Can Haptics Facilitate Interaction with an In-Vehicle Multifunctional Interface?

Annie Rydström, Robert Broström, and Peter Bengtsson

Abstract—A driving simulator study was conducted to investigate whether interaction with an in-vehicle multifunctional interface maneuvered by a rotary control can be improved if assisting haptics is provided. Two conditions were compared in the study, one in which neutral haptics was provided through the rotary control and another in which enhanced haptics was provided. Participants drove on a curved rural road while performing tasks such as list scrolling, radio tuning, address and number entry, and sound settings adjustments. When enhanced haptics was provided, the radio tuning was faster and fewer glances to the display were required, and the sound settings adjustments were completed with a reduced duration of the glances. However, improvements are needed for the other tasks. Enhanced haptics seems to facilitate interaction with functions in which the sensations can be incorporated in an intuitive way.

Index Terms—Automotive, graphical user interfaces, haptics applications, haptic I/O.

1 INTRODUCTION

Along with the extensive evolution in computer technology, the number of information and entertainment functions available in cars, such as MP3 player, navigation system, and mobile telephone, is steadily increasing. Several of these functions are not related to the driving task but make the driving more convenient and pleasurable. To deal with the growth in functions, many automotive manufacturers have merged functions into multifunctional interfaces. These interfaces are generally based on one display and one main interaction device, thus, making the center panel less cluttered with displays, controls, and buttons. However, functions that are directly accessible via dedicated controls and buttons in a conventional interface may be available several layers down in the menu structure in a multifunctional interface. The time it takes to activate a function and the duration of time the driver looks away from the road may, therefore, be prolonged. Developing multifunctional interfaces without compromising safety has become a challenge for car manufacturers. It has been suggested that haptic cues available through the interaction device may have the potential to make the interaction with an in-car interface less visually demanding [1], [2], [3]. This study focuses on whether haptic cues can facilitate the interaction with a multifunctional in-car interface maneuvered by a single rotary control.

1.1 The Use of Haptics

Prynne [4] noted that styling is important in designing conventional in-car interfaces and, accordingly, interfaces are often designed “more for the eye than for the hand” (p. 30). However, Prynne [4] explained that, even though interfaces are not deliberately designed for blind operation, drivers make use of haptic cues, such as panel recesses and large switch edges, to be able to keep their eyes on the road during the interaction. Thus, to facilitate the interaction with an in-car interface, the controls and buttons can deliberately be designed to provide haptic information that would enhance their handling. In a study by Porter et al. [5], an in-car interface was designed in which the interface devices (three pods) were coded in terms of the haptic properties size, shape, and location. It was shown that the number and duration of glances made to the display and controls were reduced compared to a standard interface.

When merging functions into a multifunctional interface maneuvered by a single rotary control, physical haptic cues that are, deliberately or not deliberately, available in a conventional interface are eliminated. To facilitate interaction with such an interface, it is possible to utilize a control with the ability to provide a variety of haptic cues such as detents, limit stops, friction, and vibration. Hence, a haptic rotary control can be programmed to imitate the feel of different conventional controls and provide sensations that correspond to features in the graphics. Multifunctional in-car interfaces providing assisting haptic cues are available in the market today; BMW’s iDrive and Mercedes-Benz’s COMAND are two examples (www.bmw.com, www.mercedes-benz.com). Both these interfaces consist of an LCD screen mounted in a high position on the dashboard and a rotary control mounted between the seats. BMW’s iDrive and Mercedes-Benz’s COMAND make use of, for example, haptic limit stops at the end of lists, adapted step angles for different functions, and haptic markings of different selections. However, although multifunctional interfaces providing haptic cues through the interaction device are commercially available, a systematic analysis of the use of haptic information in the interaction with such interfaces is lacking.

A great deal of the information in multifunctional in-car interfaces is structured in menus, but there are also several other actions the interfaces need to support. Burnett [6] described different actions that a navigation system must be able to assist, such as moving through the system (within and between menus), entering alphanumeric data, and selecting from continuous and discrete options. The same actions hold for multifunctional interfaces.

The menus in multifunctional interfaces maneuvered by a rotary control are often arranged in vertical lists. It was demonstrated by Körner [7] that the length of a list is a significant factor in terms of selection time when a mechanical rotary device is used. However, other interaction patterns can be designed with a programmable haptic rotary device. Svenberg [8] compared different ways of browsing through long lists with a haptic rotary device. In one condition, the rotary device was programmed to resemble a mechanical rotary device with an equal distance between steps. In another condition, the rotary device was programmed so that the angle between the steps decreased as the turning speed increased. In a further condition, the rotary device was programmed as a jog/shuttle dial. Hence, instead of rotating the control, it was held at an angle to scroll in the list, and a larger angle gave a faster scrolling speed. Once the control was released, it sprang back to the middle position and scrolling stopped. It was revealed that, in terms of speed, the second concept, rotation with an acceleration, was the most preferable technique. Snibbe et al. [9] proposed another way to handle long lists, which was a nonvisual alphabet MP3 browser. The browser used a haptic rotary device and an auditory display. A spoken and felt alphabetic index was provided when the device was turned. During a rapid turn, the first letter from each entry was heard, and, at slower rates, the full titles emerged. Corresponding haptic feedback was given—large clicks for a new letter in the alphabet and small clicks for individual titles. It was reported that audio feedback alone seemed to be somewhat
useful, but the haptic information seemed to improve the speed and accuracy of the navigation.

The simplest and most commonly used way to input alphanumeric data with a rotary device is to use the control to scroll and highlight characters shown in the display and press the control to select a highlighted character. This way of inputting data is called the date stamp method [10]. The graphical arrangement of the characters differs between in-car interfaces using a rotary control as an input device. The characters can graphically be placed in a line, as in the destination input in the BMW iDrive and Mercedes COMAND interfaces. Alternatively, the characters can graphically be arranged in a circle to make use of the circular movement of the control, as in the Audi MMI interface (www.audi.com). In interfaces using the date stamp method, haptics can be used, for example, to mark options that are not characters, such as a delete option. If the characters are graphically placed in a circle, the control can also be programmed to make use of the haptic property position so that a rotation of the rotary device equals the same degree of rotation in the graphics.

When using a rotary device for continuous tasks, such as adjustments, haptic cues can be used to mark different selections. Snibbe et al. [9] suggested haptic annotations, such as a texture, that gradually rise and fall around an interesting object, so-called foreshadowing. Swindells et al. [11] proposed that the interaction device could provide sensations with emotional content. For example, risky settings could feel “unpleasant” and conservative settings could feel “pleasant.”

1.2 Secondary Task Engagement

The usability of an interface refers to the ease with which a user can interact with it. Task completion time is a widely used measure of usability [12]. It is important to consider completion time when evaluating an in-car interface task since this shows the efficiency of the interaction as well as the time of exposure to distraction. In addition, the number of keystrokes needed to complete a task can be used to measure the efficiency of the interaction [12]. However, for interfaces operated in a driving context, the interaction is a secondary task to the primary task of driving. It is, therefore, particularly important to also evaluate how the interaction with the interface affects drivers’ visual behavior, driving performance, and cognitive workload. When a driver interacts with an in-vehicle interface while driving, the eyes must often be used for two different tasks at the same time. It is known that drivers look at the display more often and for longer periods of time when the secondary task becomes more visually demanding and when the task difficulty is increased [13], [14]. Several studies have shown that the visual demand imposed by the interaction with an in-vehicle interface causes impaired lane-keeping performance [15], [16]. Moreover, there are several ways to measure cognitive workload, such as different subjective assessment techniques and physiological parameters. One method that is being used more and more to indirectly measure cognitive workload while driving is the peripheral detection task (PDT) [17], [18]. The PDT measures the ability to detect light signals presented in the peripheral field of view.

1.3 Objective of the Study

The overall objective of this study was to investigate whether interaction with a multifunctional interface maneuvered by a rotary control can be improved if assisting haptics is provided. Based on previous research, it was hypothesized that:

- The time it takes to complete a task is shorter when enhanced (adapted) haptic information is provided than when neutral (fixed) haptic information is provided [8], [9].
- The number of glances needed to complete a task is fewer when enhanced haptic information is provided than when neutral haptic information is provided [5].

2 METHOD

2.1 Participants

Invitations to participate in the study were sent by letter to 100 women and 100 men. The sample was randomly drawn from the Swedish car owner register and fulfilled the criteria: 1) resident of the Gothenburg area; 2) in possession of a valid driving license for at least five years; and 3) ownership of a Volvo C30, S40, V50, or XC90 model 2003 or later. The last criterion was set to gather a group with experience of similar in-car interfaces. The age span of the sample corresponded to the age span of potential customers. The final test group comprised 12 women and 13 men ranging in age from 27 to 69 years ($M = 45.7, SD = 12.5$). A majority of the participants drove their car every day and were accustomed to mobile phones and computers. The participants were paid SEK 300 (€30) in gift coupons for their participation.

2.2 Equipment

The study was conducted using a fixed base Volvo XC90 simulator. The simulator had an automatic transmission and was equipped with logging apparatus for the collection of driving performance data. A 2.1-m wide and 1.6-m high driving scene was projected on a screen about 2.5 m in front of the driver. The road used in the study was a curved rural road. The radius of both the right and left curvatures was 1,000 m, each lane was 3.2 m wide and the signed speed limit was 90 km/h. There was meeting traffic in the left lane, but no cars were present in the driving lane, i.e., the right lane. A 7” TFT-LCD display (Deltaco, Sweden) was placed in a high position on the center panel (Fig. 1) and the interaction device, a programmable haptic rotary device (ALPS Haptic Commander, ALPS Automotive Products division, Japan), was mounted between the seats.

The experimental interface was implemented in Macromedia Director MX (Adobe Systems, Inc., USA). The interface program managed the sensations provided through the rotary control and the graphical scenes displayed on the center panel display. A modified PDT equipment called the visual detection task (VDT) was used to measure cognitive workload [19]. In the VDT, a single LED is used that is positioned in the central field of view rather than in the periphery (Fig. 1). The visual stimuli were presented with a random temporal variation between 3 and 5 seconds, and the participants responded by pressing a button attached to the
index finger of the left hand. Reaction time within 3 seconds after a stimulus was recorded. If a participant did not respond to the visual stimuli, the response time was counted as 3 seconds. Eye movements were recorded using faceLAB 4.3 (Seeing Machines, Australia). The two eye tracking cameras were mounted on the dashboard in front of the participants (Fig. 1). An analysis software, the Visual Demand Measurement (VDM) Tool [20], was used to analyze eye movement data.

2.3 The Experimental Interface

The experimental interface was designed to contain functions typically included in multifunctional interfaces currently available in the market. In a multifunctional interface, a user must often go down several layers in the menu structure before reaching the desired function. To make the interaction with the interface more authentic, the experimental interface, therefore, included three levels: a main menu (a short list), a middle menu (a short list), and the core level. The short lists included six items, which were all visible in the display. It should be noted, however, that only the core level functions are included in the analysis. The core level included: MP3 lists, an FM radio frequency band, address input in a navigation system, number input in a telephone system, and sound settings adjustments (Table 1).

Two conditions were compared in the experiment, one in which neutral haptics (N) was provided through the rotary device and another in which enhanced haptics (E) was provided. The related properties for a rotary device are angle and torque. In the N condition, the device emulated a mechanical rotary device in

<table>
<thead>
<tr>
<th>Function</th>
<th>Graphics</th>
<th>Description</th>
<th>The haptics in the E condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP3 list</td>
<td></td>
<td>48 song titles are listed in alphabetical order. The list moves when the marker reaches the second last or the second first item.</td>
<td>Max torque, steps: 20 mN•m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Step angle: 10°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max torque, walls: 90 mN•m</td>
</tr>
<tr>
<td>FM radio frequency band</td>
<td>Manual tuning</td>
<td>Strong stations are marked. A step with the rotary control causes the frequency band to move one step.</td>
<td>Max torque, steps: 15 mN•m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Step angle: 8°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max torque, strong stations: -80 mN•m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max torque, walls: 90 mN•m</td>
</tr>
<tr>
<td>Navigation system -</td>
<td>Set destination by city</td>
<td>The letters are arranged in a circle to make use of the circular movement of the control. There is a delete (arrow) and a guide option.</td>
<td>Max torque, steps: 20 mN•m</td>
</tr>
<tr>
<td>address input</td>
<td></td>
<td></td>
<td>Step angle: 12°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max torque, delete/guide: 80 mN•m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Step angle, delete/guide: 20°</td>
</tr>
<tr>
<td>Telephone system -</td>
<td>Dial number</td>
<td>The numbers are arranged in a circle to make use of the circular movement of the control. There is a delete (arrow) and a dial option.</td>
<td>Max torque, steps: 25 mN•m</td>
</tr>
<tr>
<td>number input</td>
<td></td>
<td></td>
<td>Step angle: 30°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max torque, delete/dial: 80 mN•m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Step angle, delete/dial: 30°</td>
</tr>
<tr>
<td>Sound settings</td>
<td>Sound settings</td>
<td>The control is rotated to adjust the level at a bar. The active bar is marked with a frame. The control is pushed to activate the next bar.</td>
<td>Max torque, steps: 25 mN•m</td>
</tr>
<tr>
<td>adjustments</td>
<td></td>
<td></td>
<td>Step angle: 20°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max torque, midpoint: 80 mN•m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max torque, walls: 90 mN•m</td>
</tr>
</tbody>
</table>

A dotted line indicates that the haptics continues to be provided through the whole list/frequency band.
which each detent was separated by 15 degree and the maximum torque was 25 mN-m. While the same haptic information was provided in all functions in the N condition, the haptic information varied between the functions in the E condition (Table 1). A damper, i.e., a friction proportional to the knob velocity, was added for all functions in both the N and E conditions (30 mN-m/s).

A clockwise rotation of the control equaled a downward movement in the MP3 lists. To be able to scroll quickly, the step angle and maximum torque were adjusted in the MP3 lists and the FM radio frequency band in the E condition [13]. In addition, to make the interaction with the FM radio frequency band less dependent on vision, there were haptic markings for the strong stations [14]. To provide consistency between the movement of the control and the corresponding movement in the display, the step angles for the navigation and telephone input were adjusted in the E condition so that one 360 degree rotation with the rotary control equaled 360 degree in the graphics. In addition, the torque was increased before, between, and after the nonalphabetic options of delete and guide/dial [14]. With this design of the markings, it was expected that it would be easy to reach the first and last characters (A and Z, 1 and 0). To make it possible to reach the midpoint in the sound settings adjustments without looking at the display, the endpoints and midpoint at the bars were haptically marked in the E condition [14].

### 2.4 Tasks

A beep indicated to the participant that a new task was initiated and the task, e.g., “Enter Dallas as destination,” was shown at the secondary task display. The participant pressed “OK” (by pressing the control) to start after which the main menu was shown. For every task, the participants had to choose the right option in the main menu and the middle menu and finish the task correctly at the core level. In the MP3 task, the participants had to mark the correct music track and press the control to confirm. In the radio task, the participant had to place the marker at the correct strong station and press the control to confirm. In the navigation and telephone tasks, the participant had to type in the right destination or number and then mark the guide/dial option and press the control to confirm. All bars had to be set at the midpoint in the settings task. If the participant made an error, such as selecting the wrong item in a list, selecting the wrong radio station, verifying an incorrectly spelled destination or wrong number, or adjusting a bar in the sound settings incorrectly, a view was shown in the display in which the task description was repeated. The only option in this view was “Back,” which returned the participant to the previous view, and the participant then continued the task. When a task was completed correctly, a beep was given as feedback and the screen turned black until the next task was initiated. A new task started 15 seconds after the previous one was completed. To reduce practice effects, the tasks, i.e., MP3 tracks, radio frequencies, navigation destinations, telephone numbers, and settings adjustments, did not repeat throughout the experiment. However, all tasks were similar, e.g., all destinations were well known and included six characters, the telephone numbers included six numbers and were easily chunked (e.g., 17 18 19) and all target tracks in the MP3 lists were roughly as far down in the lists.

### 2.5 Procedure

Upon arriving to the laboratory, each participant was given a brief description of the experimental procedure, was offered the opportunity to ask questions about the study, and was asked to complete a consent form. When the eye tracking cameras had been calibrated, the participant was informed about the VT. The participant then practiced driving for a couple of minutes to become acclimated to the simulator and was instructed to try to respond to the visual stimuli.

The experiment had a within-subject design. The two experimental conditions included in this paper are two of the four conditions tested during the experiment. The other two conditions were based on other interface configurations, i.e., touch screen and alternative display position. Results from these additional, conditions are reported elsewhere (e.g., [21]). A major concern observed in previous experiments with similar conditions and pilot testing was that there is a considerable learning effect over time in terms of driving and simultaneous secondary task engagement. Therefore, to minimize these learning effects, the study was divided into a training session, where the participants trained at interacting with all conditions, and a subsequent experimental session. To keep the time between conditions constant, the conditions were presented in the same randomized order in the experiment as in the training.

During the training session, the participants were not instructed about the differences in the sensations provided through the rotary control in the different conditions. The participants went through five stationary practice trials for each condition and then went through the same trials while driving. They were given a break after the training session during which they were asked to complete a background questionnaire. The experimental session was analogous to the training session, but the tasks differed. During the experimental session, a 30-second long baseline, i.e., driving without performing secondary tasks, was taped in each condition. All tasks, including the baseline, were randomized over the conditions so that the participants did not solve the same tasks with the same condition and in the same order. The participants were instructed to try to stay in the center of the lane and maintain the speed limit indicated by the signs (90 km/h). The participants were also instructed to solve the secondary tasks and respond to the visual stimuli to the best of their ability. The participants were asked at the end of the experimental sessions whether they experienced any differences between the concepts and, if so, whether they considered the haptics helpful. A whole session took a total of about two hours.

### 2.6 Dependent Variables

Performance of the interaction with the experimental conditions was measured in terms of task completion time and number of keystrokes [12]. Every step with the control and all presses of the control were recorded as keystrokes. The number of keystrokes over the optimal number of keystrokes to complete a task was included in the analysis. Eye movements were analyzed in accordance with the ISO metrics number of glances and glance duration [22]. The detection performance of the visual stimuli (VT) was measured in terms of response time [19]. Lateral control performance was measured in terms of the variation in lateral position, i.e., standard deviation of lane position. VT response time and standard deviation of lane position was also collected for baseline driving.

### 3 Results

To compare the neutral haptics (N) and enhanced haptics (E) conditions, within-group t-tests (two-tailed) were made separately for each task for all the dependent variables. Subsequent statistical analyses were conducted for the variables of VT response time and standard deviation of lane position to examine whether the values for the tasks differed from the baseline values. Thus, for these variables, one-way repeated measures ANOVAs were also made and followed up by simple contrasts. An alpha level of 0.05 was used for all statistical tests. All results are graphically summarized in Fig. 2.

#### 3.1 Secondary Task Performance

In terms of task completion time, it was shown that the participants solved the radio task significantly faster when using the E condition than when using the N condition, \( t(24) = 5.15, p < 0.001 \). Task completion time did not differ significantly between the conditions.
for the MP3, navigation, telephone, and settings tasks. The results showed that the number of keystrokes was significantly higher for the radio, navigation, and telephone tasks when the E condition was used, \( t(24) = -2.15, p < 0.05 \), \( t(24) = -3.62, p < 0.001 \), and \( t(24) = -2.70, p < 0.05 \), respectively. In contrast, the number of keystrokes was significantly lower for the settings task when the E condition was used, \( t(24) = 2.56, p < 0.05 \). The number of keystrokes did not differ significantly between the conditions for the MP3 task.

### 3.2 Eye Movements

Errors in the eye tracking data collection caused corrupted data for six of the participants and the data from these participants were thus excluded in the analysis. Hence, eye movements were analyzed for 19 participants for whom a satisfactory quality of the tracking was available.

The results showed that the number of glances to the display was significantly fewer when participants solved the radio task with the E condition \( t(24) = 3.05, p < 0.01 \). The number of glances did not
differ significantly between the conditions for the MP3, navigation, telephone, and settings tasks. In terms of glance duration, it was shown that the participants’ glances were significantly shorter when the E condition was used for the settings task, \((24) = 3.20, p < 0.01\). Glance duration did not differ significantly between the conditions for the MP3, navigation, and telephone tasks.

3.3 VDT Response Time

There were no significant differences between the N and E conditions in terms of VDT response time. However, the subsequent ANOVAs including baseline showed that a significant difference was present in both the N and E conditions, \(F(3,16,75.74) = 9.27, p < 0.001\) and \(F(2,99, 71.84) = 2.85, p < 0.05\), respectively. Mauchly’s test of sphericity indicated that the assumption of sphericity had been violated; the degrees of freedom were, therefore, corrected using Greenhouse-Geisser estimates of sphericity [24]. For the N condition, the simple contrasts showed that VDT response time was significantly different from baseline for the MP3, radio, navigation, telephone, and settings tasks, \(F(1,24) = 5.44, p < 0.05\); \(F(1,24) = 4.94, p < 0.05\); \(F(1,24) = 19.51, p < 0.001\); \(F(1,24) = 18.47, p < 0.001\); and \(F(1,24) = 6.16, p < 0.05\), respectively. For the E condition, the simple contrasts showed that the navigation and settings tasks were significantly different from baseline, \(F(1,24) = 7.55, p < 0.05\) and \(F(1,24) = 4.74, p < 0.05\), respectively (telephone \(p = 0.052\)).

3.4 Lateral Control Performance

While no significant differences were found between the N and E conditions in terms of the standard deviation of the lane position, the subsequent ANOVAs including baseline showed that there was a significant difference for the N condition, \(F(3,02,72.58) = 3.01, p < 0.05\). However, the ANOVA for the E condition showed no significant difference, \(F(1,48, 35.60) = 1.82, p = 0.184\). Mauchly’s test of sphericity indicated that the assumption of sphericity had been violated; the degrees of freedom were, therefore, corrected using Greenhouse-Geisser estimates of sphericity [24]. For the N condition, the simple contrasts showed that the standard deviation of lane position was not significantly different from baseline for any of the tasks (telephone \(p = 0.051\)). Even though the ANOVA did not indicate a significant difference in the E condition, the simple contrasts showed that the navigation task was significantly different from baseline, \(F(1,24) = 5.00, p < 0.05\).

3.5 Interview Question

About two-thirds of the participants stated that they experienced a difference between the sensations provided through the interaction device in the two experimental conditions. Some of these participants said that they experienced the varying haptic information in the E condition as disturbing before they realized what it was intended for. More than half of the participants who felt a difference between the conditions said that they experienced the faster scrolling and haptic markings in the radio frequency band, and the markings at the midpoints in settings, as useful. A few of the participants who experienced a difference between the conditions stated that the haptic markings of the “delete” and “guide/dial” options in the navigation and telephone functions were helpful as reference points. In addition, several participants commented that, in the long run, when they had become more skilled at interacting with the interface, they would probably make greater use of the haptic cues.

4 Discussion

The results of this study indicate that the radio task was solved more rapidly when the enhanced condition was used; thus, for this task, the hypothesis that interaction is faster when enhanced haptic information is provided was confirmed. However, the results also indicate that this effect did not hold for the MP3, navigation, telephone, and setting tasks. Moreover, the number of keystrokes was higher in the enhanced condition for the radio, navigation, and telephone tasks, whereas the number of keystrokes was significantly lower for the settings task.

There were somewhat contrasting results between task completion time and number of keystrokes made for the radio task; the radio task was solved significantly faster when the enhanced condition was used, but the number of keystrokes was significantly higher. These results may indicate that it was easy to pass the target in the fast scrolling, thus, increasing the number of keystrokes. With more prominent haptic markings of the strong stations, it should not be possible to pass a marking without noticing it. Moreover, there were no significant differences in terms of task completion time between the conditions for the navigation and telephone tasks, but the number of keystrokes was higher in the enhanced condition for these tasks. Hence, the haptic cues used for these tasks did not facilitate interaction as expected. It seems that the varying haptic information somehow made the participants interact unsystematically. In the interview, some of the participants actually said that they experienced the varying haptic information in the enhanced condition to be disturbing before they realized what it was intended for. It was also apparent from the interviews that only a few participants experienced the enhanced haptic information provided in the navigation and telephone tasks as useful. Other haptic cues and interaction patterns that may facilitate alphanumeric input should be evaluated. For example, an improvement might be to utilize a spelling function, like those found in today’s navigation systems, where characters become ineligible depending on the possible entries. In addition, the most relevant nextcoming characters could be indicated haptically. In the settings task, there were no differences between the neutral and enhanced conditions in terms of task completion time, but the number of keystrokes was lower in the enhanced condition. Here, the haptic marking seems to have been helpful when locating the middle position. Moreover, no significant differences in terms of time and number of keystrokes were found between the conditions for the MP3 task in this study. Previous research has shown that the length of a list is a significant factor in terms of selection time [7] and haptics can make list scrolling more effective [8]. In view of the fact that the MP3 lists in this study included only 48 items, they may have been too short to show any advantages of the enhanced haptics. However, it would be interesting to implement and test the nonvisual alphabet MP3 browser of Snibbe et al. [9] since this concept allows the user to keep the eyes on the road, or to at least implement large clicks for a new letter in the alphabet and small clicks for individual titles.

Previous research has shown that the number and duration of glances made to the display are reduced when an interface is designed with usable haptics cues [5]. This study hypothesized that the number of glances needed to complete a task is fewer when enhanced haptic information is provided through the interaction device. This hypothesis was only confirmed for the radio task. For this task, the fewer number of glances made to the display can be attributed both to the ability to scroll faster and to the haptic markings of strong stations. It was also hypothesized that the duration of glances is shorter when enhanced haptic information is provided. This hypothesis was confirmed only for the settings task. This indicates that the participants relied to some extent on the haptic markings. In view of these results, it is interesting to make an association with the interview results since several of the participants stated that they found the haptic information in the radio and settings tasks to be useful. The reason for the enhanced haptics having facilitated the interaction with these particular functions is probably that it was intuitive and easy to grasp.

There were no differences between the conditions in terms of VDT response time, which indicated that there were no differences in cognitive workload between the conditions. In the neutral
condition there were significant differences between the baseline and all tasks. In the enhanced condition, it was shown that the navigation and settings tasks increased VDT response time as compared to baseline. These results point toward that the secondary task engagement induced some cognitive workload on the participants, but to a lesser extent in the E condition.

There were no differences between the conditions in terms of lateral control performance. The results indicated that the participants swerved on the road significantly more during the navigation task than during baseline in the enhanced condition. However, overall, the secondary task engagement does not seem to have affected driving performance to a large extent. It should nevertheless be noted that the test leaders noted large individual differences in how secondary task engagement affected lateral control performance; some participants stayed tightly in the lane while others had difficulty to properly control the vehicle.

This study shows that interaction is better in some tasks, i.e., in radio and settings task, when enhanced haptics is provided. These results are promising. The shorter time a driver is distracted by a task and the less time spent at looking at the in-car display during interaction the better. However, improvements are needed—particularly for alphanumeric input. This study shows that it is important to carefully test the use of the haptics before implementing it into a commercial product. On the other hand, the results of this study must be seen in the light of the interface being new to the participants and the limited time the participants had to learn the system. Although the participants trained at interacting with the interface for almost an hour before the experiment, this may not have been long enough for the participants to learn the system thoroughly. Several participants said that, when they had become more skilled at interacting with the interface, they would probably make greater use of the haptic cues. Prynne [4] wrote that, in conventional interfaces, drivers make use of haptic cues, such as panel recesses and large switch edges, to be able to keep their eyes on the road during interactions. This perhaps holds for haptic cues provided through a single rotary device when the user has learned the system more thoroughly.

The driving task was made as realistic as possible in this experiment, within the limitations of a fixed-base driving simulator. However, there is always a trade-off in experiments between experimental control and ecological validity. The driving demand varies over time in real driving. By controlling the driving environment, it was possible to keep the demands of the driving task constant, and it was thus, also possible to systematically compare the different experimental conditions. The experimental interface included a single interaction device. Systems currently in the market vary in terms of graphics, interaction devices, and interaction patterns. For example, in the BMW iDrive, the rotary control can also be slid in four directions, while this is not possible in the rotary control in the Audi MMI, which instead makes use of additional buttons. In addition, these interfaces can be maneuvered by steering wheel controls, which allow interaction with the interface while still keeping the hands on the steering wheel. It would be interesting to investigate the use of haptics in steering wheel controls and other kinds of in-car interaction devices.

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