INFLUENCE OF DISPLAY TYPE ON DRIVERS' PERFORMANCE IN A MOTION-BASED DRIVING SIMULATOR

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Abstract

Different solutions are used on driving simulators to provide visual feedback. In this study, we investigated the influence of projection technology and field of view on drivers' performance in a slalom driving task. We tested a head mounted display against a curved projection system on our CyberMotion simulator, based on an anthropomorphic robot arm. The results showed that drivers performed significantly better using the projection screen than the HMD. The FoV and the motion simulation did not have a measurable influence on the performance.

Introduction

It is well known that large projection screens with wide field of view (FoV) provide motion cues in the periphery of the visual field that can result in a greater sense of vection (Hettinger & Riccio, 1992; Mohler, Riecke, Thompson, & Bülthoff, 2005), more accurate navigation abilities (Alfano & Michel, 1990), and more accurate perception of self-motion (Pretto, Ogier, Bülthoff, & Bresciani, 2009). For instance, in a driving simulation scenario, a wide FoV provides a better estimation of speed (Jamson, 2000; Pretto, Vidal, & Chatziastros, 2008) while in flight simulation a FoV bigger than 60 degrees helps in the cruise phase (Keller, Schnell, Lemos, Glaab, & Parrish, 2003). However, motion-based simulators often lack the space for large projection screens, and therefore small screens or head mounted displays (HMD) are sometimes used.

Traditional HMDs provide a small FoV and create discomfort in the user (Mon-Williams, Warm, & Rushton, 1993). Wide FoV visualization systems may also result in greater simulator sickness compared with more limited FoV devices (Sparto, Whitney, Hodges, Furman, & Redfern, 2004). However, recent lightweight HMDs, combined with head tracking, reduce the users' discomfort and provide a wide horizontal FoV (Peli, 1998). Yet, these devices influence distance judgments (Willemsen, Colton, Creem-Regehr, & Thompson, 2009). Therefore, the use of HMDs instead of large screens, and the corresponding impacts on driving capabilities, is still an issue but also represents an interesting option for motion-based driving simulators. Moreover, the effects on driving performance of wide FoV in these two types of visualization devices need to be assessed using state-of-the-art setups. To address these issues we used our CyberMotion simulator to compare drivers' performance on a slalom task with different visualization setups and different FoV sizes. Such task was chosen because it requires driving accuracy, which might be influenced by the visual information available from wide FoVs.

Simulated motion represents also an important factor in driving precision, and depending on the visualization device, this might interfere with drivers' accuracy. Specifically in absence of head tracking, the HMD could create visuo/vestibular conflict due to unintentional head motion induced by the simulator motion. Therefore, we compared drivers' performance also between static conditions in which head motion is minimized.

Method

Setup

Apparatus

The CyberMotion simulator is based on an anthropomorphic robot manipulator with six degrees of freedom (Figure 1) and derived from an industrial heavy load robot (Kuka AG, 2010; Teufel et al., 2007).

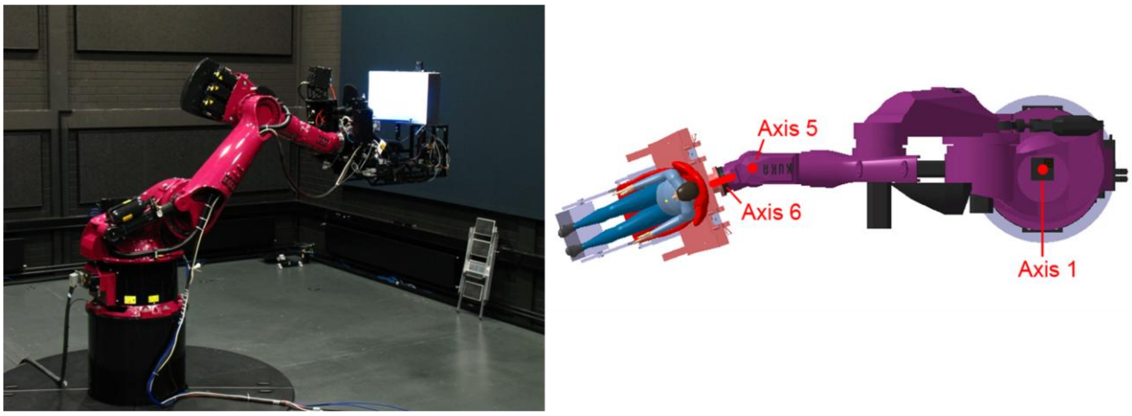

Figure 1. (a) The CyberMotion Simulator. (b) A sketch of the simulator axis used in the experiment, seen from the top. Axis 1 at the base simulated lateral translations. Heading and roll motions were simulated by axis 5 and 6.

A force feedback steering wheel was used as input device for closed-loop control of the virtual vehicle. As visualization devices, we used a projection screen mounted in front of the seat with a horizontal FoV of 90º and a vertical FoV of 45º. A video projector displayed an image of 1152x450 pixels on a curved screen at a distance of approximately 73 cm in front of the subject's eyes (Figure 2a). For comparison, we used a Sensics xSight 6123 HMD (Sensics Inc., 2010) with a horizontal FoV of 118º and a vertical FoV of 45º (Figure 2b). The low weight of 400 grams limits neck strain and therefore makes it particularly suitable for use on a motion simulator. Each eye piece is rotated outwards off the viewing direction by 16.75º and consists of six individual OLED micro displays. Special lenses are used to overlap all six displays to one seamless image of 1920x1200 pixels in each eye. Given a binocular overlap of 53º, the resolution of both eyes combined is 2664x1200 pixels. Since no head tracking was used, a similar transport delay for both visual systems can be assumed.

Figure 2. (a) The projection screen mounted to the CyberMotion Simulator; (b) the Sensics xSight HMD. The optics for both eyes can be moved sidewise to match the user's anatomy.

Vehicle simulation

Heading and roll motion of the virtual car were simulated according to a simple vehicle model based on Ackermann steering geometry, using axis 5 and 6 respectively (Figure 1b). Lateral translations were mapped into planar circular trajectories with a radius of 3.1 meters. The lateral displacement on the road was simulated by rotating axis 1 at the base of the robot with a scale factor of 0.6 . The used vehicle model was validated in a previous study and behaves dynamically in a sensible manner (Pretto, Nusseck, Teufel, & Bülthoff, 2009).

Visual environment

The visual environment was modeled using the 3D rendering engine OGRE and consisted of a straight road in a forest setting. Trees of different size were placed randomly alongside the road and were repositioned throughout the experiment. A stone wall flanked the textured road to provide a richer visual feedback (Figure 3).

Figure 3: Screenshot of the environment as displayed on the screen in the 90º FoV condition.

The slalom path was outlined by 15 gates over three consecutive sections. Each gate was 2 meters wide and alternately displaced 3 m to the left and to the right of the center line on a two-lane road. The distance between gates was 62.5 meters in the first and third section, while it varied between 45 and 55 meters, in steps of 2.5 meters, in the middle section. At every run, all five inter-gate distances in the middle section occurred only once, in random order.

Participants

Ten experienced drivers (1 female, 9 males) were paid to participate in the experiment. They had at least four years of driving experience on a daily basis. The age of the participants was ranging from 22 to 38 with an average of 25.7 years. All subjects had normal or corrected to normal vision using contact lenses. None of them wore glasses. Before entering the simulator they signed an informed consensus.

Design and procedure

The drivers' task was to complete the slalom course and drive as smooth as possible through each gate. Participants were instructed to rest their head at the back of the seat to minimize involuntary head movements. The simulation started 100 m before the first gate and lasted for 100 more meters after the last gate.
After entering the simulator, participants were provided with a brief training session. First, they saw a video of the optimal driving path; afterwards, they performed once the slalom with the screen setup and 90° FoV to familiarize with the simulator motion and the experimental conditions. The virtual vehicle was traveling at a constant speed of 70 km/h.
Each participant carried out the slalom maneuver with five display settings: I. screen with small FoV (45º); II. HMD with small FoV (45º); III. screen with wide FoV (90º); IV. HMD with wide FoV (90º); V. HMD with very wide FoV (118º). Two additional conditions without physical motion (screen and HMD with 90º FoV) to control for HMD discomfort with static head were added. The vertical FoV was 45º in all conditions.
In a typical driving session, a driver performed four blocks of twelve slalom maneuvers, alternating with another driver after each block. The visualization devices were alternated over the four blocks and between the two drivers. A block with HMD consisted of four conditions (no motion, 45º, 90º and 118º) repeated three times in random order. In turn, a block with screen consisted of three conditions (no motion, 45º and 90º) repeated four times in random order. Short breaks after four slaloms were allowed to prevent motion sickness. An entire session lasted approximately four hours.

Measures

A smooth trajectory that passes through the center of each gate was computed using cubic Hermite splines as a flexible estimation of a sinusoid curve (Cossalter & Doria, 2004). Driver's performance was measured in terms of deviation from this path within each two consecutive gates. The Root Mean Square Error (RMSE) from the path was averaged across participants and compared between the tested conditions.
All data was recorded at the rate of 12 ms for the entire experiment. The data from the first and the last gate, as well as from missed gates, were excluded from the analysis.

Results

We found a significant difference in the performance between the two devices. At a paired-sample t-test the HMD resulted to provide significantly worse results than the screen ($t_9 = 3.566$, $p < 0.01$). This result is supported by the observation that 27 gates were missed when using the HMD, while only one was missed when using the screen. The size of the FoV had no significant effect on driving precision, with both HMD ($F(2,18) = 0.85$, $p = 0.41$) and screen ($t_9 = 0.593$, $p = 0.568$) (Figure 4). Simulated motion did not improve driver's performance in our slalom task ($F(1,9) =$

0.17, p = 0.69). Furthermore there was no interaction between motion and the two devices ($F(1,9) = 0.99$, $p = 0.35$).

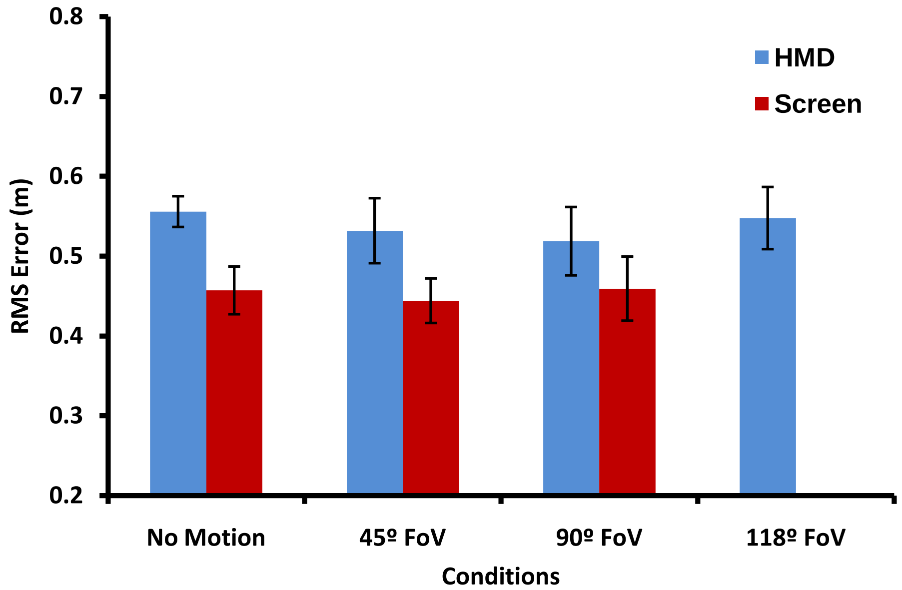

Figure 4. Driving performance under different display and motion conditions. Each bar represents data averaged across 10 subjects. The “No Motion” conditions were provided with a FoV of 90º. The error bars indicate standard errors.

Discussion and Conclusions

Our study shows that the deviation from the optimal path in a slalom-driving task is lower when drivers see the virtual environment on a screen rather than on an HMD. This result is consistent with the findings of a previous study in which subjects performed worse with HMD on a self-motion perceptual task (Riecke, Schulte-Pelkum, & Bülthoff, 2005).

Although the resolution, as well as brightness and contrast, were superior in the HMD as compared to the screen, other features of the device might have contributed to its bad performance. A recent study compared HMDs with real world situations and showed that restricted FoV together with high inertial weight on the head results in bad distance judgments (Willemsen, Colton, Creem-Regehr, & Thompson, 2009). However, in our study the HMD had a lower weight and a wider FoV, therefore we might assume that potential effects on perception were reduced.

Other critical factors of the HMD are pincushion and keystone distortion. It has been shown that pincushion distortion does not affect perceptual judgments (Kuhl, Thompson, & Creem-regehr, 2008). In the Sensics HMD, however, the image of each eye is generated by merging the images of six sub-displays, each of them with little pincushion distortion. Moreover, no method to compensate for keystone distortions in the individual displays is provided by the manufacturer and, therefore, it is not possible to set up a perfect transition between the sub-displays in the outer regions of the visual field. How all these optical distortions are perceived is still an issue that needs to be further investigated.

Recent works have shown that a FoV limited to 58º and 42º did not affect humans' abilities in distance judgments (Creem-Regehr, Willemsen, Gooch, & Thompson, 2005; Knapp & Loomis, 2003). In line with this, our study demonstrates that a large FoV does not improve drivers' capabilities to accomplish a slalom task. This result can be explained by the drivers' gaze behavior when driving around a curve. It has been shown, indeed, that drivers look at the inner edge of the road when approaching a curve (Land & Lee, 1994) and therefore, in a slalom task, the driver's gaze is likely to be directed towards the inner side of the approaching gate. In our experiment, the widest visual angle between the heading of the vehicle and the approaching gate was less than 10º. This would indicate that the slalom task is essentially performed in central vision, and additional cues provided by the periphery of the visual field are not taken into account. The smallest (45º) FoV condition of our experiment contained already all the useful information and a slalom path with sharper curves would be necessary to enhance the role of a wide FoV.

In our study physical motion did not affect drivers' performance. In contrast, it has been shown that physical motion improves pilot's performance on a complex helicopter control task (Nieuwenhuizen, Zaal, Teufel, Mulder, & Bülthoff, 2009). This suggests that motion supports the pilot to carry out demanding maneuvers, but it is less important when operating vehicles with more direct control as in our experiment. We assume that experienced drivers could easily carry out our slalom task, resulting in performance saturation. We will address this in future projects by increasing the difficulty of the task.

Finally, the lower performance in the HMD conditions cannot be attributed to the lack of head tracking. In fact, no interaction effect was found between trials with and without physical motion, even within the HMD conditions. This supports the assumption that unintentional head motion was limited and visual/vestibular conflicts were minimal.

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