Influence of visual output devices on speed perception in car simulators

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Abstract - *In traffic research simulators are an important tool for gaining knowledge in a safe and economical way. Nevertheless, there are some well-known shortcomings. One of them being the underestimation of speed in car simulators. But does speed perception vary across output devices? This paper presents a study where participants experienced overtaking scenarios with an Head-Mounted Display (HMD) and a monitor setup in otherwise identical car simulators. The collected data indicates that speed perception is indeed influenced by the output device.*

Keywords: *Keywords: Virtual reality, human-in-the-loop simulation, speed perception, driving simulator.*

1. Introduction & Related Work

In traffic simulation speed resembles a central parameter. The assessment of ones own speed as well as the speed of other participants is a crucial factor for the determination of appropriate behavior and therefore a safe user interaction - inside the simulator as well as in a real traffic scenario. Unfortunately, subjects tend to have major problems assessing speed in simulated Virtual Environment (VE)s (Banton, et al., 2005; Godley, Triggs, and Fildes, 2002; Hussain, et al., 2019; Löchtefeld, Krüger, and Gellersen, 2016; Wu, et al., 2017). This in fact could generate misjudgments and therefore critical scenarios that would otherwise not occur in real life. Reasons for this can be technical factors like display resolution, screen size, frame rate, latency, Field of View (FOV), spatial vision and display brightness (Fischer, Eriksson, and Oeltze, 2012; Jamson, 2000). Therefore, it is to assume that the visual output device may have a significant influence on speed perception (Hurwitz, Knodler, and Dulaski, 2005; Mallaro, et al., 2017; Pala, et al., 2021; Schneider, et al., 2022). Also, psychological constructs like *presence* may be interesting in this context since it enables subjects to act as if they are present in the VE. Moreover, the study takes *simulator sickness* into consideration, which negatively affects the subject and his or her evaluations in general (Kolasinski, 1995). Past simulator studies that targeted speed perception often concentrated on a single output device (Hurwitz, Knodler, and Dulaski, 2005; Hussain, et al., 2019). Few studies are comparing output devices concerning their ability to enable realistic speed perception. Also the existing studies (Blissing, Bruzelius, and Eriksson, 2022; Himmels, et al., 2023; Zöller, et al., 2019) do not focus on this particular aspect since they are looking into general driving tasks with the aspect of speed perception being only one facet. This study focuses specifically on the interaction between output device and speed perception to illustrate differences between commonly used setups.

2. Methodology

The two car simulators are identical systems, only using two different visualization devices. They are fixed-base systems with force feedback steering wheels and pedals. Furthermore, the simulators consist of a dashboard with a display for the speedometer (Fischer, et al., 2014; Rehm, 2023). The CarSim with display output uses three identically 65” Samsung GQ-65Q90R TV’s with a resolution of 3840 x 2160 p and a refresh rate of 60 Hz (Hifi-Regler, 2023). The displays are arranged in 90° angles and cover a FOV of 160°. Distance from gaze origin to front display measures ca. 100 cm (variable because of seating position and subject movement). Brightness, saturation and contrast were kept at default values. The CarSim with Virtual Reality (VR) output uses the *HTC Pro Eye*. The HMD has two 3,5” OLED displays with 1440 x 1600 pixels per eye (2880 x 1600 pixels combined), a refresh rate of 90 Hz and a 110° FOV (HTC VIVE, 2023). Distance from gaze origin to lenses varies between 2-4 cm (lens distance adjustable). Brightness, saturation and contrast were kept at default values. The integrated headphones were not used. Each test subject calibrated the device to fit his or her individual interpupillary distance.

The procedure started with a short training session followed by the *production method*, where the participants were asked to produce a certain speed. Afterwards the *estimation method* was carried out. This method comes in three conditions: *estimation-static*, *estimation-dynamic* and *estimation-dynamic-Head-up-Display (HUD)* which were carefully balanced over all participants to avoid order effects. In static condition subjects did not move, in dynamic condition they had a fixed forward velocity without being aware of the exact speed value whereas in the condition *estimation-dynamic-HUD* a speedometer displayed that information.

Test subjects were overtaken by five identical-looking vehicles. Overtaking speeds were 80/100/120/130 and 180 km/h. The order of estimation conditions as well as overtaking speeds were randomized.

The virtual environment consists of a 5 km long road with four lanes. Next to the roadway there are ditches on both sides and at a further distance, the scene is framed with 3 meter high noise barriers. The lanes are located at 0 NN and are designed so that they are all the same width, taking the lane markings into account.

32 subjects were tested (24 male, 8 female, 0 diverse). The average age was 33 years, with no person younger than 19 or older than 70. All participants had a car driver's license. The dependent variables for the study were speed perception, presence (measured by the Presence Questionnaire (PQ) Version 3.0 (Witmer, Jerome, and Singer, 2005)) and simulator sickness (measured with the Simulator Sickness Questionnaire (SSQ) (Robert S. Kennedy and Lilienthal, 1993)). The current PQ (2005) provides 29 questions. Question 2, 13, 17, 26, 27, 28 and 29 were removed since they confused subjects in pretested or posed an inadequate fit with the study's objectives. The SSQ was not adjusted.

3. Results

The data was processed in *Python*, *R* and *JASP*. A 95% credible interval was used for all analyses. To evaluate the speed perception in the different conditions a Linear Mixed Model (LMM) was used. The post-hoc analyses were p-value corrected with the *Tukey* method.

In order to evaluate how the speed of overtaking vehicles is perceived in the two simulators, an LMM analysis was conducted, in which the influence of the simulators and the overtaking speed on the deviation of speed perception was tested. The results show that the coefficient estimate for the relationship between actual overtaking speed and the deviation in guessed speed was $\beta = 0.6897 (SE = 0.0092)$. This means that on average each one-unit increase in the actual speed, the predicted estimate of the deviation from the guessed speed increased by 0.6897 units. This effect was highly significant $(t = 75.05, p<0.001)$. A significant interaction between simulator type and actual speed was found $(\beta = -0.0538, p<0.001)$. This suggests that the increase in deviation with speed was less pronounced in the *CarSimVR* condition than in the *CarSimDisplay* condition (Figure 1).

Further more it was evaluated how well participants were able to produce a given speed of 50 km/h. The results showed that the participants in both car simulators on average underestimate their own speed. The coefficient estimate for *CarSimDisplay* is 35.12, with a standard error of 2.62, the coefficient estimate for *CarSimVR* is 21.73, with a standard error of 2.59. In order to correct for the fact, that the deviations are naturally higher for higher speeds, the deviation was normalized by dividing it by the actual speed.

The results of the presence questionnaire were evaluated, with a particular focus on the feeling of presence depending on the type of simulator. Before conducting the analysis the groups were tested for a normal distribution. The *Shapiro-Wilk Test* indicated that the data is not normally distributed. Given the within-subject design, the non-parametric *Wilcoxon-Signed-Rank Test* was used. The results showed no significant differences in presence between the simulator conditions.

In order to evaluate the differences in the simulation sickness scores between the simulators, it was tested whether the data follows a normal distribution. The *Shapiro-Wilk Test* indicated that the data is not normally distributed. Therefore the non-parametric *Wilcoxon-Signed-Rank test* was chosen for the analysis. The results show that there is a significant difference between the simulators regarding the average simulation sickness score ($W = 113.500$, $z = 3.039$, $p = 0.003$). Simulation sickness was significantly higher in the *CarSimVR* condition ($M = 15.449$, $SD = 26.875$) compared to the *CarSimDisplay* condition ($M = 5.984$, $SD = 12.601$).

4. Discussion and Conclusion

The data suggests that the use of a HMD does indeed enhance the accuracy of speed assessments in comparison to the display condition, especially in the context of high overtaking speeds. This findings apply to static and dynamic conditions equally. Output devices didn't influence the feeling of presence in a significant way but had notable impact on simulator sickness scores, which were lower in display condition. Since the lowest speed was 80 km/h, the extrapolated data must be treated with caution, but based on the collected data it is to assume that the benefits of the HMD concerning accuracy decline with decreasing speed. Since at 80 km/h the difference across both simulators is rather small, future studies would benefit from more low speed measuring points. In summary, it was found that speeds are estimated differently in different simulators. It can be assumed that other traffic simulators like e.g. pedestrian or bike simulators are also effected, presumably even more since they vary broadly by design. This circumstance might affect multi-user-studies incorporating different kind of road users. A followup study will explore the impact of Geometrical Field of View (GFOV) adjustments. Moreover a new HMD with higher display resolution as well as more complex VEs will be introduced to further investigate the aspects of depth perception and motion parallax effects.

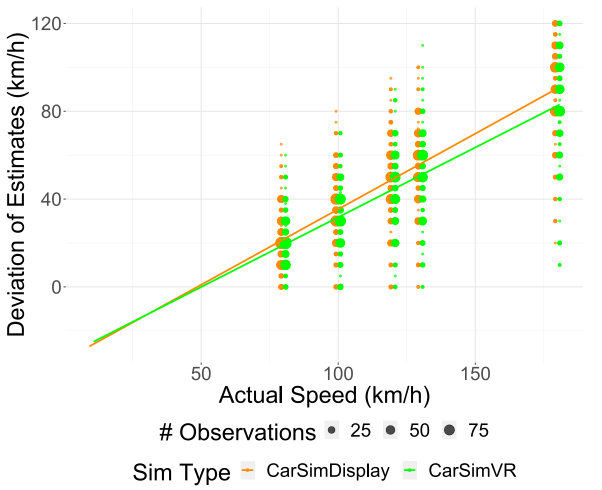

Figure 1: Linear Regression for Estimate Deviation: Interaction between Simulator and Actual Speed.

5. Used Acronyms

FOV	Field of View
GFOV	Geometrical Field of View
HUD	Head-up-Display
HMD	Head-Mounted Display
LMM	Linear Mixed Model
PQ	Presence Questionnaire
SSQ	Simulator Sickness Questionnaire
VE	Virtual Environment
VR	Virtual Reality

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