Studying UX Aspects of In-Car Vibrotactile Interaction

Arjan Geven[1], Reinhard Sefelin[1], Manfred Tscheligi[1,3],
Clemens Kaufmann[2], Ralf Risser[2]

[1] CURE – Center for Usability Research & Engineering
[2] FACTUM OGH
[3] HCI & Usability Unit, ICT&S Center, University of Salzburg

Abstract: The increased amount of In-Vehicle Information & Communication Systems (IVIS) leads to an increased amount of messages that have to be relayed to the driver. In this paper we present an experiment with vibrotactile interaction in a driving simulator that transfers information through the driver's seat. The first system we tested was a route guidance system (turn left or right at the next crossing, through vibration pulses left or right). The second system gave speed adaptation cues that urged the driver to slow down when speeding. The results indicate reduced workload compared to typical auditory and visual cues. Users responded slightly more positive towards the vibrotactile cues compared to auditory cues when they were given the choice. The main advantage was mentioned to be the unobtrusiveness compared to auditory and visual cues.

1 INTRODUCTION

Every year, new technology is presented that is designed to support the driver in various respects, also referred to as Advanced Driver Assistance Systems (ADAS) or In-Vehicle Information & Communication Systems (IVIS). Although this technology is primarily designed to be of aid to the user, the abundance of information these systems produce has to be presented to the driver and can distract him or her from the primary task of driving, reducing situational awareness and increasing mental workload (NHTSA, 1997).

So far, information has mainly been communicated to the driver using the auditory (sounds, earcons and speech) and visual modalities (lights, icons, figures, written text). Visual signals are less protruding, but also take longer to interpret and the visual channel is largely taken up by the primary driving task. Auditory signals can be used to warn the driver effectively, but are restricted through limited memory capacity, the absence of a 'trail' (there is no way to store and process the information at a later time), the irritations associated with sudden interruptions, the possible overload of too many alarms and the annoyance of passengers.

The communication of information through the haptic modality is a possible addition to reduce the distractions posed by the increasing amount of required communication. Research so far suggests that haptic cues can have a positive effect on response time in a driving task compared to visual and auditory cues (Enriquez, M., Afonin, O. et al. 2001, Lee, J., Stoner, H. et al. 2004a) as well as more effective than visual cues (Sklar, A. E. & Sarter, N. B. 1999). However, it is rather difficult to generalize results as the haptic communication that is used varies greatly between experiments, ranging from steering wheel vibrations to braking pulses to increased resistance of the gas pedal.

We can define three different priorities for information that IVIS systems communicate to the driver. These are (A) *General Information* – not relevant for the direct driving task (B) *Medium-Level Instruction* – cue that does not require immediate reaction, and (C) *Warning for Danger* - cue that requires an immediate reaction. This priority classification of a cue defines the modality best suited for communicating the information. High priority information maps well to the auditory channel, which causes immediate response, medium priority and low priority information suit well to visual displays that do not irritate and distract the driver. With regards to haptics, the information density that can be conveyed is relatively low, but can give varying degrees of importance and interpretation is natural. This makes haptic feedback rather unsuitable for the A-category, low-priority, information, but could be of use for less-intrusive versions of auditory cues that should be reacted on in the (B-category) near future (e.g. pedal feedback and steering wheel vibrations that support the driver task, without irritating the driver and/or passengers). C-category danger cues need immediate reactions, requiring natural mappings and minimal cognitive overhead, which can be given through fitting haptic solutions (Lee, J.D., Hoffman, J.D. et al. 2004).

2 Experiment

In the study we conducted, we focused on communication of in-car systems with the driver, using various means for communication, requiring evaluation of various systems, various communication mechanisms and various interactions, combined with a high level of immersion and contextual experience. As a real implementation of this would not only be costly, but also possibly unsafe and partly simply unavailable, we had to develop a simulation of the driving task that supports active participation of the driver (unlike storyboards, step-through simulations, etc.), retains a real-world context and allows us to test various driver support systems and their effects on the driver.

To this end, we developed a flexible experience prototype, using the open-source software Blender that allowed us to realize an interactive virtual world. The modular prototype makes it possible to let any pre-programmed event occur at any time in the virtual world, and at the same time record important data related to workload. In addition, we tried to keep as many as real-world context intact, such as crossing pedestrians, road signs, environmental sounds, interruptions by radio, as well as a steering wheel and pedals to operate the car.

To create a lifesize driving experience, the environment was projected on a wall using two beamers, see Figure 1. With this environment, we could rapidly change traffic settings and experiment with various situations to see how drivers react on different kinds of cues and combinations of cues, and can also adapt the prototype for future projects as it can be changed quickly to other virtual world situations. We report an experiment that we performed with aid of the prototype environment described above to assess user experiences with haptic, vibrotactile, feedback in two different settings: in the first setting we equipped the virtual vehicle with *haptic route guidance*; in the second setting we equipped the vehicle with *haptic speeding warning* (intelligent speed adaptation, ISA). The first system tells the driver where to turn left or right; the second system tells the driver when the local speed limit is crossed, to prompt him or her to slow down (for more information regarding the exact background of ISA, see e.g. the website of the Leeds ISA Project (http://www.its.leeds.ac.uk/projects/isa/). The goals of the experiment we performed here were twofold. The first goal of the experiment was to find out whether haptics can help to reduce driver distraction and focus on the road. Secondly, we wanted to gain more insight in how user experience haptic feedback in the car. We implemented these two systems in the driving environment and invited 19 participants for this study (11 male, 8 female, average age 37,5). The users were given time to test-drive for 10 minutes. Participants were told to complete the trip as fast as possible but keep in line with normal traffic regulations. To increase the workload for the users, traffic messages were played that participants had to remember and were asked questions about them.

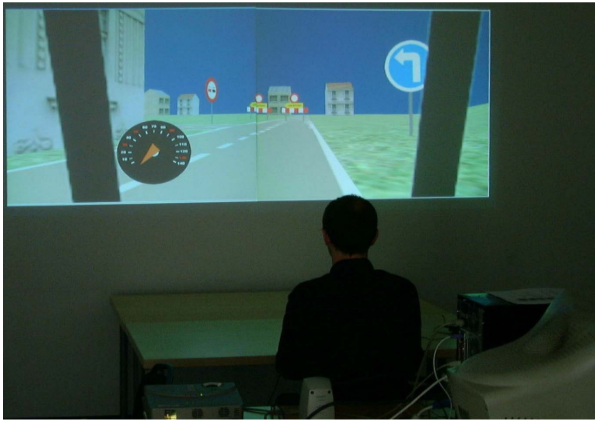

Figure 1: The Driver Experience Prototype

The actual experiment was performed in a within-subjects design with two conditions, consisting of a route through the virtual world taking on average 2 x 15 minutes to complete. In condition A, the route guidance was issued by speech: “please turn left at the next crossing” and the speeding warning haptic, consisting of 1 second-long vibrating pulses on both sides at the same time, as long as the speed of the vehicle was higher than the allowed maximum speed as designated by traffic signs along the route.

The haptic warning took place through the driving seat. On the left and right side of the seat a small electric motor was attached that vibrated on cue of the experimenter (Wizard of Oz-style, operated by the conductor of the test). In condition B, the route guidance was haptic, a three-pulse vibration on the side for turning at the next crossing, and the speeding warning audiovisual, a typical "peep and blink" signal, similar to the system used in the trials of the pilot project in (Sklar, A. E. & Sarter, N. B. 1999), a repeating tone is played and a blinking red light is displayed, both indicating speeding.

During the experiment, we measured a number of workload variables. When workload increases, more corrections are required to maintain a straight path, measured in steering wheel deviation (De Waard, D. 1996). Similarly, as workload increases, speed decreases (Jordan, P.W. & Johnson, G.I. 1993). Each of these was measured in a period of 10 seconds around the occurrence of a warning, as well as during similar control situations where no warning was played. We also asked participants to remember the traffic messages played. Furthermore, we observed the behavior of the participants.

3 Route Guidance Results

We recorded average speeds around the time a warning was given. When the route guidance asked the participant to turn, average speeds were higher in the auditory condition than in the haptic condition (46,7 and 42,1 km/h resp., $p<0.05$). In the control setting, no such difference occurred (34,8 and 33,8 km/h resp., $p>0.1$). The auditory route guidance was followed correctly by all the participants. However, three participants failed to turn on one occasion using the haptic route guidance. When we ask participants about the traffic messages they remember, it turned out that the haptic route guidance gave fewer problems than the auditory route guidance: 12 people answered correctly with auditory route guidance compared to 17 people with haptic route guidance. Finally, in a questionnaire after the tests, we asked our participants directly which of the two systems they preferred, and got mixed results: 6 people said they preferred the auditory route guidance system, whereas 7 people preferred the haptic route guidance. 6 other people did not have a clear preference.

In the haptic setting, users remember more of the radio traffic messages, indicating that haptic cues can be used as simultaneous cues next to other cues. Furthermore, the average speeds were a bit higher with haptic route guidance than with the auditory route guidance, indicating that the haptic cues might produce lower mental workload. However, it turned out that our implementation of haptic route guidance requires some effectiveness improvements, as three users once did not follow the haptic route guidance instruction to turn left, whereas all users followed the auditory route guidance correctly, which is why we would not recommend vibrotactile haptics for time-critical warnings, at the moment.

4 Speed Warning Results

We recorded average scores for speed around the time a warning was given. Here, it turns out that no significant differences occurred between the two conditions in terms of speed. Users typically did not speed at all, and when they did, they quickly reduced their speed after the speeding warning prompted them to do so. Speeding warnings generally ignited more steering wheel corrections (SD of 2.2° in normal driving vs. SD of 16.1° during speeding warnings). We also found significant differences in the amount of steering wheel corrections required. The haptic warning produced a SD of 14.9°, the audiovisual warning produced a higher SD of 17.2° ($p<.01$), indicating a higher workload for the audiovisual signal. In a questionnaire after the tests, we again asked our participants directly which system they preferred, and got small support for the haptic system: 10 people preferred the haptic speeding warning, 7 participants preferred the audiovisual speeding warning. 2 other people had no clear preference for either.

When speeding warnings were played, the standard deviation in steering wheel angle turns out to be higher in situations with audiovisual cues, indicating that the haptic speeding warning results in lower mental workload. As a feedback system that is less obtrusive than audio but more noticeable than a visual display, the haptic feedback seems to be successful, which was also mentioned by the participants. For this kind of medium-level instructions, vibrotactile haptics seem to work well.

5 Conclusions

We found mixed results for the application of haptic cues. The effectiveness in the route guidance causes some problems and contradicts with [0]. This might be due to the specific vibrotactile implementation we chose, which stresses again the importance of making a difference between haptics and haptics, where more specific nomenclature is required to be able to more easily distinguish between findings with various haptic displays.

Regarding the general effect of haptic cues to reduce load, we can cautiously conclude that this can be achieved using vibrotactile cues to give the user additional information, even in our prototype implementation. However, the information that can be transmitted is limited. The effectiveness of haptic cues partially depends on other vibrotactile information users may receive, e.g. when the road surface is rough, hindering the perception of important cues for route guidance, but less of a problem in the case of speeding as the surface itself will give some kind of vibrotactile information.

Regarding the success of vibrotactile cues in the two specific systems, we saw that not all users followed the haptic route guidance system, but found more positive results with the speeding warnings, and the majority of our participants also indicated that they would prefer speeding information through vibrotactile cues. This would be a less intrusive kind of warning than an audiovisual signal (e.g. less noticeable by other passengers), and distract and irritate the driver less.

As future work, we are looking to expand the experience prototype to other fields of application, such as immersive context for mobile applications and pedestrian support and create further improvements to the prototype experience, e.g. by adding more scenery and landmarks and increasing the field of view.

6 ACKNOWLEDGMENT

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