The Impact of Haptic and Visual Secondary Tasks on Drivers' Visual Behaviour and Driving Performance - a Qualitative Analysis

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ABSTRACT

Studies have shown that different kinds of secondary tasks affect visual behaviour and driving performance in different ways. Eye movements and driving performance were recorded while participants drove a simulator and performed haptic-manual and visual-manual secondary tasks. The data recorded were plotted and then qualitatively analysed. It was obvious that it is inappropriate to look for effects on gaze concentration caused by task load with the type of simulation used in this study. The driving data plots showed that reaction time was longer in situations of haptic-manual and visual-manual tasks compared to driving with without secondary task. The secondary tasks did not affect road sign detection or lane keeping performance.

Keywords
In-car interfaces, haptic information, visual distraction, cognitive distraction

INTRODUCTION

Car driving is a complex task. A driver has to deal with steering and speed control and at the same time pay attention to traffic, road signs and other road users. Diverting attention from the driving task has been shown to be a factor that often contributes to incidents and crashes (Neale et al., 2006). Driver distraction is an umbrella term for occasions in which drivers temporarily focus on something not related to the driving task (Kircher, 2007). Driver distraction can be visual, auditory, biomechanical (manual) and cognitive (Ranney et al., 2001). Studies carried out in real and simulated driving environments have shown that different kinds of distractions affect visual behaviour and driving performance in different ways. Distractions caused by visual-manual interaction with in-vehicle devices, such as the radio, a cell phone or an mp3 player, have been the focus of numerous studies. Visual-manual interaction with equipment in the car has been shown to result in frequent and long periods of visual time off road (Chisholm et al., 2007; Wikman et al., 1998) and concentration of the returning gaze to the centre area of the road, i.e. time is spent looking straight ahead at the cost of fewer peripheral glances (Victor et al., 2005). Visual-manual interaction also results in decreased lane-keeping performance (Engström et al., 2005; Wikman et al., 1998), decreased detection performance and increased reaction time (Chisholm et
al., 2007; Horberry et al., 2006). It is obvious that the eyes should be on the road and the hands on the wheel to be able to drive safely. Alternative ways to interact with in-vehicle systems have been suggested in the literature. One example is voice control. Graham and Carter (2000) showed that speech-based interaction, compared to visual-manual interaction, reduced some of the adverse effects on driving caused by operating the system. On the other hand, it has also been demonstrated that speech based interaction can introduce a cognitive load on the driver (Lee et al., 2001). Hence, it is not only important that the eyes are on the road and the hands on the wheel; it is also central that the mind is on the road. It has been found that gaze is concentrated towards the centre area of the road in situations of auditory and cognitive load (Harbluk & Noy, 2002; Victor et al., 2005) and detection performance and reaction time are affected (Patten et al., 2004; Strayer & Johnston, 2001). In contrast to findings on visual distraction it has been demonstrated that auditory and cognitive load can lead to increased lane-keeping performance (Engström et al., 2005). Another alternative to visual-manual interaction is the use of haptic information (Bengtsson et al., 2003; Burnett & Porter, 2001). Few attempts have been made to evaluate the use of haptic information in the interaction with in-vehicle equipment. Porter et al. (2005) designed an in-car interface in which the interface devices were coded haptically. It was shown that the number and duration of glances to the display and controls were reduced compared to a standard interface.

There are several different ways to measure drivers' visual behaviour. One limitation of the ISO, measuring glance frequency and glance duration (ISO 15007-1), is that these measures can only be used to measure effects caused by visual secondary tasks. An alternative to glance based measures is the measure called Percent Road Centre (PRC) (Victor et al., 2005). This measure focuses on how much time is spent looking at the centre area of the road and can be used to evaluate visual behaviour during both visual and non-visual secondary tasks. Several driving simulation software programs are available for evaluating driving performance. One driving simulation software is the Lane Change Test (LCT) (ISO 26022). In the LCT simulation a driver drives at a constant speed of 60 km/h on a straight three-lane road on which no other cars are present. Signs instruct the driver to change lanes. An LCT track takes three minutes to complete, and 18 lane changes are made during a track. The LCT derives a single measure of driving performance, which is the mean deviation from a normative path. Late perception of signs or missed signs, slow lane change and poor lane keeping result in greater deviation (Mattes, 2003). Since the output of the LCT is a single measure, no discrimination is made between effects caused by different kinds of distractions. Engström and Markkula (2007) studied the effects of visual-manual and cognitive distraction on LCT driving performance. To identify the types of errors made, the lane position data were plotted for the different conditions. It was shown that visual-manual tasks caused more overshoots in the lane change, whereas cognitive tasks caused several missing and erroneous responses to the lane change signs.

The aim of the present study was to qualitatively compare how haptic-manual and visual-manual secondary tasks affect visual behaviour in terms of gaze concentration and LCT driving performance in terms of reaction time to lane-change instructions, missed signs and lane-keeping performance.
METHOD

This paper is based on a secondary, qualitative analysis of eye tracking and LCT data. The original analysis of the data is published elsewhere (Rydström et al., 2008). The original experiment had a between-subjects design and four secondary task conditions. Two of the conditions, a haptic condition and visual condition, are further analysed in this paper.

Participants

The two test groups included ten participants each. Of the 20 participants four were women and 16 were men. The majority of the participants were students 22 to 46 years of age ($M = 28, SD = 5.7$). The criterion for participation was possession of a driver’s license. To ensure eye-tracking data of good quality, no eyeglasses were to be used. The participants were permitted to wear contact lenses.

Equipment

The study was conducted using a fixed base Volvo XC90 driving simulator. The LCT driving scene was projected on a screen in front of the participants (Figure 1). The interaction device, a haptic rotary device (ALPS Haptic Commander, ALPS Automotive Products Division, Japan), was mounted on the centre panel of the simulator. The experimental interface was implemented in Macromedia Director 8.5 (Adobe systems Inc., USA). The interface program managed the haptic sensations provided through the interaction device and the visual menu in the centre panel display. The tasks to be completed were presented verbally in headphones and were visually given on a display placed on the dashboard. faceLAB 4.1 (Seeing Machines, Australia) was used to record eye movements. With two video cameras faceLAB measures 3D head position and gaze direction at a sample rate of 60 Hz. An analysis software, Visual Demand Measurement (VDM) Tool (Victor et al., in press), was used to interpret the eye movement data.

![Figure 1. The LCT driving scene and the driving simulator with: a centre stack display (1), a rotary device (2), a display presenting tasks (3) and eye tracking cameras (4).](image-url)
Experimental conditions

The two experimental conditions provided a menu with four texture items, A, B, C and D. In the haptic condition (H) (Figure 2) representations of the four textures were provided through the rotary device as it was turned. The textures were rendered as repeated and evenly distributed ridges, i.e. alternated high and low torque, over a 30º rotation angle. Textures A, B, C and D had 0, 3, 6 and 30 ridges, respectively. Salient ridges were incorporated between every texture in the menu to indicate borders, and restricting walls were incorporated outside the scale limits on each end of the menu. In the visual condition (V) (Figure 2) the textures were displayed on the screen at the centre panel of the simulator. The active texture was marked with a transparent blue cursor. The cursor moved in the menu as the rotary device was turned. A smooth sensation was provided as the device was turned and restricting walls were incorporated outside the scale limits on each end of the menu. The design of the experimental conditions is described in more detail in Rydström and Bengtsson (2007).

Procedure

During the experiment the test leader sat in the front passenger seat of the simulator and controlled the equipment and read test instructions aloud from a manuscript. A brief description of the experiment was given at the beginning of a session. To improve data quality, face markers were placed on the participant’s face before the eye-tracking system was calibrated. After instructions on the LCT had been given the participants drove two training tracks and one baseline driving track. The participants then practiced the secondary task in two training series. In the first training series the participants were to learn which letter (A, B, C or D) represented which texture and were free to explore a menu in which the menu items were provided in alphabetical order. In the second training series the participants practiced the secondary task as it would be displayed while driving. The task was to locate and select items in the haptic or visual menu. The tasks to be completed, e.g. ”Locate A”, were automatically presented to the participants orally in the headphones and in written format in the display in front of the participants. The participants located and selected the requested item by turning and pushing the rotary device. As soon as one task was completed the next was initiated. The target texture and the positions of the textures changed for every new trial. A beep was given as feedback after a task was completed successfully. The participants had to successfully complete 12 tasks in a row to pass the training.
After practicing, the participants completed two dual-task driving tracks, of which the first was a training track. The participants finally drove a second baseline driving track. Eye movements and driving performance were recorded during the two baseline tracks and the dual-task track.

RESULTS AND DISCUSSION

Victor et al. (2005) showed that the gaze concentrates on the centre area of the road during cognitive tasks. Victor et al. also demonstrated that when a driver looks back at the road during a visual task the gaze concentrates on the road centre. The fixation density plots in Figure 3 show that the fixations are quite clustered during baseline driving; almost all fixation points lie within the predefined road centre area (circle). The fixation pattern for baseline driving does not differ a great deal from the pattern in the H condition. The fixation density plot for the V condition shows two areas of assembled fixations, the one area being the road centre (within the circle) and the other the secondary task display. The fixations on the road centre area are quite clustered within the circle. When compared to baseline driving no increased gaze concentration can be observed. However, is clear from the plot for the V condition that less time was spent looking at the forward road compared to baseline.

Figure 3. Fixation density plots derived from one participant for baseline driving (upper left), the H condition (upper right) and the V condition (lower left). The circle, which has a radius of 10°, is the predefined road centre area.
In the original experiment Rydström et al. (2008) calculated that baseline driving gave a PRC value of over 90%, i.e. over 90% of the fixations were inside the circle with a radius of 10°. It has been shown that the PRC value for real driving is around 70% (Victor et al., 2005). An explanation for the absence of a gaze concentration effect in this study is that the driving simulation used did not make use of mirrors and for that reason no peripheral glances were required. In addition, no glances at the speedometer were needed since the speed was system controlled (the fixations beneath the main cluster in the H and V conditions are glances at the display presenting the tasks to be completed). The participants consequently looked almost solely straight ahead even during baseline driving. Victor et al. found effects of gaze concentration even in simulated driving environments. However, it is clear that it may not be suitable look for a gaze concentration effect in the type of driving simulation used in this study.

The literature suggests that reaction time decreases when a driver is distracted by an in-vehicle task (Horberry et al., 2006; Patten et al., 2004). It can be seen in Figure 4 that the response to the lane change signs was slower in both the H and V conditions compared to baseline. Since the tasks were given one after another during the H and V conditions, most of the driving was spent with only one hand on the steering wheel, whereas both hands could be held on the steering wheel during baseline driving. Thus it is also possible that a biomechanical interference affected the response time.

Studies have shown that detection performance is affected when a driver is distracted by a cognitive or visual-manual task (Chisholm et al., 2007; Strayer & Johnston, 2001), and it is known that visual-manual tasks affect lane-keeping performance (Engström et al., 2005; Wikman et al., 1998). It can be seen in Figure 4 that only a small number of missed signs and overshoots were present in the H and V conditions. Hence, detection performance and lane-keeping performance did not seem to be affected by the secondary tasks used in this study.
Figure 4. The raw LCT data for the final baseline driving tracks (upper figure), H condition (middle figure) and V condition (lower figure). The normative path is plotted in the background. The arrows indicate missed signs and the circles indicate large overshoots in the lane change.
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