Motion Sickness When Driving With a Head-Slaved Camera System

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SUMMARY

In a field experiment, we examined motion sickness incidence when driving with a head-slaved camera system. More specifically, we looked at the contribution to motion sickness of visual feedback on head roll and of stereoscopic view with the head-slaved camera system. The system was capable of motion in all three rotational degrees-of-freedom (DOFs). In the experiment, twelve subjects drove a car around a closed circuit in four different viewing conditions. In two conditions, no feedback on head roll was present by disabling the roll DOF of the camera platform (i.e., resulting in a 2 DOF system), and either mono view or stereo view was used. In the other two conditions, visual feedback on head roll was present (i.e., a 3 DOF system), and again either mono view or stereo view was used. As a baseline, subjects also drove with direct view, either with an unrestricted field-of-view (FOV) or with FOV-restricting goggles. The 2 DOF conditions were tested on a separate day from the 3 DOF conditions, and a direct view condition always preceded a condition with the head-slaved camera system. Upon completion of the driving task in each condition, the subjects filled in the motion sickness questionnaire (MSQ). Simulator sickness questionnaire (SSQ) total scores were derived from the MSQ. Results showed a significant difference between the 2 DOF and 3 DOF conditions (average SSQ total scores of 17.7 and 8.4, respectively). No significant differences between mono and stereo conditions were observed. These results indicate that motion sickness incidence with our head-slaved camera system can be reduced considerably by adding a roll component to the system.

INTRODUCTION

When driving with the hatch closed, drivers of armoured vehicles use periscopes to view the outside world. However, the field-of-view (FOV) of these periscopes is often very restricted, resulting in large blind areas in front and to the side of the vehicle and gaps between adjacent periscope views (Van Erp, Padmos & Tenkink, 1994). These problems impose restrictions on fast and accurate driving in many operational environments (Van Erp & Padmos, 1997; Van Erp, Van den Dobbelsteen & Padmos, 1998). As an alternative, we developed a head-slaved camera system for driving in such poor visibility conditions. This system consisted of a two degrees-of-freedom (DOF; heading and pitch) motion platform with two small cameras mounted on it, a mechanical headtracker, and a helmet-mounted display (HMD) for image presentation (see Figure 1). The camera motion platform is slaved to head movements of the driver, so that the camera orientation always matches the orientation of the driver's head. In this way, the driver can look around with the camera system in a natural manner. Also, other sensors, such as image intensifiers or thermal imagers, may be used to enhance the visibility of the driving scene in case of darkness, fog, snow, smoke or dust (e.g., Casey, 1999). Oving and Van Erp (2001a, 2001b) tested the feasibility of the head-slaved camera system for driving an armoured vehicle in a real world experiment. Their results showed that driving with such a head–slaved camera system is feasible, and that driving performance was even improved compared to the conventional periscope system. However, several drivers reported symptoms of motion sickness when driving with the system.

Figure 1. The TNO Human Factors head-slaved camera system mounted on an armoured vehicle. On the left, the camera motion platform with the two cameras, the HMD and the mechanical headtracker is shown, while a close-up of the camera platform is shown on the right. The periscopes are located just in front of the hatch opening.

In general, motion sickness occurs when the brain receives inadequate or conflicting sensory information about the orientation and movement of the body in its environment (Reason & Brand, 1975). Especially information about the orientation of the head relative to the gravitational force is critical (Bles, Bos, De Graaf, Groen & Wertheim, 1998). The different sensory systems provide a coherent set of information about the orientation in the world in normal circumstances. However, discrepancies between the visual information and the vestibular and proprioceptive information about real world motions may occur when an indirect viewing system is used. Such discrepancies are known to provoke motion sickness.

At least four sources for such discrepancies exist in the TNO head-slaved camera system. First, of the six possible DOFs of head motion, only two rotations (i.e. heading and pitch) are measured and relayed to the camera motion platform. No visual feedback about the third type of rotation (i.e., head roll: the rotation around the line-of-sight) is presented in the HMD. However, drivers do roll their head during driving, even up to 20° or further (Zikovitz & Harris, 1999; Van Erp & Oving, in press). This omission of roll is believed to be more detrimental than the exclusion of the translations. When the eyes are focussed on an object, the effects of translational motions are more apparent in the periphery than in the central portion of the visual image. This is less so with head roll. When the head is rolled to one side, and the eyes remain stationary relative to the head, the complete retinal image is rotated in the opposite direction with the same magnitude. In addition, the HMD oculars fill up a large portion of the visual field of the eyes, up to a total of 130° per eye, while only the central 45° is used for displaying the camera images. Because of this lack of peripheral information, the drivers thus have to rely mainly on this central visual imagery in the HMD to determine head motions. However, the information on head roll that is normally available in this view, is now absent, and this may have led to the high incidence of motion sickness observed with the head-slaved system. Second, it is possible that the lower quality of the images, such as the relatively low resolution and contrasts, and presence of image smear, contributed to the motion sickness. This also relates to the use of stereo images in the system. For instance, Ehrlich (1997) reported a higher simulator sickness incidence with stereo images in a simulator, compared to mono images. So it is possible that (improper) stereo cues contributed to the motion sickness reports. In this view, it should be noted that we used a relatively large horizontal distance between the cameras (e.g., approximately 12 cm). This was done to create images with hyperstereo, which provides a stronger depth contrast and may result in a better binocular depth perception with camera view. Third, inherent delays in the head-slaved system result in discrepancies between the visually perceived orientation from the camera images and the vestibularly and proprioceptively sensed orientation. These delays are due to the video processing and the (dynamic) response characteristics of the motion platform. Fourth, the offset between the camera viewpoint and the physical position of the driver can also result in a discrepancy. For instance, in the field experiment, the camera platform was placed on the midline of the vehicle, while the driver was sitting on the left side (Oving & Van Erp, 2001a, 2001b).

We hypothesised that the omission of visual feedback about head roll may be the main contributor to the observed motion sickness with the system, because this omission results in the largest possible discrepancy between the visually observed motion and the vestibularly and proprioceptively sensed motion. This hypothesis is supported by a study of Craig, Jennings and Swail (2000), who used a head-slaved camera system for helicopter flying. They observed motion sickness symptoms when head roll compensation was absent in the camera platform (i.e., a 2 DOF system), but less so when it was present. We tested this hypothesis in the present study, by examining the effect of head roll compensation on motion sickness incidence with the TNO head-slaved camera system. In addition, we studied the effect of stereo view on motion sickness. Previous research has shown that the application of stereo images may prove beneficial for driving performance with a head-slaved camera system (Van Erp & Van Winsum, 1999). However, this advantage has to be weighed against any potential negative effects of using stereo view, such as the potential for motion sickness, because the choice for stereo view with a head-slaved viewing system has considerable impact on system specifications.

METHOD

Subjects
Twelve subjects, nine men and three women, voluntarily participated in the study. They were all employees of TNO Human Factors. Their age ranged from 22 to 36, with an average of 31 years. None of the subjects reported any uncorrected vision deficits.

Tasks
The study was performed on a closed circuit that is part of the Vlasakkers training ground of the Royal Netherlands Army. The experimental task of the subjects was to drive around a triangle shaped section of the circuit, with a length of approximately 250 m. In each condition, the subjects drove around the circuit freely for approximately ten minutes before they started with the experimental task, to accommodate them to the specific viewing condition. They subsequently drove eight laps around the triangle. The driving direction was changed from clockwise to counterclockwise, or vice versa, after each two consecutive laps.

Because it has been observed that head roll amplitude correlates positively with lateral acceleration (Van Erp & Oving, in press), the subjects were asked to drive the triangle at, more or less, comparable speeds in all conditions. In this way, potential differences in head roll amplitude between conditions are less likely the result of a difference in driving speed between conditions.

Apparatus
The system used by Oving and Van Erp (2001a, 2001b) on armoured vehicles was modified to enable head-slaved roll motion of the camera platform, in addition to the other two rotations (see Figure 2). Each DOF of the camera platform could be turned on or off individually. A common passenger car was then outfitted with a customised roof rack on which the modified camera motion platform of the head-slaved system was mounted. The camera platform was located on the left side of the car, above the driver's position, and approximately 60 cm above and 40 cm behind this position (see Figure 2). The mechanical headtracker was installed inside the vehicle, and rigidly attached to the driver's seat.

Figure 2. The modified head-slaved camera system (3 rotational DOFs) mounted on a passenger car (left side), and a close-up of the system (right side).

Two CCD cameras were mounted parallel on the platform with an inter-camera distance of 8 cm. This was smaller than the distance of 12 cm used by Oving and Van Erp (2001a, 2001b), although this horizontal separation is still considerably larger than the average inter-pupillary distance (i.e., 6.4 cm). The NTSC camera images were converted to VGA before they were displayed in the HMD. The HMD was a Kaiser ProView60, with a FOV of 48° (H) × 36º (V) and a resolution of 640 (H) × 480 (V) pixels. In combination with the lens type that was used, this resulted in a magnification factor of approximately 0.96 (i.e., objects in the camera images thus appeared to be slightly smaller than they were in reality). The update rate of the image system was 60 Hz. The delay in the image channel was approximately 50 ms, on average. This is exclusive of any dynamic latency due to the response characteristics of the motion platform. The mechanical headtracker allowed for 6 DOFs of head motion, but only registered the three rotations. The motion box of the mechanical headtracker did not limit normal head motions during driving.

Experimental design

Conditions

We looked at the effects of visual feedback on head roll, and of stereo view with the head-slaved camera system, on the incidence of motion sickness symptoms when driving with the system. The presence of head roll feedback was manipulated by either disabling the roll DOF of the camera motion platform, or by enabling this DOF. The two other DOFs of the system (i.e., heading and pitch) were always enabled, so the subjects drove with either a 2 DOF system or a 3 DOF system. When the roll DOF was disabled, the camera platform was always positioned such that it was horizontal (i.e., a roll angle of 0º) relative to the car. In the stereo view mode, both cameras were operational. In the mono view mode, the left side camera was turned off and the image of the right side camera was send to both displays of the HMD, so that both eyes viewed the same image (i.e., a bi-ocular display system). The combination of these two manipulations resulted in four experimental conditions with the head-slaved camera system: 1) 2 DOF with mono view, 2) 2 DOF with stereo view, 3) 3 DOF with mono view, and 4) 3 DOF with stereo view.

In addition, the subjects drove in two direct view conditions. In one condition, the subjects drove with view restricting goggles that limited their instantaneous FOV to 45º (H) × 35º (V). This FOV approximated the instantaneous FOV with the head-slaved system. In the other condition, no view restrictions were imposed (i.e., normal driving). These two conditions can be seen as baseline conditions for motion sickness incidence during driving.

Design

Each subject performed the driving task in all experimental conditions (i.e., a within-subject design). Each subject drove on two separate days, with the 2 DOF conditions always on a separate day from the 3 DOF conditions. This was done to avoid possible transfer of motion sickness symptoms between these two conditions. Due to scheduling restrictions, this was not possible for the mono and stereo view conditions. Each day consisted of four conditions: the two conditions with direct view (one with the FOV-restricting

goggles and one without) and the two conditions (mono view or stereo view) in either the 2 DOF or the 3 DOF set-up of the camera platform. The subjects always started in a direct view condition, and then drove in one of the conditions with the head-slaved system. They subsequently drove in the second direct view condition and finished the day in the remaining condition with the head-slaved system. Thus a direct view condition always preceded a condition with the head-slaved camera system. Under the assumption that the direct view conditions would not be very provocative for motion sickness, this was done to reduce any potential transfer effects between the HMD-system conditions on a single day. Each condition lasted approximately 20 minutes, including the 10 minutes of free driving in the beginning of each condition, .

Six of the subjects started in the 2 DOF conditions, with three subjects starting with mono view and three subjects starting with stereo view. This also applied to the six subjects that started in the 3 DOF conditions. On the second day, the order of the conditions with respect to mono or stereo view was reversed for each subject. This also applied to the two direct view conditions: subjects that started in the FOV-restricted condition on the first day, started in the no-restriction condition on the second day, and vice versa.

Upon completion of the experimental task in each condition, the subjects were asked, among others, to fill in a modified version of the motion sickness questionnaire (MSQ). This modified MSQ included a 4-point scale for several questions, making it possible to derive simulator sickness questionnaire (SSQ) scores from it (Kennedy, Lane, Berbaum & Lilienthal, 1993). We used the SSQ total score, because our head-slaved camera system has more in common with a simulator than with the real world (e.g., degraded quality of the visual information, delays in the presentation of the visual images, etc.).

Statistical analysis

The SSQ total scores collected in the conditions with the head-slaved camera system were analysed with a repeated measures analysis of variance (ANOVA) with two independent variables: Roll feedback (present or absent) and View condition (mono view or stereo view). Regarding the first independent variable, roll feedback was present in the 3 DOF conditions, and it was absent in the 2 DOF conditions. The SSQ total scores for the direct view conditions were analysed separately, by means of an ANOVA with a single independent variable with 2 levels (unrestricted view or restricted view). In a subsequent analysis, the SSQ scores from the conditions with the head-slaved camera system and from the direct view conditions were analysed together. Data from non-significant effects in the previous analyses would be pooled for this comparison. Therefore, the specific statistical design for this ANOVA is presented in the Results section. When applicable, significant effects were analysed further with post-hoc Tukey tests. All analyses were performed with α set at .05.

RESULTS

The ANOVA on the SSQ scores in the head-slaved camera conditions showed a trend for a main effect of Roll feedback [$F(1,11)=4.60$, $p<.056$]. No main or interaction effects of View were observed, suggesting that the use of stereo images did not result in more, or less, motion sickness symptoms than the use of mono view. We therefore pooled the data regarding the viewing conditions in each DOF condition. The data in the direct view conditions were also pooled, because no significant difference was observed between the two types of baseline conditions (i.e., SSQ total scores of 2.5 and 3.2 for the unrestricted condition and the restricted-FOV condition, respectively).

The resulting pooled data were subsequently entered in a repeated measures ANOVA with Viewing system as a single independent variable with 3 levels (2 DOF, 3 DOF and direct view). The results showed a significant effect for Viewing system [$F(2,22)=8.56$, $p<.01$]. A post-hoc Tukey test indicated significant differences between the 2 DOF and 3 DOF conditions and between the 2 DOF and the direct view conditions ($p<.05$). The average SSQ total score was 17.7 in the 2 DOF condition, 8.4 in the 3 DOF condition, and 2.9 in the direct view condition. These results are shown in Figure 3. It also shows a qualitative description of the SSQ total score, based on simulator sickness research, as an indication for the severity of the reported sickness symptoms (Stanney, Kennedy & Drexler, 1997).
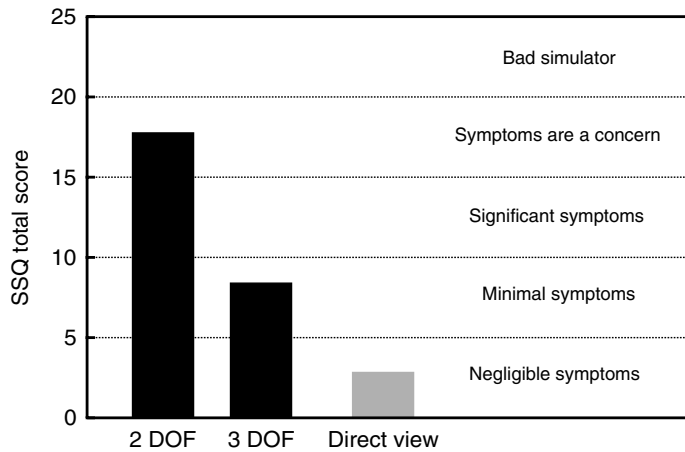
Figure 3. The average SSQ total score for the 2 DOF and 3 DOF conditions (black bars) and for direct view (grey bar). The verbal qualification of the SSQ total scores is taken from Stanney et al. (1997).

DISCUSSION

The results of the experiment clearly showed that visual feedback on head roll with the head-slaved system reduces motion sickness incidence. When visual feedback on head roll was present, substantially less motion sickness symptoms (as measured by the SSQ total score) were reported, than when such visual feedback was absent. This is in line with the results of Craig et al. (2000) regarding motion sickness reports with a head-slaved camera system for helicopter flying. Thus, enabling head-slaved roll motion of a camera platform is beneficial for the physical comfort of the operator.

However, there were still symptoms of motion sickness reported when feedback on head roll was present. This is reflected in the average SSQ total score in those conditions (i.e., a score of 8.4). This indicates that other characteristics of the head-slaved camera system, such as the inherent delays, also contributed to the observed motion sickness, but to a smaller extend than the absence of roll feedback. Therefore, research aimed at identifying these characteristics and their impact on motion sickness remains necessary. Please note that the absence of a statistical difference between the SSQ scores of the 3 DOF and direct view conditions should not be interpreted as indicating that there is *no* difference at all between these conditions. The power of the study may not have been high enough to detect significant differences between these conditions, since only twelve subjects were tested. Although it should also be noted that the power was large enough to detect differences between the 2 DOF and 3 DOF conditions.

The present experiment did not show an effect of stereo view on motion sickness, indicating that mono view and stereo view contributed equally to motion sickness. Again, this absence of a significant result does not necessarily mean that stereo view has *no* effect at all on motion sickness. Therefore, we can only conclude that stereo view certainly has less influence on motion sickness than the absence of head roll in the system.

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