed ($2 \times 3$) in the seat pan at the horizontal direction, two were placed on each side of the seat pan bolster, and four were placed ($2 \times 2$) in the back support at the horizontal direction. The positions and directions of the vibrators used in this study are presented in Figure 1. The locations and directions settings followed the guidelines of Ji et al. (2011).

On the visual display, graphics were generated by PC hardware that delivered a 60 Hz frame rate at a 1280 × 1024 resolution. The screen was installed 2 m in front of the driver at the same level as the windshield of a vehicle. An LCD projector (VPL-CX21, Sony, Tokyo, Japan) was installed in a specific position. The graphics
FIGURE 1 Positions and directions of vibrators in the seat (color figure available online).

were presented as a heads-up display in the middle of the screen, and the simulator was installed with standard PC speakers. At the driver’s location, the loudness of the auditory signals was 70 dB, which was louder than the background noise (60 dB) of the engine and traffic. Major data were coded by a 60 Hz frequency.

2.2. Experimental Design

**Experiment 1.** Experiment 1 measured reaction time, subjective satisfaction, and workload for the haptic, visual, and auditory displays of signals used primarily for the vehicle navigation system. The independent variables in Experiment 1 were signal (go straight, turn left, turn right, speed limit) and modality (visual, auditory, haptic) with 4 × 3 within-subject design variables. For visual and auditory signals, we used the same signals that are used in general vehicle navigation systems, such as arrows for go straight, turn left, and turn right, and the speed limit. The methods for presenting the visual and audio displays were described in section 2.1. In the haptic interface, the go straight signal was generated from the seat pan’s back row to the front row of vibrators as in the experiment of Van Erp and Van Veen (2001). Each row generated a burst duration of 120 ms and an interstimulus interval of 510 ms without intervals between the three rows. The turn left and turn right signals generated in the seat bolsters were two 158-ms bursts with an interstimulus interval of 46 ms and were generated in the same form as previously described in 206-ms intervals (Sayer, Sayer, & Devonshire, 2005). The speed limit signal generated in the back support were two 726-ms vibration bursts separated by 78-ms intervals as used the vibration form of Sayer et al. (2005). Figure 2
FIGURE 2  Signals and modalities of Experiment 1 (color figure available online).

describes the signals and modalities of Experiment 1. All go straight, turn left, turn right, and speed limit signal modalities were offered for the same duration to maintain fairness between modalities.

The dependent variables in Experiment 1 were reaction time, subjective satisfaction, and subjective workload. The reaction time for each signal was measured in milliseconds from the time of the signal to time operating left turn signal, right turn signal, or stepping on the accelerator or brake. For accurate results, we took each measurement three times and all cues were provided randomly. The subjective satisfaction questionnaire consisted of four criteria: “easy to understand,” “quick to understand,” “comfortable,” and “easy to learn” based on Lewis (1995). The subjective workload consisted of four criteria: “mental demand level,” “physical demand level,” “temporal demand level,” and “frustration level” based on Hart and Staveland (1988). Subjective satisfaction and subjective workload were measured immediately after each signal, and the questionnaire was designed with a 7-point scale. The vibration intensity in Experiment 1 was 30.14 Hz at amplitude of 2.65 G for the seat pan and bolster and 34.21 Hz at 3.38 G in the back support. These intensities match the guidelines of Ji et al. (2011).

Experiment 2. Experiment 2 measured reaction time, subjective satisfaction, and subjective workload associated with the haptic, auditory, and multimodal (haptic + auditory) displays of the ringing signal used by vehicle Bluetooth hands-free systems. The independent variables in Experiment 2 were the modality (haptic, auditory, multimodal [haptic + auditory]) and the haptic cue position (seat pan, seat bolster, back) with 3 × 3 within-subject design variables. For the haptic signal, we used the phone vibration form used by mobile phones. The signal consisted of two 2,500-ms bursts separated by 500-ms intervals. The auditory signal also used the sound (or bell) of a mobile phone, and the duration of the haptic and auditory signals was the same.

The dependent variables in Experiment 2 were reaction time, subjective satisfaction, and subjective workload. The reaction time for each signal was measured in
millisecond intervals from the time of the signal to the time the “answering a call” button located on the steering wheel was pressed. For an accurate result, we took three measurements for each signal, and all cues were provided randomly. The subjective satisfaction and subjective workload were measured as in Experiment 1. The vibration intensity in Experiment 2 was the same as in Experiment 1.

Experiment 3. Experiment 3 measured drivers’ subjective awareness, urgency, usefulness, and disturbance levels at various vibration intensities and positions of the signal for a driver drowsiness warning system. The independent variables of Experiment 3 were intensity (high and very high) and haptic cue position (back support, seat pan, back support and seat pan) with 2 × 3 within-subject design variables. Ji et al. (2011) determined that the intensity level of the vibration is considered strong at over 42.35 Hz, 5.13 G. Therefore, to measure the effect of intensity, we divided signals into those of high intensity (42.35 Hz, 5.13 G) and very high intensity (50.49 Hz, 7.24 G). The vibration signal consisted of three 1,500-ms bursts separated by 500-ms intervals as in Kozak et al. (2006). To obtain accurate results, we took three measurements for each signal and all cues were provided randomly.

The questionnaire for Experiment 3 consisted of four criteria: “awareness level,” “urgency level,” “usefulness level,” and “disturbance level” based on Kircher, Kircher, and Claezon (2009). Participants answered the survey after receiving signals for driver drowsiness, and the questionnaire was designed with a 7-point scale.

2.3. Procedure

Before participants began the experiments, they were instructed regarding the purpose, procedure, and order of tasks of the study. Participants were provided with the opportunity to learn and practice the signals and methods used for each experiment in advance. They could practice as much as they wanted, and practiced an average of 15 min before each experiment. The experiments were performed in order of experiment and lasted an average of 40 min each. Participants were given a rest break between each experiment for at least 20 min or more depending on the request of each participant. Participants completed each experiment at the laboratory with only the experimenter and subject present. They were able to speak freely about their feelings after each experiment was finished.

3. RESULTS

3.1. Experiment 1

Experiment 1 measured reaction time, subjective satisfaction, and subjective workload for signals from the vehicle navigation system. The results were analyzed using a repeated measures analysis of variance (ANOVA) with the following independent variables: signal (go straight, turn left, turn right, speed
limitation) \times \text{modality (visual, auditory, haptic)}. Deviation from sphericity was taken into account by applying the Greenhouse–Geisser adjustment during the analysis. In the analysis of reaction time, 3.6% (haptic: 5.42%, visual: 2.92%, auditory: 2.5%) of the trials in Experiment 1 were ruled out because there were incorrect responses or no reaction within 5,000 ms. The two-way ANOVA revealed significant main effects of the signal, $F(3, 111) = 31.89, p < .001$, and modality, $F(2, 74) = 193.73, p < .001$. All means and standard errors are presented in Figure 3. Pairwise tests ($\alpha = .05$) showed the go straight signals took significantly longer to respond to than the left, $t(171) = 7.018, p < .001$, and right, $t(167) = 8.588, p < .001$, signals; speed limit signals took significantly longer to respond to than the left, $t(166) = 8.579, p < .001$, and right, $t(161) = 8.663, p < .001$, signals. The auditory modality took significantly longer than the visual modality, $t(227) = 5.757, p < .001$; the visual modality, $t(219) = 11.246, p < .001$, and auditory modality, $t(220) = 18.874, p < .001$, took significantly longer than the haptic modality.

In the subjective satisfaction results, we found significant main effects of modality, $F(2, 38) = 5.67, p = .007$, on “easy to understand”; modality, $F(2, 38) = 8.58, p = .001$, and signal, $F(3, 57) = 2.97, p = .039$, on “quick to understand”; and modality, $F(2, 38) = 6.41, p = .004$, on “easy to learn.” The criterion of “comfortable” was not significant. Pairwise tests ($\alpha = .05$) indicated an easier understanding of the auditory modality than the haptic modality, $t(79) = 3.543, p = .001$, and visual modality, $t(79) = 2.096, p = .039$; a faster understanding with the visual modality, $t(79) = 2.683, p = .009$, and auditory modality, $t(79) = 4.412, p < .001$, than the haptic modality; a faster understanding with the auditory modality than the visual modality, $t(79) = 2.094, p = .039$; and easier learning with the visual modality,
Table 1: Mean Scores and Standard Deviations of Modality by Subjective Satisfaction and Subjective Workload in Experiment 1

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Modality</th>
<th>M Score (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Haptic</td>
<td>5.56 (0.16)_a</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>5.83 (0.15)_a</td>
</tr>
<tr>
<td></td>
<td>Auditory</td>
<td>6.16 (1.31)_b</td>
</tr>
<tr>
<td>Subjective satisfaction</td>
<td>Easy to understand</td>
<td>5.44 (1.65)_a</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>5.85 (1.41)_b</td>
</tr>
<tr>
<td></td>
<td>Auditory</td>
<td>6.23 (1.30)_c</td>
</tr>
<tr>
<td></td>
<td>Quick to understand</td>
<td>5.44 (1.65)_a</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>5.85 (1.41)_b</td>
</tr>
<tr>
<td></td>
<td>Auditory</td>
<td>6.23 (1.30)_c</td>
</tr>
<tr>
<td></td>
<td>Easy to learn</td>
<td>5.59 (1.49)_a</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>6.09 (1.30)_b</td>
</tr>
<tr>
<td></td>
<td>Auditory</td>
<td>6.30 (1.31)_b</td>
</tr>
<tr>
<td>Subjective workload</td>
<td>Temporal demand</td>
<td>2.04 (1.24)_a</td>
</tr>
<tr>
<td></td>
<td>Visual</td>
<td>1.79 (1.17)_b</td>
</tr>
<tr>
<td></td>
<td>Auditory</td>
<td>1.59 (1.16)_b</td>
</tr>
</tbody>
</table>

Note. Mean scores are significantly different at the $\alpha = .05$ when the subscripts are different.

$t(79) = 2.869, p = .005$, and auditory modality, $t(79) = 3.905, p < .001$, than the haptic modality (see Table 1).

In the subjective workload results, there was a main effect of modality, $F(2, 38) = 5.15, p = .011$, on “temporal demand.” There was no significant main effect of “mental demand,” “physical demand,” or “frustration level.” Pairwise tests ($\alpha = .05$) indicated that a greater temporal demand with the haptic modality than the visual modality, $t(79) = 2.359, p = .021$, and auditory modality, $t(79) = 3.862, p < .001$ (see Table 1). There was no significant main effect for all criteria on subjective satisfaction and subjective workload as a result of the analysis of the haptic signal on signal types.

### 3.2. Experiment 2

Experiment 2 measured reaction time, subjective satisfaction, and subjective workload for a Bluetooth hands-free system. The results were analyzed using a repeated measures ANOVA with the following independent variables: modality (haptic, auditory, multimodal [haptic + auditory]) $\times$ position (seat pan, seat bolster, back support). Deviation from sphericity was taken into account by applying the Greenhouse–Geisser adjustment. There were no incorrect or missed responses in Experiment 2. The two-way ANOVA revealed a significant main effect of modality, $F(1, 58) = 6.36, p = .014$. The means and standard errors are shown in Figure 4. Pairwise tests ($\alpha = .05$) showed the auditory modality took significantly longer to respond to than the haptic modality, $t(59) = 6.351, p < .001$; the haptic modality took significantly longer than the multimodality, $t(59) = 2.140, p = .036$; and the auditory modality took significantly longer than the multimodality, $t(59) = 8.355, p < .001$. 

In the subjective satisfaction results, there was a significant main effect of modality, $F(2, 38) = 8.115, p = .001$; on “quick to understand” and a main effect of modality, $F(2, 38) = 6.957, p = .003$, on “easy to learn.” The main effects of “easy to understand” and “comport” were not significant. Pairwise tests ($\alpha = .05$) indicated faster understanding when using the auditory modality, $t(19) = 2.734, p = .013$, and multimodality, $t(19) = 3.816, p = .001$, than with the haptic modality; and easier learning with the auditory modality, $t(19) = 3.047, p = .007$, and multimodality than with the haptic modality, $t(19) = 2.482, p = .023$ (see Table 2).

In the subjective workload results, there was a main effect of modality, $F(2, 38) = 4.657, p = .016$, on “temporal demand.” There was no main effect for “mental demand,” “physical demand,” and “frustration level.” Pairwise tests

Table 2: Mean Scores and Standard Deviations of Modality by Subjective Satisfaction and Subjective Workload in Experiment 2

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Modality</th>
<th>M Score (SD)</th>
</tr>
</thead>
</table>
| Subjective Satisfaction | Quick to understand | Haptic 6.15 (0.88)_a  
                      |                | Auditory 6.55 (0.69)_b  
                      |                | Multimodal 6.68 (0.43)_b  
                      | Easy to learn   | Haptic 6.07 (1.13)_a  
                      |                | Auditory 6.70 (0.57)_b  
                      |                | Multimodal 6.63 (0.43)_b  
| Subjective Workload    | Temporal demand | Haptic 1.77 (1.17)_a  
                      |                | Auditory 1.25 (0.44)_b  
                      |                | Multimodal 1.35 (0.70)_b  

Note. Mean scores are significantly different at the $\alpha = .05$ when the subscripts are different.
(α = .05) indicated greater temporal demand with the haptic modality than with the auditory modality, \( t(19) = 2.476, p = .023 \), and multimodality, \( t(19) = 2.246, p = .037 \) (see Table 2).

### 3.3. Experiment 3

Experiment 3 measured the subjective “awareness level,” “urgency level,” “usefulness level,” and “disturbance level” for a driver drowsiness warning system. The results were analyzed using a repeated measures ANOVA with the following independent variables: intensity (high, very high) × haptic cue position (back support, seat pan, all [back support + seat pan]). Deviation from sphericity was taken into account by applying the Greenhouse–Geisser adjustment. The two-way ANOVA revealed a significant main effect of intensity, \( F(1, 23) = 20.86, p < .001 \), and position, \( F(2, 46) = 13.14, p < .001 \), on “awareness level.” For the “urgency level,” there was also a main effect of intensity, \( F(1, 23) = 11.79, p = .002 \), and position, \( F(2, 46) = 10.49, p < .001 \). There was a main effect of intensity, \( F(1, 23) = 5.13, p = .033 \), on “disturbance level.” The main effect of “usefulness level” was not significant. Regarding the haptic cue position, pairwise tests (α = .05) indicated more awareness of the back support position, \( t(47) = 4.658, p < .001 \), and all (back support + seat pan) position, \( t(47) = 4.336, p < .001 \), than with the seat pan position, and a greater urgency with the back support position, \( t(47) = 4.658, p < .001 \), and all (back support + seat pan) position, \( t(47) = 3.463, p = .001 \), than with the seat pan position (see Figure 5). Regarding the haptic cue intensity, pairwise tests (α = .05) indicated greater awareness, \( t(71) = 4.624, p < .001 \), and urgency, \( t(71) = 5.181, p < .001 \), with the very high intensity than with the high intensity, and more disturbance with the very high intensity than with the high intensity, \( t(71) = 3.061, p = .003 \); see Figure 6).

![FIGURE 5](image-url) Mean score for “awareness level” and “urgency level” depending on position in Experiment 3.
4. DISCUSSION

The reaction time results in Experiments 1 and 2 showed that the haptic and multimodal displays led to superior reaction times, as found in previous studies (e.g., Tan et al., 2003; Van Erp & Van Veen, 2004). However, the subject satisfaction and subject workload results conflicted with reaction time results.

In Experiment 1, participants felt that signal comprehension was slower when using the haptic modality than with the visual and auditory modalities. Also, participants responded that the temporal demand when using the haptic modality was greater than with the visual and auditory modalities. However, the results show that the reaction time with the haptic interface was faster.

There are several reasons for these results. All participants were familiar with vehicle navigation systems because the technology has propagated rapidly. In the aspects of ease of understanding, ease of learning, speed of understanding, and temporal demand, therefore, participants felt more familiar with the visual and auditory displays than the haptic interface. Also, because the visual display was provided as a head-up display in the middle of screen, these signals were easier to see than signals provided by the small, separate screens generally used for vehicle navigation systems. Similarly, because the auditory display was provided in a manner similar to a vehicle speaker system, it was easier to hear than the auditory display generated by a separate vehicle navigation device. As a result, the unfamiliarity of the haptic interface and the relatively familiar and unusually salient visual and auditory displays may have caused a lower subjective satisfaction with information delivered by the haptic modality, despite the fact that the participants responded faster with haptic displays.

Although participants might be relatively familiar the visual and auditory display used in Experiment 1, participants did not feel a physical or mental burden...
when using the haptic interface, and the frustration level did not differ significantly among the participants. The haptic modality showed no difference from the visual and auditory modalities in the subjective “comfortable” results, indicating that participants were able to easily receive information provided by the system. That is, haptic signals used in this study might have been designed for users to accept intuitively. Ho et al. (2005) also confirmed the importance of the intuitiveness of a haptic interface. As a result, if drivers are properly trained to use haptic seats and have enough time to get used to them, they are easily accepted by drivers. This experiment was limited in that we were not able to conduct trials under a variety of conditions. Therefore, further study of the preferences for multimodal signals is warranted, as well as experiments on signal pattern preferences.

In Experiment 2, there was no significant difference between the haptic modality and the auditory or multimodality for the criteria of “easy to understand,” “comfortable,” “mental demand,” “physical demand,” and “frustration level.” This can be explained because mobile phones already offer ringing signals with vibration, so it is not surprising that the results showed that users were more familiar with the haptic interface of a ringing signal than the navigation signals. Moreover, there exist possibilities that participants got used to the haptic interface as all participants participated first in Experiment 1 and then in Experiment 2, having a rest break in between each experiment.

The reaction time showed that the haptic and multimodal displays faster than auditory display. Also, we found that participants felt that their understanding of the haptic modality was slower, temporal demand of the haptic modality was greater than auditory modality or multimodality, and learning of the haptic modality was difficult than auditory modality or multimodality. As in Experiment 1, this was caused by the unfamiliarity of receiving a haptic signal through the seat. As a result, there is a need to train people to use haptic seats and have enough time to get used to them. Furthermore, it is reasonable to support Bluetooth hands-free systems using haptic seats, and we recommend multimodality when it is offered.

The results of Experiment 3 showed the implications of the positioning and intensity of the haptic interface. We discovered that participants felt that their awareness and urgency of the haptic warning signal through the back support was greater than its seat pan position. But there was no significant difference in disturbance level between both positions. Also, when the haptic interface was used as information delivery in Experiment 2, it was confirmed there was no dependence on haptic cue position. Therefore, haptic signals can be presented by completely dividing the seat positions into seat pan and back support according to the purposes of the information systems and driver warning systems, and we suggest that back support is more appropriate to deliver warning signal. We expected that a division in the seat position would allow us to send signals without confusing the driver. Also, according to the intensity results in Experiment 3, the intensity of the haptic cue should not simply be increased for the driver warning system. This is because the increased intensity was a disturbance during driving, although it caused the driver to pay more attention and react urgently. When actual vehicles are supplied with haptic seats, additional experiments should be conducted to find the proper intensity in actual driving environments.
5. CONCLUSIONS

We designed and evaluated haptic interfaces to improve flexibility of delivering information and driver safety. We evaluated haptic interfaces with a more subjective point of view than previous studies in this area, using a user-centered design approach. Our results showed that haptic seat interfaces performed better than visual and auditory interfaces, but the participants needed to adjust to the new technology. Therefore, our study highlights the crucial importance of designing haptic seat interfaces that are intuitive with an easy-to-understand learning program. In addition, it helps to present users with information via multimodalities rather than the haptic modality alone.

Haptic seat interfaces should support both information systems and driver warning systems in IVIS. However, the delivery of many signals can confuse drivers. Therefore, it is reasonable to divide signals between the seat pan and back support according to their purpose, and we suggest that back support is more appropriate to deliver a warning signal. When haptic cues are presented as warnings, it is recommended that they have the proper intensity. To confirm our results, they need to be replicated in other conditions.

Even though the haptic seat interfaces were new to the participants, we confirmed the possibility of implementation because the user ratings were more than 5 points of 7 for subjective satisfaction and less than 3 points of 7 for subjective workload.

Although the simulator conditions limited the experiment, we provided an environment similar to actual driving. Also, although participants were able to get sufficient rest in between each experiment, there exist possible confounding effects of fatigue. The three experiments were conducted in the same order. Therefore, further research is necessary to verify the effects of fatigue and order.

This study contributes considerations and guidance for the implementation of haptic seat interfaces, but because we used a new approach to the haptic interface in vehicles, these conclusions need to be verified in more realistic driving situations. We ultimately expect the improvement of flexibility and safety in the interactions between a driver and an intelligent vehicle.

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