DEPTH PERCEPTION IN DRIVING SIMULATORS

Observer-produced motion parallax, how it affects car drivers’ position and perceived presence

Lisa Palmqvist
This study was done in collaboration with the Swedish National Road and Transport Research Institute (VTI). VTI is an independent research institute that contributes to the knowledge within the domains of infrastructure, traffic and transport and is world leading in research and development of driving simulators (VTI, n.d.). The author wants to thank Jonas Andersson Hultgren, Anne Bolling and Pia Lindström at VTI for all the help and support that made this study possible.

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Driving simulators of today are lacking the full third visual dimension. This makes comparing driving simulators with driving in real life problematic. Thus it is important to improve the simulators' validity. The present study investigated whether the depth cue observer-produced motion parallax (Obs-PMP) affects drivers' performance and perception of presence. Twenty-two participants (11 males and 11 females) drove in a driving simulator with and without Obs-PMP. An experiment with two scenarios was conducted, in which one scenario took place in an urban environment and one in a rural environment. Distance estimation, judgments of speed and perceived virtual presence was investigated. An effect of Obs-PMP on lateral positioning of the car just before an overtaking and of scenario on head movement was found. This suggests that Obs-PMP affects driver's performance in driving simulators and motivates further research on the area, e.g. comparing simulators with real life scenarios.


Driving simulators are frequently used in traffic research in order to study various traffic scenarios with related traffic phenomena (e.g. Anund, Kecklund, Vadeby, Hjälmdahl, & Akerstedt, 2008; Caird & Hancock, 1994; Hallvig et al., 2013; Kircher & Ahlstrom, 2012). Compared with real driving, the simulator facilitates control and manipulation of the different variables and provides a safer environment for the participants than driving on a real road (Hallvig et al., 2013; Keshavarz & Hecht, 2012). It has been shown that simulator training is more efficient than conventional ways of learning, such as using text books and lectures performed in classrooms (Lombard & Ditton, 1997). The current view of the virtual environment (VE) is presented with a two-dimensional projection of the visual scene. The lack of some of the natural depth information observed in a real environment, limits the perception of depth when presenting the VE to the driver (Andersson Hultgren, Blissing, & Jansson, 2012). Although the simulations are compelling, the driver in the simulator will not get the richness of depth information that exists in a real life driving situation.

In order to get a three-dimensional percept, the brain uses multiple sources of information (hereafter referred to as "cues") (Gibson, 1950). The brain takes advantage of the physiological state of the eyes being approximately six inches apart on the human head, which is the basis for binocular cues. For example, this causes the observation of a nearby object to be projected with two slightly
different images on the retina as result of the two slightly different viewing angles. When these two images are merged in the striate cortex, the brain interprets the discrepancy (the binocular disparity) of the two images as a cue for depth. Thus two objects at different distances from the observer will have different amounts of such binocular disparity that signals their different locations in depth (Gibson). Ocular convergence is another binocular cue of depth. The binocular disparity in stereopsis, only works on objects that are relatively close to the observer, approximately within 30 m (Cutting & Vishton, 1995; Kemeny & Panerai, 2003). In order to perceive depth at longer distances, monocular cues (that does not require both eyes) are used. Examples of these cues are (1) differences in shadows and light on the object, (2) objects occluding or hiding one another (occlusion), (3) linear perspective, (4) relative size of similar objects on different distances, (5) the accommodation of the lens of the eye, (6) aerial perspective, (7) loss of detail with distance and (8) the relative motion of objects, also referred to as motion perspective or motion parallax (Gibson). Rigid objects (attached to the ground) at different distances from the observer will be perceived to move differently in relation to each other. This differential motion of the objects, arising when an observer fixes his or her gaze, is called motion parallax or optical flow (Kemeny & Panerai).

There are two components of motion parallax. One component is the object-produced motion parallax (Obj-PMP) which is when objects in the environment moves across the retina as a function of distance from the observer. Objects that are far away from the observer will be perceived to move slower than objects of the same speed close to the observer. Another component is that the observer can induce motion parallax by moving his or her head, which is called observer-produced motion parallax (Obs-PMP). The main difference between Obj-PMP and Obs-PMP is that in Obj-PMP the observer does not have to produce movement to get motion parallax information. In Obs-PMP binocular disparity works in a similar way as in stereopsis, the two images will differ on the two retinas when the head is moved sideways. For example, when an observer moves his or her head from left to right, the motion of closer objects will appear to be greater than the motion of objects farther away (Gibson, 1950). The same effect is achieved when an observer sits on a train or any other transportation, but without him or her having to move their head or changing gaze, this is Obj-PMP. The Obj-PMP is already implemented in many VEs, but the Obs-PMP is not. A way to introduce a more realistic perception in the VE of a driving simulator is to implement Obs-PMP so that it correlates with head movements of the driver. The simulator would register the position of the head and change the presentation of the environment in accordance with the position of the head. This should enhance the perception of depth (Rogers & Graham, 1979).

Kemeny and Panerai (2003) raised the question whether introducing motion parallax from the driver’s head movements can be crucial for estimating depth when driving in a simulator. The role of motion parallax has not yet been satisfactorily examined. The two components of motion parallax could be integrated to yield potential benefits in terms of the perception of distance, speed judgment and virtual presence. Adding cues available to the observer on the display
increases the information given to the observer and would in turn increase the consistency and accuracy with which the judgments of depth are made (Cutting & Vishton, 1995). Whereas Obs-PMP cues would work well on objects close to the observer, an important research question is whether the Obs-PMP also can affect perception of more distal information and driver performance (e.g. Kemeny & Panerai, 2003).

Cutting (1997) reviewed research on the just noticeable difference (JND) of depth and he concluded that in relative motion perspective, motion parallax, the JND differs depending on how fast the observer moves his or her head and whether the observer is in a (fast) moving vehicle. Cutting argued that the motion perspective is most at use within 1.5 to about 30 m to the observer, but insinuated that these distances can change if the observer is in motion. Cutting (1997), Kemeny and Panerai (2003) point out that further research on this issue is necessary. Thus, it is essential to accurately perceive speed and distance when driving. Situations such as overtaking, braking and obstacle avoidance are maneuvered with access to this information (Kemeny & Panerai, 2003). Kemeny and Panerai contend that humans, in a natural setting, use different visual cues for determining speed and distance, cues such as those used for depth perception.

Whether the results of the experiments in simulators can be generalized to driving on a real road has been challenged (Hallvig et al., 2013; Kemeny & Panerai, 2003). It is common to divide validity in a driving simulation into absolute validity and relative validity. Absolute validity is defined as the possibility to observe the exact same, absolute, behavior in the simulator. Relative validity is defined as the observation of relatively similar behaviors. Absolute validity of the driving simulator has been observed in route-choice behavior whereas relative validity has been observed in speed- and lateral-control behavior (Godley, Triggs, & Fildes, 2001; Kaptein, Theeuwes, & Van Der Horst, 1996). Drivers tend to drive faster on a straight road, showing that speed estimation in simulators have poor absolute validity but have been reported as obtaining good relative validity. Relative behavior has also been obtained in lateral positioning on the road (Jamson, 2001). Witmer and Singer (1998) state that the effectiveness of simulators and other VEs correlates with drivers’ perceived presence.

There have been many definitions of presence. Lombard and Ditton (1997) sum up some of these, and present six different concepts from previous research. The first being the presence as social richness, which is to what extent a medium in the VE is perceived as sociable, personal, intimate, warm or sensitive. Second, presence as realism divides realism into social realism and perceptual realism. Social realism refers to the extent to which the VE is portrayed to be plausible to happen in a real world scenario. Perceptual realism is to what extent the event looks realistic as it would appear in real life. Third, Lombard and Ditton write about presence of transportation. This, in short, is how well subjects feel like they are being transported into the VE and feel like the VE is the real world. The forth concept is presence as immersion. A subject that is completely immersed in the VE has all their senses (e.g. hearing, sight, touch and balance) engaged in the VE and only perceives what is happening in the VE. The final concepts are presence as social actor within
Medium and presence as medium as social actor. Both of these refer to how well a subject can interact with the VE and the mediums in it. The central idea in all of the concepts above is to achieve a “perceptual illusion of nonmediation” (Lombard & Ditton, 1997) or the sense of being there. (Note that the illusion of being present in the VE is merely an illusion and needs to be separated by having a delusion). Lombard and Ditton call out for research that can determine and standardize the variables thought to encourage presence.

The most frequently used method for measuring presence in VE is to use a questionnaire. The questionnaires have been shown to be useful in measuring presence in VEs (Regenbrecht, Schubert, & Friedmann, 1998). Subjective measured presence is claimed to be the basic essential measurement (Sheridan 1992). Witmer and Singer (1998) developed a questionnaire that is intended to measure the driver’s virtual presence. Increased presence correlates with increased enjoyment, involvement and task performance. Thereby, increased presence is central in order to get the VEs useful and profitable (Lombard & Ditton, 1997). The validity of the questionnaire has been disputed whether it is actually measuring the presence experienced by the subject (Usoh, Catena, Arman, & Slater, 2000). As an answer to this, Witmer, Jerome and Singer (2005) evaluated their questionnaire and argued that it is a reliable and valid method for measuring presence. Another way of measuring presence is to measure physiological responses from the subject, which has proven to be an effective method (Meehan, Insko, Whitton, & Brooks 2002). However, it can also be considered that measuring presence physiologically is time demanding, expensive and not always reliable (Regenbrecht, et al.). In the present study, the focus was on performance and experience of virtual presence, as opposed to physiological responses as a measurement of presence.

The aim of the present study was to conduct an experiment to investigate whether Obs-PMP in a driving simulator can have an effect on the driver’s performance and perceived presence in the VE. The effect of Obs-PMP was tested in a situation where the participants were driving in two conditions, one condition with the Obs-PMP, and the other without. It was also examined how realistic the two different VEs were perceived by the driver using the questionnaire Witmer et al. (2005) developed. This questionnaire was answered orally by the driver immediately after driving in the simulator in each Obs-PMP condition. In addition it was studied whether Obs-PMP affects the driver’s performance in terms of speed and distance judgment. As a way to measure to what extent the Obs-PMP was used by the driver, the car position on the road and head movement was recorded.

Andersson Hultgren et al. (2012) found no significant effects, on lateral positioning of the car, speed judgment and head movement of the driver when driving with the condition motion parallax as a depth cue. Due to low image resolution and lack of restriction on the driver’s position when overtaking, the participants might not have realized that the cue was available. This could have resulted in that they did not use the depth cue to gain more information in the field-of-view, presented on the simulator display. To avoid this, two different scenarios were included in the present study. One was conducted in an urban environment with a visually complex scene that would make the driver encouraged to change his or her head...
position in order to gain extra information. A second scenario took place on a rural road with a less rich environment (e.g. no crossroads, pedestrian crossings, etc.) The Obs-PMP implemented in the experiment was expected to yield a higher fidelity in the simulator and thus lead to a higher presence and more accurate speed- and distance perception for the driver.

Method

Participants
Twenty-two drivers participated, of which 11 were males and 11 were females. The age of the drivers varied from 23 to 52 years (M=32.14 SD=9.44). All participants were blinded with respect to the purpose of the study. The participants were paid 300 SEK for participating and were recruited via VTI database of volunteers. Among the included participants, 31.8 % (7 participants) had never driven the simulator before and 68.2 % (14 participants) had been driving the simulator at one or more earlier occasions; 31.8 % (7 participants) had driven one time before, 9.1 % (2 participants) had driven 2-3, times, and 22.7% (5 participants) had driven more than 3 times.

Design
A within-group design was adopted. Previous research has indicated that individual’s prior representation system could influence the sense of presence in a VE (Slater, Usoh, & Steed, 1994). To avoid the risk that the order of driving conditions would make a difference, the presentation order of Obs-PMP was counterbalanced: half of the participants drove with the Obs-PMP feed-back followed by the same scenario without the feed-back, and the other half in the reverse order.

Material
  Driving simulator
The simulator III (Figure 1) that was inaugurated in 2004 at VTI’s premises was used. A Saab 9-3 cabin was placed in the simulator and manual transmission was used. The simulator’s motion function consisted of three parts: linear motion, a tilt function and a vibration table. The maximum acceleration of the simulator was 0.8 g. The linear movement was used to simulate lateral forces. Acceleration and braking maneuvers were simulated with the tilt function. A vibrating table was used to simulate friction between the car's wheels and the road. The cabin itself could tilt up to three degrees and bank up to six degrees, and was also able to move relative to the screen 6 cm vertically and longitudinally. The presentation of the visual stimuli was made possible by computer generated graphics at a resolution of 2.8 arc-minute/line pairs horizontally and 2.7 arc-minute/line pairs vertically. The simulator had a horizontal field-of-view of 120 degrees on a curved projection screen. Three smaller LCD-screens were mounted to simulate the rear-view mirrors. In order to simulate noise from tires and engines, the simulator contained a surround sound system.
Figure 1. Motion platform of the simulator used in this experiment. The arrows represent the different ways for the simulator to move, and thus simulate different forces and tactile feed-back such as acceleration, retardation, and forces when turning and friction of the road. Down to the left is the control station where the monitor was seated.

The general software used for the simulator is based on Open Source, and the software producing the Obs-PMP effect was developed by Andersson Hultgren et al. (2012). The Obs-PMP software is based on cameras detecting the drivers’ head movements, which changes the projection on the screen so that the surroundings always are shown from the driver’s point of view.

Presence questionnaire
In Scenario 1 three questions were asked, based on Slater, McCarthy and Maringelli (1998), to be rated on a 7-point scale (see Table 1). Anything the driver said or commented on was noted. The Presence Questionnaire (PQ) developed by Witmer and Singer (2005) was used to evaluate the degree to which subjects experience virtual presence. The PQ use a 7-point scale and was translated into Swedish. Twelve of the in total 32 questions were included. The questions were chosen so that they included at least one of the different subscales (involvement, adaptation/immersion, interface quality and visual fidelity) listed by Witmer and Singer. This questionnaire was used in Scenario 2.
Table 1. The questions asked after training session, first condition in Scenario 1 and second condition in Scenario 1

<table>
<thead>
<tr>
<th>Question</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. During the time of the experience, which was strongest on the whole, your sense of being in the real world of the laboratory, or being in the virtual environment on the road</td>
<td>I had a stronger sense of being in...</td>
</tr>
<tr>
<td></td>
<td>1. the real world ...</td>
</tr>
<tr>
<td></td>
<td>7. the virtual reality of the road</td>
</tr>
<tr>
<td>2. How comfortable did you feel doing the overtaking maneuver?</td>
<td>The maneuver was...</td>
</tr>
<tr>
<td></td>
<td>1. very easy to perform ...</td>
</tr>
<tr>
<td></td>
<td>7. very hard to perform</td>
</tr>
<tr>
<td>3. (Only second time) Which of the two different overtaking maneuvers did you prefer?</td>
<td>I preferred...</td>
</tr>
<tr>
<td></td>
<td>1. I preferred the 1st...</td>
</tr>
<tr>
<td></td>
<td>2. I preferred the 2nd.</td>
</tr>
</tbody>
</table>

Perceived presence and performance measures

Perceived presence was measured with responses to questions rated on a 7-point scale. The responses from a subject were summed up to a total score. This total score was then divided by the number of questions in the test, which was used as an overall mean of perceived presence for the questionnaire. Head movement was defined as the maximum value relative to a base-line. Direction of movement (left or right) was separated by positive and negative values. Lateral position was measured in relation to the mid-line being the zero position, and defined as the position where the driver initiated the overtaking. Initiated overtaking was defined as the point where (from the steering wheel angle signal) the last local maximum above 3° and the last local minimum below 1° was found. The same point was used for measuring distance to the truck in front. These variables were the same for both scenarios. In scenario 2, three variables were added; estimated distance to truck in front, being the two values reported from the driver (the estimated 30 and 60 m) by pressing a button on the wheel, judged speed, also being reported from the driver by pressing the button, time to collision with oncoming traffic, was measured when driver initiated overtaking. Time to collision indicating the size of chosen gap for overtaking, see Table 2.

Simulator training

Before the experiment started, the drivers were given approximately 10 min of training in the simulator in order to get experienced with driving in the VE of the simulator. The training consisted of driving in an urban environment and a rural environment with a speed limit of 50 km/h and 70 km/h, respectively. After a couple of min in the rural environment a slow driving truck (50 km/h) appeared ahead, driving in the same direction. The driver was instructed to estimate when he/she was at 60 m and 30 m behind the truck in front of them by pressing a button placed on the right hand side of the steering wheel. The driver was then
instructed to conduct an overtaking maneuver. A second truck appeared and the procedure was repeated. The driver received oral feed-back on the estimated distance behind the truck in order to use as a reference during the experiment.

Table 2. Dependent variables measured in the two scenarios.

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived presence</td>
<td>Perceived presence</td>
</tr>
<tr>
<td>Head movement</td>
<td>Head movement</td>
</tr>
<tr>
<td>Distance to parked truck</td>
<td>Longitudinal position before overtaking</td>
</tr>
<tr>
<td>Lateral position before overtaking</td>
<td>Lateral position before overtaking</td>
</tr>
<tr>
<td></td>
<td>Estimated distance to truck in front</td>
</tr>
<tr>
<td></td>
<td>Speed judgment (three different)</td>
</tr>
<tr>
<td></td>
<td>Time to collision</td>
</tr>
</tbody>
</table>

Scenario 1 – Urban environment
Driving in an urban environment included performing an overtaking maneuver. The implementation of Obs-PMP provided the driver with more depth cues when moving his or her head. The purpose of Scenario 1 was to place the driver in a situation in which it would be an obvious information gain if the driver moved his or her head, see Figure 2. This was done by placing the truck just after a crossroad followed by a pedestrian crossing. The more complex environment provided more optical cues at lower or no speed, thought to enhance the effect of the motion parallax.

The driver drove along a straight road with a speed-limit of 50 km/h and was instructed to drive as if it was a real-life situation and to overtake any obstacles that were encountered. After 835 m a large truck standing still appeared on the right-hand side of the street, see Figure 2. The truck was parked and was blocking the driver’s field-of-view. Oncoming traffic was consistent and the driver had to stand still and wait for a period of time. After standing still for approximately 20 s, the oncoming traffic ceased and the driver could do an overtaking maneuver and pass the site. The entire procedure was repeated with a balanced trial of Obs-PMP condition. After each driving condition, including the training, the driver was asked the three questions based on Slater (1998), see Table 1.
In Scenario 2, the driver was instructed to estimate distance to the vehicle ahead and to do multiple overtaking maneuvers. The driver also conducted a speed judgment test and answered the PQ. The setting was a rural road with upright objects such as trees and side posts and consistent oncoming traffic with varying gaps between vehicles.

The purpose of Scenario 2 was to study whether the driver would in any way be affected by the use of Obs-PMP in terms of estimating distance to oncoming vehicles and positioning of the own vehicle on the road. It was also investigated as to what extent the driver's presence and speed- and distance perception in the simulator was affected. This was done by the speed judgment test in the end of Scenario 2, and by instructing the driver to report when he/she thought to be 30 and 60 m, respectively, behind the truck in front of him/her.

The drivers drove along a straight road with a speed-limit of 70 km/h. After driving 500 m a truck appeared on the road with a speed of 50 km/h, see Figure 3. The driver was instructed to estimate when the own vehicle was behind the truck.
at a distance of 60 m and then 30 m. When the driver thought the requested position was achieved, he/she pressed a button on the steering wheel. The driver then conducted an over-taking maneuver. Oncoming traffic was driving with 100, 400, 250 and 600 m gaps between vehicles. The driver was instructed to overtake the truck when he or she thought it to be appropriate and safe. A new truck appeared 300 m after the last truck and the procedure was repeated until 16 distance estimations and 8 overtaking maneuvers had been done.

The speedometer in the simulator was then turned off and a text instructing the driver to try to hold a speed of 50 km/h showed up on the screen, see Figure 4. When the driver thought he/she held the correct speed he/she pressed a button on the steering wheel. Two more speeds, one of 90 km/h and one of 50 km/h were shown on the screen before the driver was instructed to stop the car. The driver then answered the PQ orally. The entire procedure was repeated with a balanced trial of Obs-PMP condition.

![Figure 4](image_url)

Figure 4. Scene from the speed judgment test. The text on the screen is instructing the driver to keep 50 km/h.

Results

Out of the 22 participating drivers, data were collected from 18 drivers. One driver had to abort the experiment due to simulator sickness during the training session. Another driver was excluded due to technical problems with the head-tracking equipment such that the display could not yield an Obs-PMP feed-back. A third driver was excluded due to technical problems with the driving simulator, and a forth driver's data were not recorded. For the rest of the 18 drivers data were successfully collected.

Results from dependent t-tests (two-tailed) of Obs-PMP conditions showed no significant effect on reported presence in Scenario 1, \( t(17)=-1.65, p=.117 \), and Scenario 2, \( t(17)=0.67, p=.514 \). No effects were found on distance to the parked truck in Scenario 1, \( t(17)=-.74, p=.468 \), and time to collision when initiating
overtaking in Scenario 2, \(t(17)=-1.82, \ p=.919\). A tendency of an effect on the longitudinal position to the truck at the time of overtaking was found in Scenario 2, \(t(17)=-1.94, \ p=.069\). Means and SD are shown in Table 3.

Table 3. Mean (SD) of drivers judged speed, estimated differences and longitudinal position in Scenario 2, with and without Obs-PMP.

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>With Obs-PMP</th>
<th>Without Obs-PMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>(first)</td>
<td>(second)</td>
<td>(third)</td>
</tr>
<tr>
<td>50 km/h</td>
<td>50.6(6.3)</td>
<td>81.3(10.6)</td>
</tr>
<tr>
<td>90 km/h</td>
<td>50.7(9.2)</td>
<td>62.0(15.8)</td>
</tr>
</tbody>
</table>

Means and standard errors of lateral position and head movement are displayed in Table 4. Two way repeated measures ANOVAs with scenario with two levels (Scenarios 1 and 2) and Obs-PMP with two levels (OFF and ON) were conducted. See Table 3. For the lateral position, there was no significant effects of scenario, \(F(1,17)=.709, \ p=.411\), \(\eta^2=.017\), and scenario \times\ Obs-PMP, \(F(1,17)=.892, \ p=.358\), \(\eta^2=.006\). However the main effect of Obs-PMP was significant, \(F(1,17)=8.51, \ p=.010, \eta^2=.056\), see Figure 5.

![Figure 5](image-url) Means and std. errors for lateral position in both scenarios with and without Obs-PMP. There was a significant effect of Obs-PMP \((p<.05)\).

For the head movement, there were no significant effects of Obs-PMP, \(F(1,17)=1.96, \ p=.180\), \(\eta^2=.008\), and scenario \times\ Obs-PMP, \(F(1,17)=.535, \ p=.474\), \(\eta^2=.002\). However the main effect of scenario was significant, \(F(1,17)=11.3, \ p=.004\), \(\eta^2=.101\), see Figure 6. The means and standard deviations for the judged speed are shown in Table 3. A two way repeated measures ANOVA with judged speed with three levels (50 km/h, 90 km/h and 50 km/h) and Obs-PMP with two levels (OFF and ON) was conducted. There were no significant effects of Obs-PMP, \(F(1,18)=.076, \ p=.786\), and speed \times\ Obs-PMP, \(F(2,36)=1.30, \ p=.284\). The means and standard deviations for the estimated distances are shown in Table 3.
Figure 6. Means and std. errors for head movement in both scenarios with and without Obs-PMP. There was a significant effect of Scenario \( (p < .05) \).

A two-way repeated measures ANOVA with distance behind the truck with two levels (30 m and 60 m) and Obs-PMP with two levels (OFF and ON) was conducted on the distance estimations (to the truck in front of them). No significant effects were found of Obs-PMP, \( F(1,17)=.830, \ p=.375 \), and distance × Obs-PMP, \( F(1,17)=.025, \ p=.876 \).

Table 4. Means (std. errors) listed for lateral position and head movements in both scenarios and with or without Obs-PMP. F-values, degrees of freedom, and p-value from two way ANOVAs revealed a significant effect \( (p < .05) \) of Obs-PMP on lateral position and of scenario on head movement.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Lateral Position</th>
<th>Head Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>117.3 (8.0)</td>
<td>12.3 (1.2)</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>110.6 (3.7)</td>
<td>9.4 (0.8)</td>
</tr>
<tr>
<td>With Obs-PMP</td>
<td>119.1 (3.6)</td>
<td>11.1 (1.0)</td>
</tr>
<tr>
<td>Without Obs-PMP</td>
<td>108.8 (6.3)</td>
<td>11.0 (0.9)</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\text{Scenario} & : F(1,17)=.709, \ p=.411, \ \eta^2=.017 & F(1,17)=11.3, \ p=.004*, \ \eta^2=.101 \\
\text{Obs-PMP} & : F(1,17)=8.59, \ p=.010*, \ \eta^2=.056 & F(1,17)=1.96, \ p=.180, \ \eta^2=.008 \\
\text{Scenario} \times \text{Obs-PMP} & : F(1,17)=.892, \ p=.358, \ \eta^2=.006 & F(1,17)=.535, \ p=.474, \ \eta^2=.002 \\
\end{align*}
\]

* \( p < .05 \)

Discussion

Driving simulators are used in research to investigate different traffic scenarios and in training as a complement to conventional teaching. It is of great importance to improve the fidelity in the simulators in order to get a simulator that is comparable with real life traffic scenarios. One way of improving the validity of the simulator is to improve the perceived depth on the projected screen by
introducing Obs-PMP as feedback of the driver's head movements (Kemeny and Panerai, 2003). Witmer and Singer (1998) have stated that the perceived presence improves the effectiveness of the simulator. The present study investigated if the introduction of Obs-PMP in a driving simulator affects the driver's behavior and perceived presence and if the Obs-PMP is used by the driver when performing different overtaking maneuvers.

An effect of scenario on head movement was found, but no effect of Obs-PMP on head-movement. There was an effect of Obs-PMP in the lateral position just before the overtaking maneuver, indicating that the driver did not have to place the car as close to the mid-line in order to see in front of the blocking truck when Obs-PMP was on. No evidence was found of Obs-PMP on the drivers’ perceived presence. The longitudinal position in Scenario 1 did not yield any significant differences in the two conditions. However, a tendency to an effect was found on the longitudinal position to the truck at the time of overtaking in Scenario 2. No effect on distance estimation or speed perception was found, but the drivers were very good at estimating the speed 50 km/h.

The drivers reported that the circumstances in Scenario 1, when the driver had to overtake a truck standing still, was very uncomfortable. Several drivers said this was due to the inconvenient placement of the truck. One of the reasons why the design of Scenario 1 was chosen was to try to get the driver to move his/her head more and this increase of movement was in fact observed. The effect of Obs-PMP on scenario shows that the drivers did move their head more in Scenario 1, in order to take in a different viewing angle.

The effect of Obs-PMP on lateral position indicates that the driver did not have to place the car as close to the mid-line in order to see in front of the blocking truck when they received the Obs-PMP feedback. The effect in both scenarios shows that it could be a consistent behavioral change in the drivers’ positioning on the road when conducting an overtaking maneuver.

There can be several reasons for the lack of perceived presence; one being that the Obs-PMP may not be an important cue for the experience of presence in a simulator. Other reasons can be the lack of reliability of the questionnaire as a measure for presence. Many drivers reported maximum score for several questions, e.g. "How natural did your interactions with the environment seem?" and "How much did your experience in the virtual environment seem consistent with your real world experiences?". This roof effect can be interpreted either as the questionnaire scale having a too small range or that the drivers did not fully understand the meaning of the questions. A top score would mean that it was almost impossible to tell the difference between the VE and the real environment. However, it might be also that the simulation is so good that it leaves not much left for improvement. Virtual presence is said to be a very important component when acting in a VE (Witmer & Singer, 1998). If the driver is not virtually present the risk that the results will not be valid in a real life comparison is great. It is also of
importance that the drivers try their best to drive the way they would in a real life situation.

The longitudinal position in Scenario 1 was not expected to be different between conditions since the drivers were "forced" to park close to the parked truck due to the way the environment was built (there was a cross-road and a pedestrian crossing just behind, preventing the drivers to stop their car too far away).

There was no effect of Obs-PMP on distance perception in terms of estimating distance to the truck ahead of their vehicle. This indicates that the problem with drivers’ difficulty to estimate distances in simulators will not be solved with implementing Obs-PMP, at least not in the way it was tested. The distance estimating test was introduced to test Obs-PMP’s impact on distance estimation but also in order to try to keep the drivers from overtaking the truck from too far of a distance. And in turn, reduce the effect of Obs-PMP detectable by the driver.

Drivers’ performance on judging their speed did not differ in the two conditions. However, they were very good at estimating driving at 50 km/h (Table 4). This is probably due to the speed limit of 50 km/h in Scenario 1; the driver had already been experiencing the requested speed and had an accurate idea of how to drive at 50km/h. On the other hand, the drivers were consistently over-estimating their own speed when told to drive at 90 km/h. The reason for the miscalculation compared to how well they performed at 50 km/h is most probably due to the fact that the drivers had not been driving at this high speed during a longer period of time before. This study does not provide evidence for drivers’ tendency to underestimate their own speed. On the contrary, results imply that drivers’ have a tendency to overestimate their own speed, driving on a straight road. Absolute validity can be achieved in a driving simulator when instructed to drive in a familiar speed. The scenario in which the driver is driving and the tasks performed in a training situation, is crucial in order to estimate speed in a simulator.

The change in lateral position implies that the driver is taking advantage of Obs-PMP when positioning the car on the road. The results show that the drivers also have an intrinsic reflex to move the head when placed in a situation with poor overview of the scenario in front of them, even sitting in a simulator. Implementation of Obs-PMP is thought to increase the validity of the simulator, by how much has to be further investigated. Previous research has stated that relative validity is obtained in lateral positioning in the driving simulator (Jamson, 2001). Introducing Obs-PMP in driving simulators could perhaps be the answer to turn the simulators relative validity to absolute validity.

It is not satisfactorily explained how the driver could see farther in front the truck since no effect on head movement was found. The reason for this may be due to the chosen head tracking measurement and how the movements were computed. The software controlling Obs-PMP was sometimes not reliable when tracking the driver’s head movement, and could have resulted in missing data. Some of the drivers reported flickering, which was a direct result of the lost head tracking. As a
result the data may have shown reduced movement, but it is also possible that the chosen measure “maximum value relative a base-line” was not optimal. Possibly the proximity of alignment between the two different times series, containing information of head movements, with- and without Obs-PMP should have been analyzed in relation to each other, would have a better analysis. Further research is suggested on how to improve the head tracking equipment and measurement. Perhaps it would have been better to measure how much the projected visual information on the screen changed from time to time in order to measure the differences in the field-of-view for the driver.

A problem with driving simulator studies is that it is impossible to do a completely double-blind study since both the drivers and the leader knows that they are driving in a simulator and not on a real road. Several drivers reported that they were reminding themselves not to move their head, as they would have in a real life situation. In order to avoid this behavior it would have been necessary to tell the driver that the Obs-PMP cue was available. Doing so would impact the validity of the study. Drawing conclusions whether the Obs-PMP is used in real life could then not have been done. One driver reported taking greater risks when overtaking the trucks in the simulator. The reason for doing so was in order to see “how the oncoming traffic would behave”. This type of behavior is highly unwanted since the driver obviously is not driving as he or she would drive in a real life situation. This problem is very hard to overcome, but increasing simulator fidelity is thought to decrease these types of unwanted behaviors.

No effect was found on the longitudinal position to the truck at the time of overtaking in Scenario 2. Even though, it is interesting to address that the driver tended to place the car closer to the truck in front, when doing the take overs when Obs-PMP was used. The reasons for not being a significant effect could be many; it is possible that the task was not complex enough or that Obs-PMP does not affect the drivers’ behavior in terms of longitudinal positioning. It would have been interesting to investigate whether it is possible to detect a difference in the longitudinal positioning in another driving task, such as a car-following task or similar.

The majority of the drivers reported preferring the second time that they did the overtaking, no matter what condition they started with. This is most likely because they had practiced more and were more comfortable with the simulator experience. A longer and more varying training session could have delimited this problem. The validity of the present study is not influenced by this, since the design was balanced.

It has not been stated exactly how Obs-PMP affects the driver's behavior in the driving simulator. However, evidence has been found supporting the implementation of such Obs-PMP, meaning that it is adequate to use Obs-PMP as a depth cue in driving simulators. Although it is necessary to continue research to find differences in drivers’ behavior and to improve the technique that produces Obs-PMP in the simulator. In order to further improve the sensation of depth in
today's driving simulators the implementation of convergence, binocular disparities and accommodation may be useful for the driver to perceive a full three-dimensional VE. Cutting (1997) argues that if these cues are lacking, the observer will perceive a dual image *described* as a flat image representing a more complex and extensive, third dimensional layout. On the other hand, it is of great importance to investigate the different implementations of depth cues in the simulator as it could yield effects that are not wanted, e.g. simulator sickness or other unwanted effects.

The next step in evaluating Obs-PMP is to compare a driving simulation with real life driving to see if the absolute validity of the simulator can be strengthened. It is also important to test how long the training sessions should last so that no learning effect emerges. The presence questionnaires need to be validated and tested for how well perceived presence correlates with simulator fidelity. The present study found no effect of Obs-PMP in a driving simulator on the drivers' perception of presence in the VE and their speed and distance perception. On the other hand, there was an effect on the driver's lateral position when conducting an overtaking maneuver and the driver's use of head movements in different situations. However further research is needed in order to determine whether this is an effect that makes the simulator more or less of a valid tool for studying traffic behavior. In order to draw further conclusions on the positive or negative effects of implementing Obs-PMP in today's driving simulators, drivers' behavior in a simulator needs to be compared with a real car driving situation.
References


