Visual Techniques to Reduce Cybersickness in Virtual Reality

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Figure 1: This paper explores the impact of two different visual techniques – i.e., peripheral blurring (PB) and field of view reduction (FOVR) – to mitigate cybersickness in user-explorable game environments. Towards this goal, we conduct an experiment recording both self-reported (SSQ) and physiological (heart rate and electrodermal activity) data from our participants.

Abstract

Cybersickness is a unpleasant phenomenon caused by the visually induced impression of ego-motion while in fact being seated. To reduce its negative impact in VR experiences, we analyze the effectiveness of two techniques – peripheral blurring and field of view reduction – through an experiment in an interactive race game environment displayed with a commercial head-mounted display with integrated eye tracker. To measure the level of discomfort experienced by our participants, we utilize self-report and physiological measurements. Our results indicate that, among both techniques, reducing the displayed field of view up to 10 degrees is most efficient to mitigate cybersickness.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality; Human-centered computing—Human computer interaction (HCI)—Empirical studies in HCI; Applied computing—Consumer health

1 Introduction

Virtual reality (VR) has opened up the possibility to experience virtual environments with an unprecedented degree of visual realism and immersion. This often comes at a price as virtual experiences may induce cybersickness (CS). CS describes symptoms that are quite similar to those of motion sickness induced by an information mismatch between the visual and vestibular system of the human body as compared to physical motion [2]. Besides being inconvenient in entertainment systems, simulators, or high-risk fields like telemedicine, this phenomenon also causes ethical concerns in exposing users willingly to these symptoms. Most importantly, it may limit the adoption of VR technology. Aside from hardware-related factors that can mitigate CS to a certain extent (e.g., high framerate renderings, high quality tracking, and reduced-latency systems), multiple techniques have been presented towards weakening the effects of CS by only manipulating the visual information. Typically, these visual techniques aim to limit the amount of optical flow and, thus, reduce the visual movement perceived by the user. Dynamically altering the user's field of view (FOV) based on the virtual movements of the scene is one common visual approach to mitigate CS. Also, gaze-contingent approaches were proposed using real-time eye tracking [1]. Other methods reduce the image quality of non-foveal regions to mitigate CS by applying blur [5] or sparse rendering [6]. Unfortunately, most of the existing visual techniques are intrusive or inefficient.

This work investigates how opaque occluding and blurring users' peripheral FOV affect CS in VR. The techniques are designed to be unobtrusive while at the same time mitigating CS in a reasonable manner. To explore their effectiveness, we present an experiment using commodity eye-tracking hardware that displays a virtual race game scenario.

2 Methods and Experiment

We investigate the efficiency of two techniques, i.e., peripheral blurring (PB) and field of view reduction (FOVR). These techniques aim for unobtrusiveness by using eye tracking beside the scene information to gaze-contingently manipulate the peripheral areas of the view. FOVR fully grays out the region outside of the circular foveal area, while PB gradually blurs the peripheral region, with the blur level increasing with the distance to the viewing point. The diameter of the restrictors is based on the linear accelerations and angular movements of the camera's point of view in the virtual scene but is always kept above the minimum of 10° [10].

We apply these techniques on a first-person VR racing simulator (cf. Fig. 1). The scene is designed to evoke a high level of CS by relying on well-known theories [7,8] and current research on its causes, e.g., ground sway, sharp curves and uneven roads [3,9]. To measure the level of CS we chose the simulator sickness questionnaire (SSQ) [4], filled out once before and after immersion. Additionally, we used physiological measures – electrodermal activity (EDA) and heart rate (HR) – associated with CS [9].

The experiment (approved by the corresponding ethics committee) followed a within-subject design with three sessions per participant, featuring the two restrictors as well as a unrestricted ground truth as comparison, in random order. At least 48 hours lay between the sessions to avoid any carry over effects. A total of 19 participants completed all three sessions (8 females, age range 21–51, mean 27.21, SD 8.02). Their task was to drive fast on a circular road for 10 minutes with the opportunity to leave the experiment in case of severe sickness symptoms. Before the main task, one minute was spent in the virtual environment without any motion to obtain

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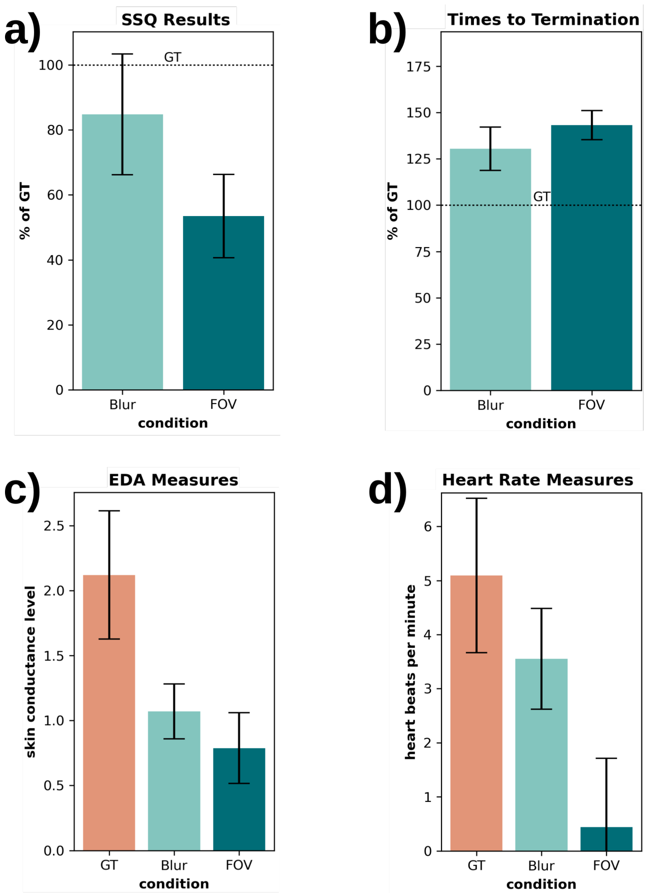

Figure 2: Statistics averaged for all conditions. Error bars represent the standard error of the mean. **(a)** SSQ relative score differences. **(b)** Average relative termination times. Only participants that aborted at least one of the sessions are considered here (N=6). **(c,d)** Averaged differences of the physiological measurements – **(c)** EDA, **(d)** HR.

physiological baseline data. During the trial participants were seated. They wore a HTC Vive Pro Eye and a motion controller was used to drive the car.

3 Results and Discussion

For the analysis of the experimental results we conducted two-sided dependent t-tests (Bonferroni-corrected) between all combinations of the conditions and a one-way ANOVA. The results indicate the effectiveness of both PB and FOVR on the proposed scenario.

Fig. 2(a) illustrates the results of the SSQs for both conditions averaged among participants. Both methods were able to reduce the overall sickness level compared to the unrestricted scene. Occluding the FOV showed to be most efficient based on the SSQs ($t = 3.63$, $p = 0.0019$).

As expected, the results confirm that, in general, the participants' experienced level of sickness was directly proportional to their capacity of endurance and, thus, the time they spent in the experiment. The average time of the experiment until dropping out in at least one of the sessions are shown in Fig. 2(b). Both visual techniques significantly increased the time people were willing to spend in the virtual environment (PB: $t = -2.6$, $p = 0.048$; FOVR: $t = -5.49$, $p = 0.0027$), with FOVR being the most efficient among both. Please note, that the data for one participant will always depend on their own characteristic resilience level, thus the need of gathering all data on a ground truth condition (GT) – scenario without any mitigation technique – to establish the individual baselines per participant. Thus, all previous values were calculated relative to these baselines.

In contrast, the nature of the physiological measures allows for establishing individual baselines per session and thus, both EDA and HR scores are obtained by the average difference between the baseline and main task data per participant for each session. These values can be seen in Fig. 2(c,d).Consistently with the results of the SSQ, both techniques achieve a substantial reduction of the measures compared with the averaged scores in the GT condition. The most significant change follows, again, when applying the FOV occlusion to the scene (EDA: $t = 2.36$, $p = 0.03$; HR: $t = 2.32$, $p = 0.033$).

Summarizing the results, both visual techniques efficiently reduce CS in VR scenes where the user is driving the experience, whereas the FOV restriction technique should be preferred when both come into question.

4 Conclusion

We investigated the effectiveness of two visual techniques to reduce cybersickness in VR, peripheral blurring and field of view reduction. Our results demonstrate that both techniques can be efficient for this reduction, and, among both, the dynamic reduction of the user's FOV seems to better contribute to a more pleasant experience.

Even though the level of experienced CS decreased in the experiment, the presented scene was a rather extreme scenario. Therefore, our future work will explore the applicability of the presented techniques to everyday VR scenes. Also, we like to investigate the effect of posture (free walking vs. standing still vs. seated) on the results.

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