Simulator Sickness and Felt Presence: Comparing Low- and High-end Virtual Reality Headsets

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Abstract. This paper reports on a study evaluating the effects of virtual reality headset performance on simulator sickness and felt presence in immersive virtual environments. Hardware advances in recent virtual reality devices, such as Oculus' *Rift* and HTC's *Vive*, positively impact on users' felt presence in virtual environments. Consequently, they may also affect, and eventually decrease the symptoms of simulator sickness. To explore these potential effects, we compared an iPhone-based virtual reality headset with an Oculus Rift DK 1 on the symptoms of simulator sickness. Results show that, although the higher quality provided by the Oculus Rift DK 1 significantly increased the felt presence in the immersive virtual environment, a difference with respect to the symptoms of simulator sickness could not be identified.

Keywords: Virtual reality, immersive virtual environments, presence, simulator sickness, human computer interaction.

1 Introduction

The quality of Virtual Reality (VR) technology is continuously improving, so that today's VR applications become increasingly more immersive and consequently also more realistic. Yet, some users still suffer from symptoms of nausea or dizziness when wearing VR headsets. Recent devices, such as Oculus' *Rift*[1], HTC's *Vive*[2], or any of its competitors, however, may have an influence on the symptoms of this so-called simulator sickness; i.e. they may help minimize these feelings. To evaluate such potential improvements, we used a smartphone-based VR headset (i.e. *Google Cardboard*[3]) and an *Oculus Rift DK 1,* and compared them with respect to experienced presence and felt simulator sickness.

[1] https://www.oculus.com/
[2] https://www.vive.com/eu/
[3] https://vr.google.com/cardboard/

2 Theoretical Background

Presence. Presence describes the subjective feeling of being in a virtual reality and is often referred to as “Being-There” [3, 14]. Sheridan further distinguishes between telepresence, i.e. the sense of being physically present with virtual objects at the remote teleoperator site, and virtual presence, i.e. the sense of being physically present with visual, auditory, or force displays generated by a computer [9].

Immersion. According to Dörner and colleagues, immersion may be defined as the ability of a technical system to enable presence by broadly addressing the users’ senses and their isolation from the environment [3, 11]. Thus, an Immersive Virtual Environment (IVE) is a world, or respectively a system for displaying a virtual world, which is capable of isolating the user from the real world and simultaneously creates a ‘virtual’ presence. One way of implementing such an IVE may be seen in the use of Head-Mounted Displays (HMD), i.e. VR headsets.

VR headsets. VR headsets isolate a user from the real environment and then they use sensors for motion tracking to adapt the virtual field of view according to his/her head movements. They may be classified according to many characteristics, although the display usually counts as the most important factor. On the one hand, one finds VR headsets which use a smartphone to display and process the relevant information. Such are called smartphone-based or respectively low-end headsets. On the other hand, there are more powerful VR headsets which use built-in displays and sensors connected to a PC processing unit to process information. Those are called computer-based or high-end VR headsets. Smartphone-based VR headsets are much cheaper yet sensor and processing power is limited by the used smartphone hardware. By contrast, high-end VR headsets have aligned displays and sensors and are thus capable of generating a much more realistic (highly resolving) virtual experience.

Simulator sickness. A rather unpleasant side effect of using VR is the so-called simulator sickness, which is often associated with symptoms such as disorientation, nausea, headaches and blurred vision [5, 6]. A reason for these side effects may be found in the so-called Sensory Conflict Theory, which describes a felt disagreement between the user’s visual perception and his/her perception of balance [7]. Such disagreements may occur in cases where the system’s sensors are not sensitive enough or its processing unit is too slow in generating the required images. Studies have shown that women are more likely to suffer from simulator sickness [12]. Similarly, people who had already experienced some sort of motion sickness are more prone to suffer from these symptoms. Also, the characteristics of the VR system/environment may affect the intensity with which the sickness is experienced [4]. So is it that aspects such as the length of the stay, the size of the field of view, or the complexity of the scenes, negatively impact on these symptoms [6]. And also, the felt presence seems to play a significant role [7, 13].

3 Research Motive

As highlighted above, simulator sickness is influenced by a number of factors, among which is also the quality of the used VR headset. Low-end and high-end VR headsets are considerable different in their provided picture quality and sensor sensitiveness, both of which may affect experienced sickness symptoms. Consequently, our goal was to determine whether such a difference in symptomatic expression is measurable. To that end, previous studies around this topic do not allow for clear result expectations. On the one hand, it was shown that better picture quality, better color depth, more sensitive sensors and a latency-free image build-up reduces sickness symptom. Yet, on the other hand, it was also highlighted that felt presence reinforces said symptoms [6].

4 Research Methodology

Following our research motive we set up a bi-modal experiment comparing felt presence (P) and experienced simulator sickness (SS) when using two different VR headsets. In Mode 1 (M1) participants were asked to use a low-end (smartphone-based) VR headset whereas in Mode 2 (M2) they used a high-end VR headset. SS and P were measured through previously used and validated questionnaires. That is, for SS we used the Simulator Sickness Questionnaire (SSQ) [5], which, according to Balk and Bertola [6], may be seen as the standard SS measurement instrument and as such provides three weighted sub-scales for nausea (SSQ-N), oculomotor (SSQ-O) and disorientation (SSQ-D), and one scale for total severity (SSQ-TS). To measure P we used Witmer and Singer's Presence Questionnaire (PQ), which provides a single PQ-TS score [14, 10].

Task Design. Participants were asked to accomplish three different tasks with each of the two VR headsets. First, they had to passively watch a 360° video containing no rapid or unexpected movements (note: in M1 they watched *Hog Rider 360°* and in M2 *Invasion!).* Next, they had to take part in a roller coaster ride that was partially rapid and jumpy (note: in M1 this was *Roller Coaster* and in M2 *Desert Ride Coaster*). And finally, they had to play a game in which they had to use their head to control a moving object around a track with varying obstacles, i.e. they were engaged in an active experience (note: in M1 they played *Ninja Kid Run* and in M2 *Poly Runner VR*). The first and second tasks were fully performed; the third task was stopped after 10 minutes total immersion time.

Technical Setup. As for the low-end VR headset, we used an *iPhone 6s* clipped into a plastic holder. The phone offers a 4.7inch display using a screen resolution of 1334 x 750 pixels, and a dual core processor with 1.85 GHz and 2 GB RAM. For the high-end VR headset, we used an *Oculus Rift DK 1*. The Oculus device offers a 4.08inch display with a screen resolution of 1280 x 800 pixels [2] and was powered by a PC with a 3.4 GHz Intel i7-7 Quad-Core Processor, 8GB RAM and a Nvidia 760 graphics adapter with 2 GB dedicated graphic memory.

Participants. A total of 16 participants (8 female) participated in the experiment. The average age was 24.38 with the youngest participant being 15 and the oldest 55 years old (SD=8,547). Twelve participants (80%) stated that they had previous experience with computer games, 9 of whom played regularly. Significantly fewer, i.e. 7 participants, stated that they had already experience with VR (46.7%). However, none of them had been in contact with VR on a regular basis.

Procedure. Participants were split in two different groups. Group 1 (G1) used the low-end VR headset first and then the Oculus device. For Group 2 (G2) the order was reversed. A 5 minutes pause separated the two runs. Before starting their VR immersion participants were asked to complete a questionnaire collecting data on demographics and VR experience, as well as a pre-test SSQ so as to prevent potential bias [5] (note: the pre-test SSQ results did not show any outliers for which none of the data records had to be excluded from analysis). Then, following each immersion, participants were asked to complete the SSQ and the PQ. Immersions were always limited to 10 minutes, for previous research has shown that after this timespan a considerable number of people would experience SS symptoms [7, 8].

5 Results

SSQ-TS and PQ-TS with respect to VR headset. Comparing the two headsets regarding their influence on experienced simulator sickness symptoms showed no significant difference; neither for the overall SSQ-TS score nor for the three sub-scores (i.e. SSQ-N, SSQ-O, and SSQ-D). As for the perceived present, we found that the Oculus device produces significantly higher presence scores (PQ-TS AVG=15.44; SD=20.05) than the iPhone based system (PQ-TS AVG=1.38; SD=14.63); $p = 0.031$.

SSQ-TS with respect to gender. Confirming previous studies [11], we found highly significant ($p = 0.000$) differences of experienced SS symptoms between genders. That is, SSQ-TS values were clearly higher with woman (AVG=15.25; SD=9.651) than with men (AVG=4.313; SD=3.790).

SSQ-TS and PQ-TS with respect to experience. Regarding previous experiences with computer gaming we found a moderate correlation between hours played per month and respective SSQ-TS (r=-0.595, p=0.002), SSQ-O (r=-0.677, p=0.000) and SSQ-D (r=-0.569, p=0.004) scores. We also found a moderate correlation between hours played per month and PQ-TS scores (r=-0.435 p=0.034). Consequently, it seems that the less one plays the higher are his/her SSQ and PQ scores.

Comparison between pre-test, immersion 1, and immersion 2. Comparing the pre-test SSQ scores with those measured after immersion 1 and immersion 2 respectively, we found that SSQ-N, SSQ-D and SSQ-TS differed significantly (cf. **Table 1**).

	SSQ-N	SSQ-O	SSQ-D	SSQ-TS
Pre-test	0.857 (SD=1.231)	1.714 (SD=1.490)	0.500 (SD=0.760)	3.071 (SD=2.464)
Immersion 1	2.500 (SD=1.862)	3.250 (SD=2.380)	2.813 (SD=2.639)	8.563 (SD=5.989)
Immersion 2	3.125 (SD=3.364)	4.313 (SD=4.362)	3.563 (SD=4.647)	11.000 (SD=11.501)

Table 1. Mean values comparing SSQ scores between pre-test, immersion 1 and immersion 2

As already stated earlier, there were no significant differences in experienced SS symptoms with respect to the used VR headsets. Compared to the pre-test scores (i.e. without headset), however, both headset types seem to trigger some symptoms. **Table 2** summarizes the relevant values.

	SSQ-N	SSQ-O	SSQ-D	SSQ-TS
No headset	0.857 (SD=1.231)	1.714 (SD=1.490)	0.500 (SD=0.760)	3.071 (SD=2.464)
iPhone-based VR	2.938 (SD=2.792)	3.875 (SD=3.324)	3.125 (SD=3.361)	9.938 (SD=9.147)
Oculus Rift DK1	2.688 (SD=2.676)	3.688 (SD=3.772)	3.250 (SD=3.598)	9.625 (SD=9.359)

Table 2. Mean values comparing SSQ scores between no headset, iPhone-based headset and Oculus Rift DK1

6 Summary, Criticism and Future Work

Our study has shown that the choice of VR headset (low-quality vs. high-quality) seems to not affect the perception of simulator sickness symptoms. However, we found significant differences in felt presence, with clear advantages for high-quality systems. Furthermore, we could confirm previous studies that showed that women are significantly more prone to symptoms of SS than men, and that VR and gaming experiences can help reduce such feelings.

These results may, however, be limited as our sample size with 16 (mostly younger) participants and a total of only 32 VR immersions was rather small. Also, the technical setup (e.g. color depth, brightness, image repetition, computing power and resulting delay) was very much adapted to the given tasks so as to allow for comparisons. Other (more advanced) task settings may, however, show greater differences between devices and shall therefore be explored in future studies.

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