Evaluating VR Driving Simulation from a Player Experience Perspective

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Abstract
The majority of HCI research in the field of automotive interfaces and driver-vehicle interaction is conducted utilizing driving simulators. High-fidelity simulators are expensive; in consequence, many researchers use consumer gaming hardware and flat screens as an alternative. In recent years VR devices have become affordable and are applied already in some driving studies. It has not been shown whether driving simulations can use VR to increase immersion in low-cost setups. We conducted a pilot study with 20 participants using a racing game as simulation software. The results of this pilot study indicate that using a VR headset can potentially dissociate participants to a higher degree from the real world compared to the use of flat screens. However, participants felt a higher discomfort using the VR HMD. Despite expectations, today's VR technology does not appear to be a generally better choice than flat screens for driving simulator studies.

Author Keywords
Driving simulation; virtual reality; HMD; player experience; simulator sickness; immersion.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces: Evaluation/methodology

Introduction

Vehicles and in particular their features like driving modes, driver assistance systems and user interfaces are evolving continuously [23]. In consequence, a lot of user studies are conducted to evaluate new concepts (e.g. [5, 10, 16, 22, 24]). As a tradeoff, many studies are executed in driving simulators, since studies in real cars are often problematic due to approvals for road traffic, liability issues, high costs for test sites or the danger that is posed by early prototypes to participants or other road users. These issues gain extra weight in the domain of highly automated driving.

High-fidelity driving simulators, for instance equipped with real car mockups on hexapods, are intended to create a realistic testing environment, however these simulators are expensive. In consequence, a lot of research is conducted in low-fidelity driving simulators that use gaming hardware and flat screens or projections in front of the driver.

Research has shown that the choice of game interface can affect enjoyment, motivation, and even in-game personality [1]. Another study showed that the control device in a racing game (i.e. Xbox 360 controller vs. U-shaped speed wheel vs. wireless racing wheel) affected game involvement [12]. This and other studies indicate that interface naturalness leads to more perceived realism, and together may predict spatial presence and enjoyment [13, 19]. Considering VR as a mediator to driving simulations, it may thus be able to provide an even more realistic and immersive experience. Yet there are also indications that familiarity with controller use can affect flow and enjoyment inversely [8]; thus the novel VR experience might also distract from the experience. Comparisons of real-life vs. high-cost simulation environments have indicated that study participants may drive differently depending on perceived realism [15], which may influence VR studies. However, perhaps due to the young age of well-realised VR, a literature search yielded no direct comparisons of VR and real-world driving, nor of VR and low-cost driving simulators.

In consequence, we investigated whether the use of VR headsets is beneficial regarding simulator sickness and discomfort compared to a flat screen driving simulator setup. Moreover, we measured presence and immersion as a factor for realism as well as emotion and motivation as measures for the participants' state. Current low-fidelity VR simulations are very specialized custom builds, thus we decided to use a racing game as simulation software that supports both modes.

Experiment

A within-subject study with 20 participants was conducted in a low-fidelity driving simulator setup to investigate the effect of a VR and a non-VR display condition on the subjective experiences of the participants.

Apparatus

The study was conducted in a driving simulator that was equipped with a RaceRoom game seat and a Fanatec steering wheel and pedals. The simulation was displayed either on three 40 inches screens or via an HTC Vive as shown in Figure 1. The racing game *Project Cars* [21] was used for the simulation. For both conditions, participants had to drive the same 20.64 km on a winding highway with the same automatic transmission vehicle. The track was fenced off so that no other vehicles were present. Participants were instructed to pass the track as fast as possible, but also with as little damage to the vehicle as possible.

In the *VR condition*, participants wore the HTC Vive with a field of view (FOV) of 110° and a resolution of 2160 x 1200 pixels. The participants had an in-cockpit perspective (see Figure 2) including a virtual representation of their body.

Figure 1: Experimental setup: Participants saw the game [21] either on the flat screens in front of them (traffic scene and a speedometer) or via a VR HMD (see in-cockpit scene in Figure 2).

Figure 2: In-cockpit perspective (VR condition) of the racing game [21]: In contrast to the flat screen condition the headset displayed the cockpit including a virtual body of the driver.

In the *flat screen condition*, the participants sat in front of three flat screens with a combined resolution of 5760 x 1080 pixels and a FOV of approximately 135° depending on the size of the participants. Instead of an in-cockpit perspective, we displayed only the driving scene (see Figure 1) since it is common in simulator studies due to the hardware steering wheel in front of the participants. As a compromise we displayed a speedometer on the lower right edge of the central screen, because participants could see the speedometer in the instrument cluster in the *VR condition* as shown in Figure 2. To keep participants focussed on the driving task and foster the simulation character, no other visualizations typically found in racing games (section times, damage etc.) were displayed. Graphic settings for both conditions were the same and geared to provide maximum frame rates.

Procedure

Each session started with an introduction to the study, a consent form, and a questionnaire on demographics and previous experience with driving, driving simulations and VR, as well as baseline simulator sickness levels and affective state. The game seat was then adjusted to the size of the participant, and the driving task and the controls were explained. Next, participants had to drive the same track in each condition once (HMD or flat panels in counterbalanced order). After each condition, they had to fill in another questionnaire to assess simulator sickness, affective state, immersion, presence, and intrinsic motivation. The session ended with a final questionnaire regarding preference and a compensation of 5 Euros. A session lasted for about 50 minutes.

Measures

The participants' *simulator sickness* was assessed with the simulator sickness questionnaire (SSQ) [7], while the *affective state* was measured via the self-assessment manikin (SAM) [2]. The immersive experience questionnaire (IEQ) [6] was used to measure *immersion*, and the presence questionnaire (PQ) [25] for *presence*; finally, the questionnaires

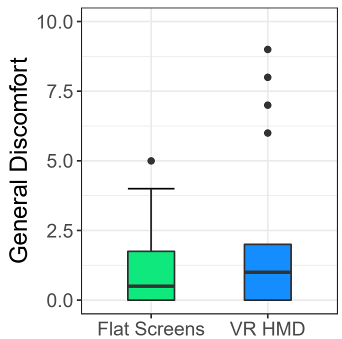

Figure 3: General Discomfort.

Measure	*M*	*SD*
V (VR)	6.667	1.3284
V (FS)	6.556	1.2935
A (VR)	4.667	2.1963
A (FS)	4.444	2.1963
D (VR)	5.667	1.5339
D (FS)	5.722	1.0741

Table 1: Means and standard deviations of the valence (V), arousal (A), and dominance (D) scores for the virtual reality HMD (VR) and the flat screen (FS) condition.

also included the intrinsic motivation inventory's (IMI) [11] *interest/enjoyment* subscale.

Participants
We recruited 20 participants (5 female, 14 male, 1 not reported) from the university population through mailing lists and social networks. Two female participants had to be excluded: one participant interrupted the experiment due to nausea after experiencing the first condition (flat screens) and filling in the subsequent questionnaires, the other passed the whole session (VR $\rightarrow$ flat screens), but the camera settings in the flat screen condition were corrupted (bumper camera instead of roof camera). The remaining participants were on average 25.06 (SD=3.19) years old. 17 of them had a computer science background. All participants owned a driving licence for an average of 7.39 (SD=3.13) years and reported driving 6.67 (SD=3.63) hours per month. 15 of these participants reported that they had at least minor experience with VR games or simulations. These participants do not represent the whole population of drivers, however they can be seen as a typical sample for such studies (e.g. [5, 10, 16, 22, 24]).

Results

The time participants needed to pass the track did not differ between conditions significantly, $t(17) = 0.49, p = 0.6$. They needed on average 638.81 s ($SE = 13.58$) in the flat screen condition and 643.26 s ($SE = 13.41$) in the VR condition.

Simulator Sickness & Perceived Discomfort
The simulator sickness questionnaire (SSQ) was used to investigate whether the visualisation methods affected the participants' comfort level. An ANCOVA with the visualisation method as repeated measures factor, SSQ total score as dependent variable, and the SSQ score baseline as covariate revealed that the baseline SSQ total score significantly influenced the SSQ total score , $F(1, 16) = 7.885$, $p = 0.017$, $partial\ \eta^2 = 0.330$. Although the VR setup did elicit higher SSQ scores ($M = 29.09$, $SD = 27.65$) compared to the flat screen setup ($M = 16.41$, $SD = 14.06$), when controlling for the SSQ baseline score, the visualisation method did not have an significant effect on the SSQ total score, $F(1, 16) = 0.652$, $p > 0.05$.

Participants were further asked *Please rate your general discomfort: On a scale of 0 – 10, 0 being how you felt coming in, 10 is that you want to stop, where are you now?* after each ride similarly to [4, 17]. As Figure 3 shows, the medians in the VR condition and the flat screen condition were 1 and 0.5, respectively. A Wilcoxon signed-rank test shows that participants felt higher discomfort in the VR HMD condition than in the flat screen condition, $W = 55.5$, $z = -2.04$, $p < .05$, $r = -.34$.

Participants' Emotions
The participants' emotions (*valence*, *arousal*, and *dominance*) were assessed with the help of the SAM questionnaire. We conducted ANCOVAs with the visualisation method as repeated measures factor, emotion scores as dependent variable, and the corresponding emotion baseline as covariate. The reported valence was significantly influenced by the baseline valence scores, $F(1, 16) = 14.834$, $p = 0.001$, $partial\ \eta^2 = 0.481$. When controlling for the baseline valence there was no effect of the visualisation method on valence scores, $F(1, 16) = 0.217$, $p > 0.05$. The arousal baseline did not significantly influence arousal ratings, $F(1, 16) = 4.401$, $p > 0.05$, $partial\ \eta^2 = 0.216$. When controlling for baseline arousal there was no effect of the visualisation method on arousal scores, $F(1, 16) = 0.194$, $p > 0.05$. Dominance scores were significantly influenced by baseline dominance rat-

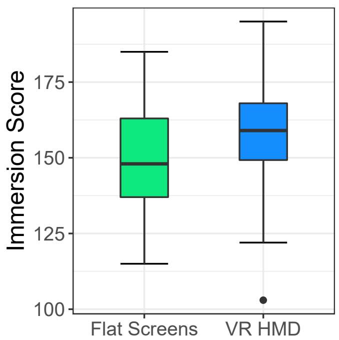

Figure 4: Immersion Score.

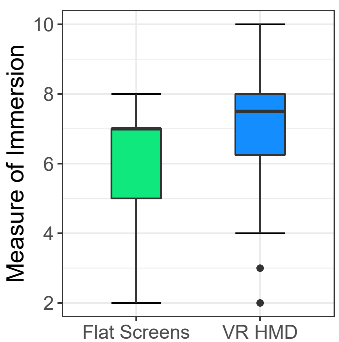

Figure 5: Single Question Measure of Immersion.

ings, $F(1,16) = 5.964$, $p = 0.027$, $partial\ \eta^2 = 0.272$. However, there was no effect of the visualisation method on dominance score when controlling for the dominance baseline, $F(1,16) = 0.002$, $p > 0.05$. In summary, when controlling for baseline emotion, there was no effect of visualisation method on SAM ratings. For an overview of the scores see Table 1.

Presence & Immersion
A dependent t-test revealed that there was no significant difference in the level of perceived presence (PQ score) between the VR ($M = 146.17$, $SE = 5.92$) and flat screens ($M = 145.72$, $SE = 5.14$) conditions, $t(17) = 0.09$, $p = 0.9$. We also could not find any significant effect on the immersion score (IEQ) (VR: $M = 154.78$, $SE = 5.21$; flat screens: $M = 149.06$, $SE = 4.95$), $t(17) = 1.2$, $p = 0.2$. This result is in line with the scores of the *Single Question Measure of Immersion* of the IEQ: the medians of the participants' ratings on a scale from 1 – 10 were 7.5 in the VR condition and 7 in the flat screen condition (see Figure 5 for interquartile ranges). A Wilcoxon signed-rank test did not reveal significant effects of the visualisation condition, $W = 79.5$, $z = -1.71$, $p = .09$. However, as the boxplots in Figures 4 and 5 show, there is an observable tendency that participants feel more immersed when using a VR headset instead of flat screens. The IEQ also provides five immersion factors: *cognitive involvement*, *emotional involvement*, *real world dissociation*, *control*, and *challenge*. We found that participants experienced significantly greater real world dissociation using the VR headset ($M = 37.29$, $SE = 1.71$) than the flat screen setup ($M = 29.11$, $SE = 1.32$), $t(17) = 4.3$, $p < .001$, $r = .72$.

Intrinsic Motivation
We used the *interest/enjoyment* subscore of the IMI to investigate how much participants liked to drive under the two visualisation conditions. Overall, the participants rated their interest and enjoyment very highly with 5.61 ($SE = 0.20$) in the VR condition and 5.60 ($SE = 0.18$) in the flat screen condition on a scale with the maximal value of 7. There was no significant difference between the two conditions, $t(17) = 0.04$, $p = 1$.

Participants' Preferences
At the end of each session, participants were asked whether they rate one of the two experienced conditions higher regarding game enjoyment (Enjoy) and several realism factors: whether participants' own behavior (Own Behavior), the vehicle's behavior (Vehicle), or the perceived speed (Speed) were more realistic in either condition. Moreover, participants had to choose with which condition they could imagine training for real driving (Training). Figure 6 shows stronger preferences for the VR HMD than the flat screens.

Discussion & Future Work
We challenged participants with two different visualisation conditions – a setup of three flat screens and a VR HMD in a low-cost driving simulator. Surprisingly, we found no differences between these conditions regarding player experience measures like participants' valence, arousal, dominance, and their intrinsic motivation. The latter as well as valence were rated highly in both conditions; overall the VR was preferred above the flat screens.

The presented analysis is based on self-reported data. Participants had to fill in several questionnaires during the session, which may have been tedious; in consequence, survey fatigue may have influenced results. Regarding perceived immersion and presence we expected higher scores for the VR condition. Yet our analysis did not reveal significant differences, although there was a slight tendency towards higher immersion in the VR condition. Moreover, we

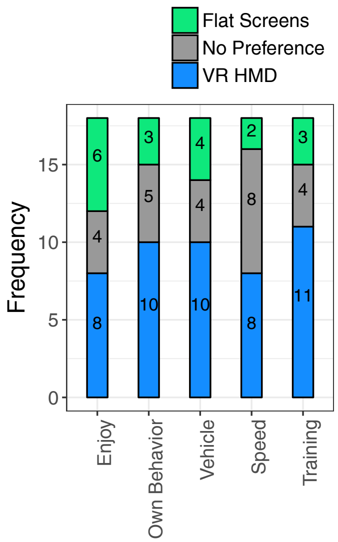

Figure 6: Participants' Preferences.

found a significantly higher degree of real world dissociation when participants wore the HMD.

We expected a higher degree of simulator sickness in the VR HMD condition based on previous research, which has also shown that these symptoms may be more prevalent in women [14, 20]. Interestingly, there was no significant difference in simulator sickness between the two conditions as measured by the SSQ. However, we found a significantly higher score for the VR condition regarding the general discomfort measured with a single question. A closer look at the data reveals several outliers, thus this result should not be overestimated. Additionally, one participant aborted the session after experiencing the flat screen condition due to simulator sickness. This is unprecedented in our group's previous work, conducted in a similar flat screen setup in the domain of automated driving [22, 24].

Through this evaluation we found insights on how to conduct future research to compare VR driving simulators to traditional low-cost simulators. A larger FOV can increase simulator sickness [9, 18]; this may also have had an effect on our results since the VR HMD had a smaller FOV than the flat screen setup. Thus, future studies should implement comparable FOVs. Further, racing games do not require participants to look around, in contrast to other driving tasks (e.g. parking or overtaking). In such scenarios, there might be stronger differences between the conditions regarding immersion and presence. Moreover, looking around may also cause a higher degree of simulator sickness. Tasks that require looking around would benefit from a VR environment because especially low-cost simulators lack of a 360 degree rendering. This trade-off could be focus of future research. We assume that the results depend on the test track and use case, therefore we recommend evaluating different scenarios that require different actions.

In conclusion, we found no distinct answer to the question which kind of setup should be used in low-cost driving simulation studies. Our pilot study highlights the need for a follow-up study with different driving tasks and objective metrics like road safety performance, drivers' behavior and physiological measures. In particular, the actions drivers perform in the vehicle are significantly different in the domain of highly automated driving; they do not drive manually and are engaged in non-driving related tasks most of the time. We assume that in such scenarios the degree of immersion and presence is vital to assess the degree of situation awareness due to the out-of-the-loop performance problem [3]. VR may offer a large potential for such studies. Surprisingly, other than real world dissociation, there was no higher immersion measurable in the VR HMD condition. This could be caused by the limitations of contemporary headsets like the small FOV. Moreover, there are other aspects that should be regarded when applying VR in driving simulation studies: To create a more fully immersive experience, the hardware cockpit should be recreated in VR exactly, and the system should implement a precise tracking of users' positions and especially their hands. In summary, despite the intuitive pre-study assumption that VR would be able to provide a more immersive and thus enjoyable and realistic experience, we cannot definitively recommend the implementation of VR technology for low-cost driving studies. In addition, we cannot claim that studies with a flat screen setup are less valid than studies conducted with VR HMDs. Future research is needed to resolve which display condition is better suited for specific scenarios.

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