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# Evaluation of Simulator Sickness for 360° Videos on an HMD Subject to Participants' Experience with Virtual Reality

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## Introduction

▶ Immersive multimedia such as virtual reality (VR) and augmented reality (AR) have seen increased applications ranging from digital games to the general consumer markets.

▶ The trend of viewing virtual environments (VEs) on head-mounted displays (HMDs) is due to large technological improvements in hardware, processors, and software.

▶ The understanding about the level of simulator sickness and cybersickness is less developed but similar important to assure customer satisfaction.

# Related Work (1)

▶ [Brunnström et al., 2018]: VR simulator of a forestry crane for loading logs onto a truck was evaluated in terms of quality of experience (QoE) and simulator sickness questionnaire (SSQ) to reveal the effects of latency for task completion.

▶ [Chessa et al., 2016]: Evaluated the physical discomfort by recording the SSQ for the Oculus Rift HMD, Google Cardboard and 3D TV.

▶ [Guna et al., 2019]: The impact of video content type on users' VR sickness and physiological response was studied shown on three generations of Oculus Rift HMDs, Samsung Gear VR HMD, and a 2D TV screen.

# Related Work (2)

▶ [Katsigiannis et al., 2019]: QoE and simulator sickness of a smart-exercise-bike VR system was evaluated using the SSQ and physiological signals.

▶ [Singla et al., 2017]: Subjective quality of omnidirectional videos at different bit rates and resolutions was evaluated along with an analysis of SSQ scores and head motion behavior.

▶ [Sevinc and Berkman, 2020]: The SSQ is compared with the cybersickness questionnaire (CSQ) [Drexler, 2006], VRSQ [Kim et al., 2018], and French SSQ (FSSQ) [Bouchard et al., 2007] developed for VR.

## Contribution

▶ Mean SSQ scores and box plots over all participants to reveal the level of occurrence of the 16 individual symptoms.

▶ Pairwise comparison of symptoms using $t$-tests to identify symptoms that are statistically different to other symptoms.

▶ Mean weighted SSQ scores and total score for the symptom clusters over all participants.

▶ Mean SSQ scores and box plots when participants are grouped into different classes of experience.

▶ Mean weighted SSQ scores and total scores for the symptom clusters when participants are grouped into different classes of experience.

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## Experimental Design

▶ The SSQ data was obtained as part of a larger subjective experiment on $360°$ video quality assessment.

▶ The stimuli were viewed on an HMD by participants having different levels of experience with VR.

▶ The subjective experiment was broken down into a pilot study with a small group of experts and a main study with different experience levels.

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# Stimuli, Software, and Equipment (1)

▶ Scenes were selected from the [VQA-ODV, 2019] database.

▶ 120 360° videos with different quality levels were obtained from four natural 360° reference video scenes of 8K resolution.

▶ 20 reference videos.

▶ 100 test videos.

▶ The stimuli were shown on an HTC Vive Pro HMD with 1440 ×1600 pixels per eye, a 110° field of view, 90 Hz refresh rate.

▶ The participants answered the SSQ using a graphical user interface under iMotion Software on a standard screen.

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## Stimuli, Software, and Equipment (2)



Figure 1: Sample frames of the four 360° video scenes in equirectangular projection from the sphere to the plane.

## Participants

▶ A pilot study was conducted with five experts familiar with immersive multimedia (2 females and 3 males).

▶ Main study engaged 30 participants (9 females and 21 males).

▶ Average age of the experts in the pilot study was 38.2 years and the participants in the main study was 29.53 years.

▶ Screening/break longer than one hour: left four participants from the pilot study and 25 participants from the main study.

▶ The breakdown of the total of 29 participants into classes of experience with VR on HMDs is as follows: 4 (experts), 12 (sometimes used), and 13 (never used).

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## Test Method

Table 1: Session Schedule

| Session | Duration | Comments |
|---------|----------|----------|
| M-ACR-HR [Singla et al., 2018] | 28-35 min. | Starts with eye-tracker calibration. Presentation and rating of $60\times2$ videos is scheduled as follows: (1) 10 s video - first time, (2) 3 s mid-grey screen, (3) 10 s video - second time, (4) Quality rating, typically, $<10$ s. |
| SSQ | $<5$ min. | Answered at the end of the session on a conventional screen. |

The participants were informed about the risks of motion sickness and were given instructions before the experiment.
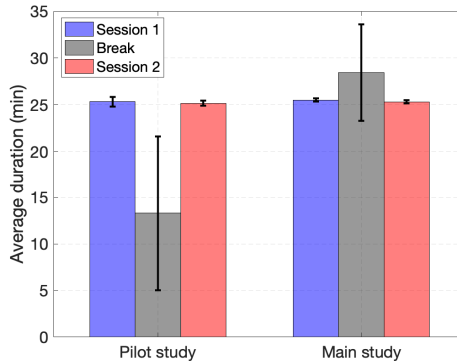
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# Average Duration



Figure 2: Average duration of each session and the break between sessions for the pilot study and main study.

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## Simulator Sickness Questionnaire (1)

Table 2: Computation of SSQ Scores [Kennedy et al., 1993].

| | | Weight | | |
|---|---|---|---|---|
| $i$ | **SSQ Symptom** | **N** | **O** | **D** |
| 1 | General discomfort | 1 | 1 | 0 |
| 2 | Fatigue | 0 | 1 | 0 |
| 3 | Headache | 0 | 1 | 0 |
| 4 | Eyestrain | 0 | 1 | 0 |
| 5 | Difficulty focusing | 0 | 1 | 1 |
| 6 | Increased salivation | 1 | 0 | 0 |
| 7 | Sweating | 1 | 0 | 0 |
| 8 | Nausea | 1 | 0 | 1 |
| 9 | Difficulty concentrating | 1 | 1 | 0 |
| 10 | Fullness of head | 0 | 0 | 1 |
| 11 | Blurred vision | 0 | 1 | 1 |
| 12 | Dizziness (eyes open) | 0 | 0 | 1 |
| 13 | Dizziness (eyes closed) | 0 | 0 | 1 |
| 14 | Vertigo | 0 | 0 | 1 |
| 15 | Stomach awareness | 1 | 0 | 0 |
| 16 | Burping | 1 | 0 | 0 |
| | **Total** | $N_w$ | $O_w$ | $D_w$ |

▶ The respondents to the SSQ can rate the presence of each symptom through a symptom variable score: (0) None, (1) Slight, (2) Moderate, (3) Severe.

▶ The 16 symptoms are further organized into three symptom clusters, i.e., nausea (N), oculomotor (O), and disorientation (D).

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## Simulator Sickness Questionnaire (2)

The scores of each symptom cluster
are calculated as

$$N_w = \sum_{i=1}^{16} w_{N,i} \cdot s_i \quad (1)$$

$$O_w = \sum_{i=1}^{16} w_{O,i} \cdot s_i \quad (2)$$

$$D_w = \sum_{i=1}^{16} w_{D,i} \cdot s_i \quad (3)$$

where $w_{N,i}, w_{O,i}, w_{D,i} \in \{0,1\}$ and
symptom scores $(s_i)$, $i = 1, \ldots 16$

$$N = 9.54 \cdot N_w \quad (4)$$

$$O = 7.58 \cdot O_w \quad (5)$$

$$D = 13.92 \cdot D_w \quad (6)$$

and the total score (TS), also
referred to as total severity, as

$$TS = 3.74 \cdot (N_w + O_w + D_w) \quad (7)$$

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# Statistical Analysis of SSQ Scores (1)
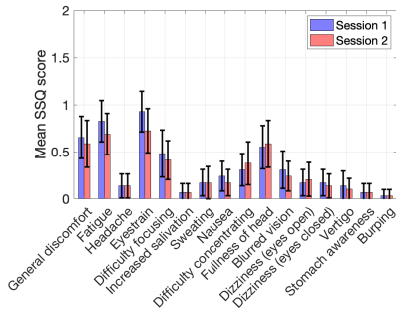


(a) Mean and 95% CI
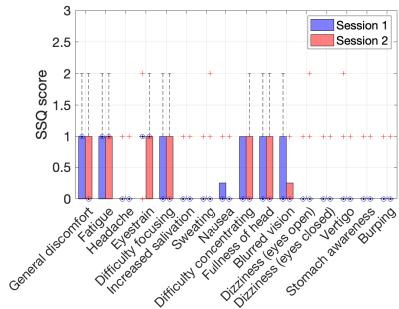
(b) "+" denotes an outlier
"○" denotes a median value

Figure 3: Statistical analysis of SSQ scores: (a) Summary statistics, (b) Box plots.

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# Statistical Analysis of SSQ Scores (2)
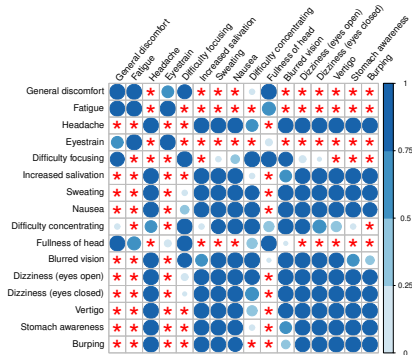


Figure 4: Illustration of p-values obtained from pairwise comparison of symptoms using t-tests with $\alpha = 0.05$. The colour bar indicates the p-value level. The diameter and colour of the circle changes with the p-value. The red asterisk indicates significant differences.

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# Statistical Analysis of Symptom Cluster Scores
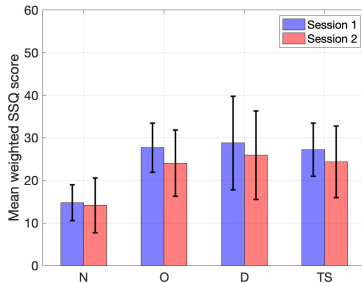


(a) Mean and 95% CI
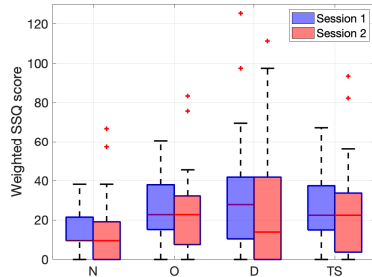
(b) "+" denotes an outlier
"○" denotes a median value

Figure 5: Statistical analysis of symptom cluster scores: (a) Summary statistics, (b) Box plots.

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# Statistical Analysis of SSQ Scores Subject to Participants' Experience with VR (1)



(a) Experts     (b) Sometimes used     (c) Never used
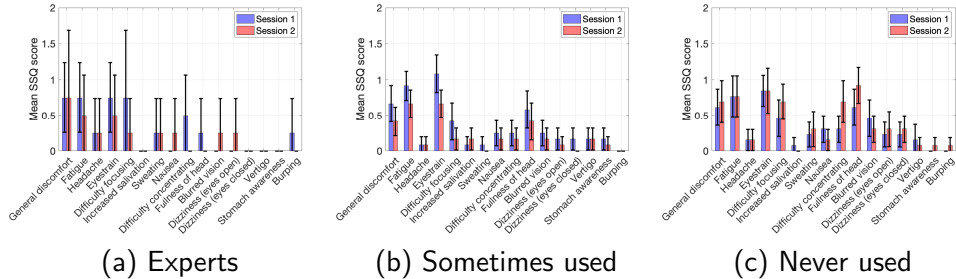
Figure 6: Mean SSQ scores and 95% CIs obtained for participants with different experience levels of VR.

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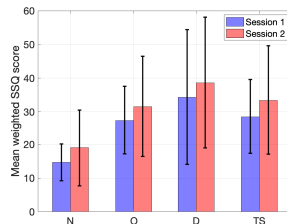
# Statistical Analysis of SSQ Scores Subject to Participants' Experience with VR (2)
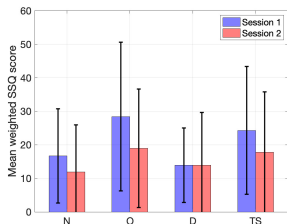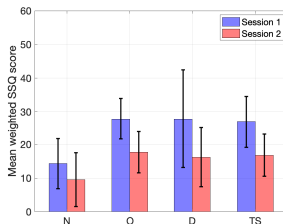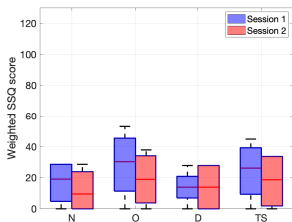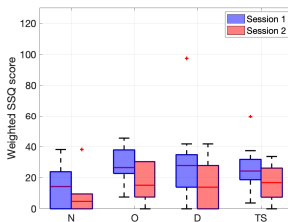


(a) Experts    (b) Sometimes used    (c) Never used

Figure 7: Mean weighted SSQ scores and 95% CIs for symptom clusters N, O, D, and TS subject to participants' experience with VR.

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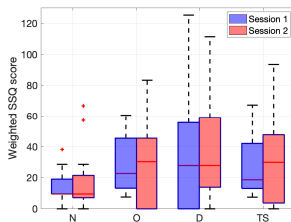
# Statistical Analysis of SSQ Scores Subject to Participants' Experience with VR (3)



(a) Experts  (b) Sometimes used  (c) Never used

Figure 8: Box plots of weighted SSQ scores for symptom clusters N, O, D, and TS subject to participants' experience with VR.

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## Conclusions

▶ The symptom clusters of oculomotor and disorientation have received higher scores compared to nausea-related symptoms.

▶ Regarding HMD technologies, the results indicate that improvements in resolution may be needed to further reduce symptoms associated with oculomotor and disorientation such as fatigue, eyestrain, difficulty focusing, blurred vision, dizziness, and vertigo.

▶ It is suggested to allow for sufficiently long breaks between sessions for inexperienced participants to avoid that simulator sickness influences their quality rating.

## Future Work

▶ Improving experimental designs for quality assessment tasks such as finding a suitable duration of exposure to $360°$ videos.

▶ Correlate the SSQ scores obtained in this experiment with the also recorded galvanic skin responses, eye-tracker data and head movement behavior of the participants with different prior experience with VR.

## Aknowledgments

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# Thank you !

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