Providing Comprehensive Navigational Cues through the Driving Seat to Reduce Visual Distraction in Current Generation of Semi-Autonomous Vehicles

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Abstract. Methods of interaction and information presentation in the automotive context have continuously been evolving in the last decade Essentially, there is an inherent need to design and research in-vehicle systems that complement and natively support a multimodal approach towards driver-vehicle interaction. Basically, most IVI tasks are classified as secondary or tertiary driving tasks, meaning the driver can allocate lower priority to these tasks as they are not time specific. This is because most visually complex secondary tasks may hinder the driver's ability to focus on the primary task of driving. However, navigation tasks should not be classified as other IVI tasks. These tasks are often time or location specific and interaction with the system in most cases, may not be optional. Therefore, drivers often get visually burdened with excessive information at the most challenging instances. In this research we propose a novel approach towards resolving this issue by developing a Haptic Seat that can provide continuous and timely navigational information without additional visual distraction.

Keywords: Human-Systems Integration · Multimodal Interaction, Haptics, In-vehicle Infotainment, Driver Distraction.

1 Introduction

Most information presented to the driver in the current generation of vehicles is through various displays within the cabin. However, certain tasks, such as navigation can be very complex and may require considerable visual attention, which may hinder the driver's ability to focus on the primary task of driving. Therefore, most car manufacturers have a dedicated navigation system installed in the IVI central stack. However, this can prove to be challenging as the navigation systems still needs to be operated using the same controls / input mechanisms as the other IVI components. Essentially, most IVI tasks are classified as secondary or tertiary driving tasks, meaning the driver may be engaged in them as they so choose. Therefore, if the driving environment is less visually or cognitively challenging, the driver may focus their attention towards interaction with the IVI system (CID, HUD, IC etc.). However, there is no compulsion (NHTSA guidelines [1]) or time constraint of when and how this interaction takes place. Considerable research [2, 3] has been done to prioritize interaction related to navigation-based tasks. One of the core ways to ensure this is to make interaction regarding these tasks as natural as possible. Because audio and visual feedback work well together [4], the combination of the two has been widely used in navigation tasks for most IVI systems. Although adding audio cues or voice-based input could reduce visual distraction, the cognitive impact can still be a concern [5]. Adding haptics could resolve some of these issues and provide a more natural and personalized interaction experience for the driver. Although this concept is not new, most of the current research focuses on information redundancy through signal specification [6, 7]. Moreover, some of these studies show that it may be possible to deliver important navigational information to the driver. However, the higher cognitive load required to achieve this may not be worth the risk. Most of the implemented systems and their feedback signals are non-intuitive and take longer to identify and recognize. These systems also have a higher threshold of learnability with limited advantages seen in short-term use. Therefore, in the present research the authors focused on detecting and understanding the core requirements of the in-car navigational task and developed a simple multimodal interaction mechanism (Haptic Seat) to overcome issues without increasing the driver's cognitive load or complexity of interaction.

2 Developing a Novel Haptic Seat (HS) Prototype

The Haptic Seat was designed to provide three distinct types of actuation cues, which included simple event-based cues, spatial navigation (directional) cues and alerts or warnings that required immediate action. To generate simple event-based cues, the system utilized two sets of Tectonic TEAX25C10-8/HS voice coil actuators embedded on either side of the driver's seat, near the placement of the thighs (Fig. 1). The two actuators on either side were attached to a plastic plate and placed horizontally within the cushion of the driver's seat. This ensured that the actuators efficiency even when a heavy load was applied to the plastic plate, and surface area of the plastic plate radiated the vibrational cues, increasing the spatial resolution of the haptic feedback. The setup, simulated low frequency clicks under the thighs of the driver, signifying event-based feedback (touchscreen click, selections etc.).

Fig. 1. The Haptic Seat uses a pair of rotatory motors (left) and TEAX25C10-8/HS actuators (right) to generate feedback.

To generate spatial navigation cues, two Fukoku USR60-E3T ultrasonic motors with asymmetrical arrangement of spherical touch points on top, were embedded within the driver seat near the Tectonic voice coil actuators. The configuration of these of touch points were created using an 8mm thick Plexiglas disk attached to the shaft of the motors. Four marbles were glued near the periphery of each disk so that three of them were close to each other while the fourth was placed on the opposite side (as seen in Fig. 1). This ensured that the rotation of the disk was perceived by the lower part of the thigh, near the popliteal fossa (knee-pit). Each motor was used to create three distinct types of actuation. A four-time, 45-degree to-and-fro rotation, a single direction two times 120-degree rotation, and a single direction two times 270 degree rotational. Both 120 and 270-degree signals were provided in two distinct bursts separated by 300ms. This actuation scheme and the designed hardware (Haptic Seat) was paired with the navigation cluster and was used to replicate right and left turning instructions, with the higher degree rotation simulating sharper turns (hard turns or U-turns).

3 User Study: Haptic Visual & Auditory Cues for Navigation

The study was conducted in a laboratory setup using a driving simulator (Lane change test software) to compare navigation feedback using conventional audio cues as well as haptic and audio cues using the Haptic Seat prototype. For the study we replicated a conventional car cabin in the lab, using a large central display (55inch Samsung Smart TV) with a Plexiglas windscreen in front of it (Fig. 2). We also added strategically mounted displays to simulate rear and side view mirrors. The simulated car cabin used a Logitech Gaming wheel and pedals as the driving controls, whereas a genuine Volvo XC60 motorized driver's seat with the embedded Haptic Seat (HS) prototype was used to provide the haptic actuation. An adapted version of the ExoPC Slate tablet running the Meego IVI system was affixed to the dashboard of the cabin towards the left side of the driving controls. This setup was similar to our previous research setup used in Nukarinen et al., [8] and Lylykangas et al., [7].

Fig. 2. Lab setup and data collected while drivers performed the LCT (primary) and Navigational (secondary) tasks.

Twenty-four participants (13 male, 11 female) were asked to operate the standard Lane Change Test (LCT) software, as their primary task, which simulated visual and cognitive load similar to driving in light traffic. The participants were asked to consider driving their primary task and not let any other tasks impede their performance. Along with the primary tasks, the participants were asked to perform 18 secondary navigational tasks, scheduled in a controlled manner (Fig. 3). The secondary task was to identify the 6 different navigational cues, provided either by visual, auditory or haptic modality, and log them by pressing the corresponding steering wheel button (Secondary Tasks = 18). These navigational cues included 3 cues for turning right ('turn right', 'turn slightly right', & 'right U-turn') and 3 for turning left ('turn left', 'turn slightly left', & 'left U-turn'). These navigational cues were always provided 1.5secs after the onset of the LCT visual cue, to ensure the cognitive load was kept constant. Furthermore, there was always a 5-second gap between the completion of the secondary task and onset of the next primary task (LCT turning task.)

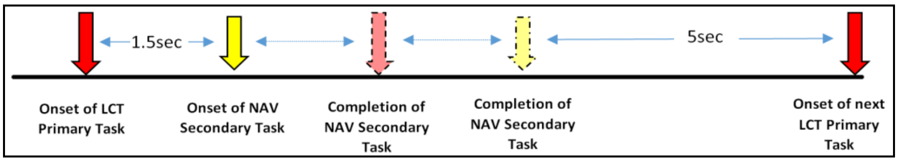

Fig. 3. Presentation of Primary (LCT) and Secondary (Navigation) tasks and their correlation to each other.

The visual instructions were provided on the ExoPC Slate device acting as the central stack, while the onscreen markers within the LCT software were disabled. The visual instruction included a pictorial illustration of the 6 navigational tasks as well as a written cue (Fig. 2). Similarly, 6 audio cues were generated by using active noise canceling headphone (Sony MX1000xm2). The audio used for these instructions was recorded from HERE maps, Android application. And lastly, we had haptic navigational cues. These cues were provided by the Haptic Seat prototype and were broken down into two parts (Fig. 4). These parts included a precursor signal, with two pulses separated by a 100ms delay, and a 2 times rotation of the motor (~2sec max) navigational signal. The precursor signal was provided using the Tectonic TEAX25C10-8/HS voice coil actuators embedded on either side of the driver's seat, while the actual turning cues was generated by the Fukoku motors, placed on both sides of the seat.

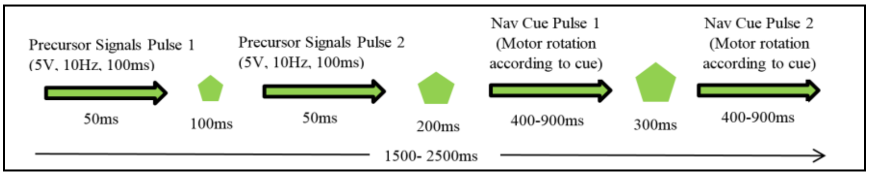

Fig. 4. Data collected while drivers performed the interaction task

4 Results

We ran a paired sample T-test to evaluate differences between primary task performance (PTP) comparing primary task errors (pTEs) and primary task completion times (pTCT) to Baseline condition as well as within each modality. Looking at PTP and pTE, we saw a statistical significance ($p < 0.05$) between the Baseline and both Audio and Visual conditions as expected. Surprisingly, haptic condition (0.67) did not yield a statistically significant difference between the baseline, which shows that errors (pTEs) were within parameter of the Baseline condition (Fig. 5). On the other hand, pTCT were much higher between the Baseline condition and all three modalities as expected. Furthermore, we saw Audio and Haptic conditions also approaching significance (0.0689). This shows that Haptic Seat based interaction increased the TCT for the primary task compared to Audio only modality. We believe this may be because the participants were not very familiar with the type of haptic feedback and it took them some time to be familiarized by its use in navigational tasks.

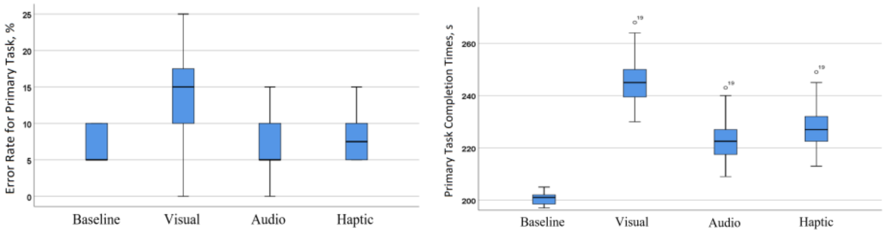

Fig. 5. (on the left) Task Errors (pTE) and (on the right) Task Completion Time (pTCT) for LCT (primary) Task.

While considering STP, we again observed that haptic and audio-based interactions were more efficient. Although there was no statistically significant difference found between the three modalities regarding errors (sTE), time to complete the task (sTCT) was statistically significant for visual-audio ($p = 0.04$) and visual-haptic ($p=0.01$) conditions. Moreover, there was no statistically significant difference between Audio and haptic modalities for both STP measures (Fig. 6), which illustrates that both Audio and Haptic only conditions were faster than Visual only condition. Interestingly, most participants choose to complete the PT (LCT task) before carrying out the ST, even though the secondary task was presented 1.5secs after the LCT task. This clearly shows that participants preferred completing the PT, and that the onset of secondary task may have distracted the participants, generating higher sTCT especially for auditory modality, as can be seen from outlier in Fig. 6.

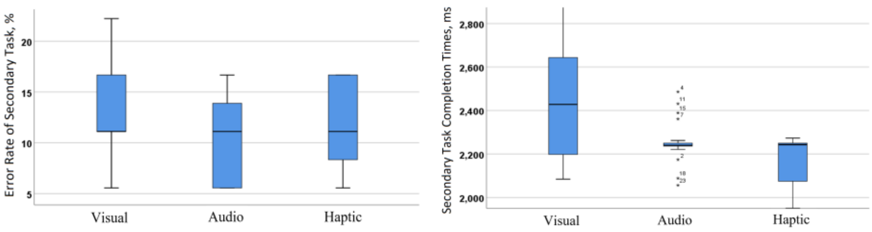

Fig. 6. (on the left) Task Errors (sTE) and (on the right) Task Completion Time (sTCT) for Navigation (secondary) Task.

5 Conclusion

A distracted driver is an inefficient driver, irrespective of the type or modality of distraction [9]. Our study shows that visual distraction can be reduced by implementing driver centric multimodal interaction systems for both primary and secondary tasks. Navigation is one such task that may compliment as well as hinder the primary task of driving. Therefore, more efficient multimodal interaction techniques need to be developed. This study was based on utilizing a novel method of providing navigational information through vibration-based actuation within the driver seat. There was a statistically significant difference between the Baseline Primary Task (PT) condition (No secondary tasks) and visual only PT as well as auditory feedback conditions while performing secondary tasks. Interestingly there was no statistically significant difference found between the baseline and haptic conditions w.r.t primary task errors.

We believe this is because the secondary task was relatively simple and did not require overloading the driver. Furthermore, if we cross reference this result with primary task completion times, we do see a statistically significant difference between the baseline and each other modality. Therefore, the drivers were slowed down by the secondary tasks, irrespective of their interaction modality as reported by Lee et al.,

Looking at secondary task performance, the results show both haptic and auditory modality based tasks were faster to perform than visual only modality. However, there was no statistical significance between haptic and auditory conditions with respect to task completion times. Conversely, the secondary task errors remained similar for all three modalities and no statistical significance seen between them. We this that participants preferred to complete the primary task, before starting the secondary task, which limited the possible distraction and task errors. This was most visible for the auditory modality and, hence, there were some outliers in the sTCT data. Interestingly, as this study was conducted in a lab setting, these results may vary considerably once the participants perform similar tasks on the road with live traffic.

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6 References

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