Graphics Interface Conference 2018, 8–11 May, Toronto, Ontario, Canada

Viewpoint Snapping to Reduce Cybersickness in Virtual Reality

Yasin Farmani*
Carleton University

Robert J. Teather†
Carleton University

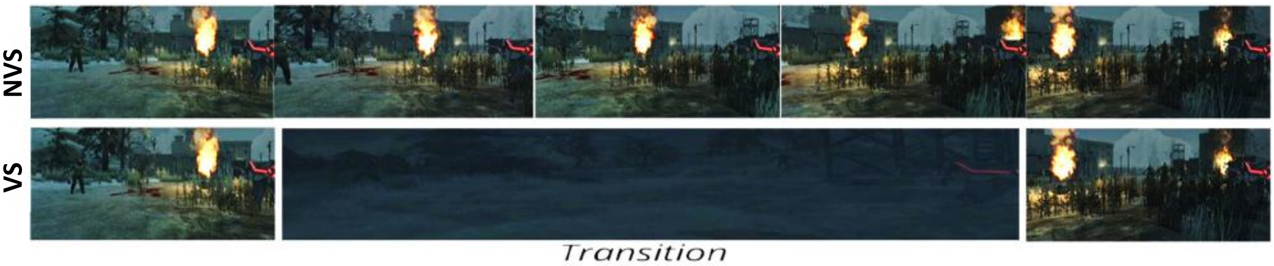

Figure 1: The top row of images shows a standard (non-snapping) viewpoint rotation. The second row shows the same rotation with our viewpoint snapping technique enabled. A fast transition eliminates the intermediate frames, i.e., the rotation becomes discrete, snapping in 22.5° increments.

ABSTRACT

Cybersickness in virtual reality (VR) is an on-going problem, despite recent advances in technology. In this paper, we propose a method for reducing the likelihood of cybersickness onset when using stationary (e.g., seated) VR setups. Our approach relies on reducing optic flow via inconsistent displacement – the viewpoint is “snapped” during fast movement that would otherwise induce cybersickness. We compared our technique, which we call viewpoint snapping, to a control condition without viewpoint snapping, in a custom-developed VR first-person shooter game. We measured participant cybersickness levels via the Simulator Sickness Questionnaire (SSQ), and user reported levels of nausea, presence, and objective error rate. Overall, our results indicate that viewpoint snapping significantly reduced SSQ reported cybersickness levels by about 40% and resulted in a reduction in participant nausea levels, especially with longer VR exposure. Presence levels and error rate were not significantly different between the viewpoint snapping and the control condition.

Keywords: Cybersickness, Visually Induced Motion Sickness, vection.

Index Terms: H.5.2. Human Computer Interaction (HCI): Interaction paradigms: Virtual Reality.

1 INTRODUCTION

Due to the advent of low-cost head-mounted displays and tracking solutions, virtual reality (VR) is now accessible to more people than ever. VR has long been used in many application areas such as healthcare, entertainment and scientific visualization [23], [26]. More recently, game companies are now developing VR versions of console and PC games, such as Serious Sam VR (developed by Croteam) or Resident Evil 7 (developed by CAPCOM).

VR offers unique benefits over other 3D (e.g., desktop) systems. Most notable is the immersive qualities of VR, which induces a sense of presence – the psychological phenomenon of feeling as though you are in the virtual place [29]. Presence is important in many VR applications, such as phobia treatment [29] and training [2]. Its importance to gaming is particularly timely, due to the recent excitement around VR gaming. Similarly, the longstanding problem of cybersickness is an increasingly important issue [6], [23] due, in part, to the potentially long VR exposures gamers may be willing to subject themselves to experience this new form of gaming. Moreover, joystick-based virtual movement (e.g., via the Oculus Touch joystick) where the user is stationary is commonly used in games. Yet, this mismatches virtual and physical motion; as discussed in depth in Section 2, such mismatches yield notably worse cybersickness than walking systems (e.g., the HTC Vive).

Based on this observation and previous research, we propose a potential solution for cybersickness in VR environments using a first-person view, such as first-person shooter (FPS) games. Our technique operates when the viewpoint is turning due to moving a mouse or other input device (e.g., joystick) that does not yield correct vestibular cues. We do not apply our technique during user head motion (i.e., via the head-tracker included with modern head-mounted displays). After all, head motion *does* yield consistent visual and vestibular information. The idea is to artificially reduce vection – the illusion of self-motion, which is linked to cybersickness – by snapping the viewpoint, reducing continuous viewpoint motion by skipping frames based on the speed of viewpoint rotation. Inconsistent locomotion is known to inhibit vection, while consistent locomotion increases vection [30]. Our technique applies this concept by “skipping” some rotational movement. We refer to the technique as *viewpoint snapping*. The technique is depicted in Figure 1.

To avoid choppy animation and to help users maintain spatial awareness, the skipped frames are not entirely dropped, but rather replaced by a very quick fading transition, as though the user is closing their eyes briefly. This reduces optical flow to improve user comfort. The technique is easy to implement at low cost and is thus potentially attractive for developers. It can be applied in setups with limited tracking space prohibiting natural movement, and potentially even for users incapable of walking [11].

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* yasin.farmani@carleton.ca
† rob.teather@carleton.ca

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However, it is unclear how effective (if at all) viewpoint snapping is at reducing cybersickness. Moreover, there are potential user performance and presence implications of employing the technique. After all, the illusion of VR relies on accurately simulating the human perceptual system; viewpoint snapping actively breaks this model.

The rest of this paper is organized as follows. We first present an overview of related work on cybersickness and motivate our technique. We then present two experiments. The first determines a threshold within which to employ viewpoint snapping – i.e., the rotational speeds where users experience the highest cybersickness levels, which would benefit most from viewpoint snapping. The second experiment compared the effectiveness of viewpoint snapping to a control condition without viewpoint snapping in a custom-developed VR first-person shooter game. Our motivating hypothesis was that viewpoint snapping can help users that are sensitive to cybersickness. The main contribution of our work is evidence that viewpoint snapping does indeed significantly, and substantially reduce cybersickness.

2 RELATED WORK

Motion sickness, simulator sickness, and cybersickness produce similar symptoms, although the cause of each is different. Motion sickness commonly occurs when traveling by car, riding amusement park rides, or even sitting on a spinning chair [7]. Simulator sickness, as implied by its name, mostly occurs in flight and driving simulators. McCauley and Sharkey [25] coined the term cybersickness, describing it as motion sickness that occurs in virtual environments. Stanney et al. [33] report that the severity of cybersickness symptoms is three times greater than simulator sickness, but also that the profile of symptoms is different. For instance, disorientation is more predominant in cybersickness, while oculomotor symptoms are less pronounced [33]. Cybersickness presents as a variety of symptoms such as nausea, headache, pallor, sweating, dry mouth, heavy-headedness, disorientation, vertigo, ataxia, and in extreme cases, vomiting [23].

Cybersickness occurs when the user visually perceives that they are moving through a virtual environment, despite the fact that they are physically stationary. This illusion of self-motion is also called vection [12], [32], which Tschermak [35] referred to as a "powerful illusionary of self-motion induced by viewing optical flow patterns". Vection can be experienced while watching a moving train and "creates the illusion that one's own stationary train is moving" [22]. According to Keshavarz et al. [22], the symptoms associated with vection are also called visually induced motion sickness (VIMS). VIMS is similar to traditional motion sickness, but usually occurs in the absence of physical movement.

The most widely accepted hypothesis as to the roots of cybersickness is presented by Reason and Brand [27]. The so-called "sensory conflicts" hypothesis suggests that situations involving conflicting visual, vestibular, and/or proprioceptive perceptual information yield cybersickness [21]. In such situations, as in VR, the visual system detects cues consistent with self-motion (i.e., vection), while the vestibular system indicates that the body is stationary with respect to gravity and position [13], [22].

Many researchers have conducted studies on cybersickness, focusing on better understanding the mechanisms that cause it [1], [7], [15], [23], and proposing potential solutions [9], [11]. Hettinger et al. [12], [13] present classic studies on vection that demonstrate the link between vection and simulator sickness (SS). As mentioned above, simulator sickness is similar to cybersickness, but occurs outside of VR environments [8]. According to the conflict hypothesis [27], mismatches between the visual system and the vestibular system during vection can lead to cybersickness. A related hypothesis – postural instability theory – suggests that changes in human balance can cause cybersickness [22], [23]. Keshavarz et al [22] studied the relationship between vection and cybersickness in detail. Their results indicate vection can be experienced without causing visually induced motion sickness (VIMS). Interestingly, they also report that vection alone is not the only prerequisite for VIMS – its combination with other factors (sensory conflicts, postural instability, etc.) yield VIMS. In addition, some symptoms like eye strain can occur without experiencing vection. Nevertheless, decreasing vection – a pre-requisite for VIMS – seems like a clear opportunity to reduce the onset of cybersickness.

Two types of vection are common in VR systems: circular vection and linear vection. Circular vection occurs during camera rotation; the scene is moving *around* the observer. Linear vection occurs during linear directional movements, when the viewed point approaches or recedes from the observer [13], [34] (e.g., when the viewer is moving forward or sideways). For our current study, we only focus on circular vection (rotation) for our viewpoint snapping technique but may revisit linear vection in future.

Previous studies have shown that changing vection speed and direction can induce more severe sickness than steady, consistent, vection caused by walking or turning at a constant speed or in the same direction [1]. Noting this, Dorado and Figueroa report that climbing a ramp in VR yields lower levels of cybersickness than climbing stairs [9], due to the less "jerky" movement. More complex and more realistic scenery also yields higher levels of cybersickness [6], since visual flow increases with movement speed and scene detail. A similar effect has been observed in flight simulators, where flying near the ground increased visual flow and vection, yielding higher levels of simulator sickness [16]. A study by Kemeny et al. [17] revealed that rotational movement causes greater sickness levels compared to translation movements in driving simulators. These results are echoed by Trutoiu et al. [34], who indicate that circular movement (rotation) causes greater cybersickness compared to translation movements.

Several researchers have proposed different approaches to reduce cybersickness during rotation. One approach involves adding a depth of field blur effect during rotation, simulating focusing the eyes at a different depth, blurring the out-of-focus parts of the scene slightly [3]. Another is the "head lock" technique [17] which temporarily completely disables viewpoint rotation (i.e., disables head-tracking) during rotation. Another technique involves dynamically changing the field-of-view during rotation [11], similar to the approach used by the VR version of the commercial game "Serious Sam"[1]. We note that all of these techniques can reduce game immersion and VR presence [2] due to changing the display fidelity. The head lock technique may also reduce spatial awareness, as the user loses all context of the 3D scene while the viewpoint is locked.

Previous studies [13], [18] have shown that vection and associated symptoms (such as cybersickness) are significantly affected by movement speed, and do not necessarily continuously increase with rotation speed. For example, Hu et al. [14] conducted a study using an optokinetic drum with black and white stripes, where they varied angular rotation speed from 15°/s to 90°/s. Their results indicate that as rotational speed increased, symptoms of induced vection increased, peaked, and then declined, with peak symptoms occurring at a rotation speed of 60°/s. This result indicates that vection and associated sickness increase to a point, then stabilize. They also found that higher navigation speeds can also increase cybersickness but the mechanism behind this is less well understood.

Based on this previous work, we propose our viewpoint snapping technique. We are unaware of precedence in the literature for the use of viewpoint snapping to reduce cybersickness. However, some commercial games use a similar approach. For example, Serious Sam VR[1] and Capcom's Resident Evil 7[2] both include a 'snap rotation' feature. When activated, this option prevents the player from rotating their viewpoint continuously, instead snapping their rotation to fixed increments. Mark Scharamm of VR-Bits[3] used a similar approach in a travel technique called 'Cloud Step'[4]. The Oculus Best Practice Guide [37] also mentions that pressing the left and right buttons cause the camera to jump by a fixed angle, thus minimizing vection during rotation.

3 PRELIMINARY STUDY

We present a first study motivating the design of our viewpoint snapping technique. This was not intended to evaluate the effectiveness of the technique, but rather to establish an approximate rotation speed threshold within which to activate our viewpoint snapping. This preliminary study was intended to determine user preferred speed and discomfort levels using a nausea questionnaire similar to that used by Fernandes and Feiner [11], and Lo et al [24]. Viewpoint snapping (using this threshold) is then evaluated in the second experiment (Section 5).

3.1 Participants

We recruited twelve participants aged 19 to 35 (4 females, 8 males). They completed a Pre-SSQ questionnaire to ensure that they did not feel any cybersickness symptoms prior to the onset of the study. No symptoms were reported.

3.2 Apparatus

3.2.1 Hardware

The experiment was conducted on a PC (i5-6500 3.2GHz CPU 3.2, GeForce GTX 970 GPU, 8GB RAM) with an Oculus Rift CV1 head-mounted display. Participants used an Oculus Touch to indicate their nausea level on a 10-point scale (see Figure 2), similar to previous work [6], [11]. To indicate their nausea level, they pointed a ray at the intended level (icon) and selected using the right trigger button of the Oculus Touch controller.

Figure 2: Nausea Likert scale questionnaire. Participants used this to rank their current nausea level every 1.2 minutes in the preliminary study, and every 2 minutes in the evaluation of viewpoint snapping.

3.2.2 Software

We used an available FPS level demo[5] (see Figure 3) as a base and customized the game. The software was instrumented to collect participant nausea levels via the survey mentioned above. The software automatically rotated the viewpoint continuously after the onset of the experiment, at a speed controllable by the experimenter.

Figure 3: Software setup. The character started in the centre of the environment, as depicted by the white camera character.

3.3 Procedure

Participants first signed a consent form and we explained the experimental method. We asked participants to rate the level of nausea from 1 to 10 after each trial. Our objective was not to quantify their level of vection, but rather to assess at which rotational speeds they experienced the greatest degree of nausea. As Keshavarz et al. [22] report, is hard to quantify vection directly because participants usually have different experiences, or may report in a biased or unreliable fashion.

Participants were instructed that they could withdraw and stop the experiment at any time, especially if they experienced extreme symptoms. The participant then put on the Oculus Rift head-mounted display. The camera started rotating while the participant looked forward. We instructed participants to hold their head stationary during this rotation. After 1.2 minutes the nausea rating questionnaire (see Figure 2) appeared on the screen. The participants rated their nausea from 1 to 10 using the Oculus Touch controller, as described in Section 3.2.1. Selecting a nausea score of "10" indicated that they wanted to stop and withdraw from the experiment. During the experiment, participants were also asked if they felt as though they were really rotating or not. Upon completion of the experiment, we asked them which rotational speed they preferred the most.

3.4 Design

The experiment included a single independent variable, *rotation speed* with 11 levels: 5□/s, 10□/s, 15□/s, 20□/s, 25□/s, 30□/s, 40□/s, 60□/s, 100□/s, 120□/s, and 200□/s. The dependent variable was the average level of nausea, as reported by participants using the Likert-scale survey seen in Figure 2.

3.5 Results and Discussion

As expected based on previous work, higher rotational speed yielded higher nausea scores. See Figure 4 and Table 1. While expected, this data gives us thresholds where cybersickness was worst, to help inform the design of our viewpoint snapping technique. Based on our findings and previous work [14], [32], the preferred rotation speed was between 15°/s and 35°/s (chosen by 10 participants). At higher speed, participants felt uncomfortable. One-way ANOVA revealed a significant difference in nausea scores by rotational speed ($F_{10,121} = 5.1, p = 0.0001$).

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[1] http://www.croteam.com/

[2] http://www.capcom.com/

[3] http://www.vr-bits.com/

[4] https://www.youtube.com/watch?v=vVVdoquKhO8&t=15s

[5] https://www.assetstore.unity3d.com/en/#!/content/59359

Table 1: Experiment one – nausea scores by rotational speed.

	Rotational Speed (°/s)										
ID	**5**	**10**	**15**	**20**	**25**	**35**	**45**	**65**	**100**	**120**	**200**
P2	1	1	1	1	1	1	1	1	1	1	1
P8	1	1	1	1	1	1	1	1	1	1	1
P6	2	2	1	2	1	1	3	3	4	4	6
P12	1	1	2	2	2	2	2	3	3	3	8
P11	1	1	1	3	4	5	5	3	5	7	8
P1	3	3	4	4	4	4	5	5	5	5	5
P5	4	5	3	2	2	3	6	7	7	8	8
P3	2	5	6	6	5	6	6	7	8	9	🟥
P7	1	2	5	6	7	8	7	8	9	9	🟥
P4	1	4	5	6	6	6	8	8	🟥	🟥	🟥
P9	1	3	4	5	6	7	8	8	🟥	🟥	🟥
P10	1	1	8	6	7	8	8	9	🟥	🟥	🟥

Nine participants reported that at the highest speed (200°/s) scene details were no longer visible, and the feeling of movement was reduced. Four participants mentioned that they instead just felt dizzy. One participant mentioned that "*I felt rotation from 10°/s to 60°/s, but after that the rotation speed becomes unnatural, details are less obvious, and I just felt more nervous tension or mental strain*". Another participant mentioned he felt more tension from speed of 40°/s to 100°/s. At the speed of 200°/s, he did not feel any movement at all. As seen in Table 1, at high rotation speeds, several participants withdrew from the study. Three withdrew at 100°/s, and two more withdrew at 200°/s.

Based on these results, we ultimately decided on a threshold of 25°/s to activate viewpoint snapping Table 1. This threshold was the average of most participants' preferred speeds (between 15°/s and 35°/s). It also corresponded to the rotational speed where nausea scores started becoming more notable (a score of "4"), followed by a steady increase in nausea scores (see Figure 4).

We note here a possible confound in this experiment, due to the fact that rotational speeds were always presented in the same order, and hence increased with exposure time. We argue that this likely did not influence our results, and that the nausea scores reported were likely due to rotational speed. Exposure time was quite short (less than 15 minutes in total), and likely not long enough to yield cybersickness due to exposure alone [32]. Previous cybersickness researchers noted that nausea scores only significantly increase due to exposure after lengthy periods of time. While the exact duration varies depending on the source, the shortest exposure time reported to cause cybersickness is 20 minutes [20] [28] and as high as 60 minutes [25]. Given that our total exposure was about 13 minutes (1.2 minutes per condition), exposure time is likely not a factor.

Nevertheless, these nausea scores are likely best thought of as approximate due to the potential confound. That said, we argue that any difference due to counterbalancing the order of rotational speeds would be quite small due to the relatively short exposure time. Moreover, it also suggests that a threshold of 25°/s is likely slightly conservative. In other words, we may be activating viewpoint snapping at a slightly lower speed than necessary, which is unlikely to influence cybersickness, but may slightly affect performance and presence. Given the range of nausea scores seen in Figure 4, the best answer is likely to "calibrate" a viewpoint snapping threshold on a per-user basis. This was not practical for our current study but will be investigated in future.

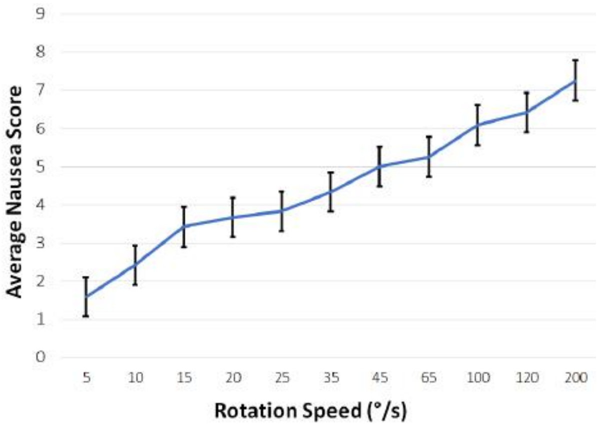

Figure 4: Average nausea rating based on different speeds. Error bars show ±1 *SE*.

4 VIEWPOINT SNAPPING TECHNIQUE

In this section, we describe our viewpoint snapping technique. For our current study, we used a mouse as an input device to control viewpoint rotation. Input devices (like the mouse or joysticks) induce cybersickness due to visual-vestibular conflicts and vection [22]. As noted by other authors, cybersickness is strongest in the absence of actual physical movements [3], [22].

We used a mouse rather than a joystick since it is a) more familiar to participants, and b) allows higher-speed position-control rotations, rather than the velocity-control rotations supported by joysticks. However, the technique is expected to work well with either input device. For example, Cloudhead Games[6] implemented a similar technique using a joystick, while Okleyros[7] used a mouse. Other similar techniques have been proposed by Oculus, who refer to it as "blinks" or "snap turns"[8].

For this initial study, we only used viewpoint snapping on vertical-axis rotation (i.e., *yaw*). So, snapping only occurred when the user was turning right or left with rotation speed over the threshold (25°/s) determined in the preliminary experiment. To activate viewpoint snapping, we used mouse movement speed (which corresponds directly to camera rotation speed) to modify the movement direction (i.e., gaze direction). When rotating above 25°/s, continuous rotation was replaced with a fast fading transition animation between 22.5° increments. The fading transition was intended to help prevent loss of spatial context, by preventing immediate jumps between viewpoint thresholds.

The effect is depicted in Figure 5 and behaves as though the user closed their eyes, quickly turned their head 22.5°, and then opened their eyes. In summary, our technique operates as follows:

- If rotation speed is less than 25°/s, no snapping occurs.
- If rotation speed is above 25°/s in a given yaw direction, the fading animation starts and the camera snaps in 22.5° increments in the specified direction.
- Upon reaching the next rotation increment, the fading transition stops (the transition speed is around 800ms).

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[6] http://cloudheadgames.com/

[7] http://doc-ok.org/?p=872

[8] https://developer.oculus.com/design/latest/concepts/bp-locomotion/

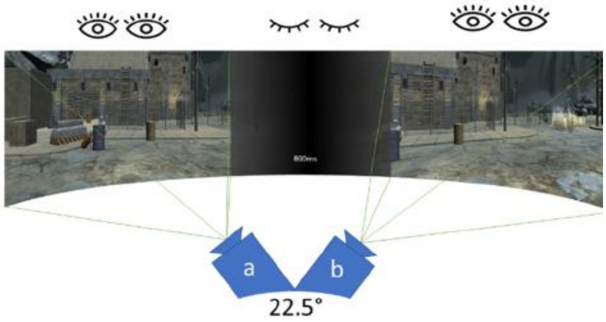

Figure 5: Viewpoint snapping. a) current position of the camera b) camera position, after 22.5° snap to the next viewpoint. Eyes indicate transition, during which, the screen darkens.

We decided on a 22.5° increment for snapping based on informal pilot testing. We initially tried a snapping distance of 45°, but found it disorienting [37]. The Oculus Best Practice guide [37] recommends a threshold of around 30° to prevent user disorientation. We tested the 30° range as well, but ultimately changed to 22.5° as we found it most comfortable. Snapping range is likely dependent on rotation speed and is a topic for future study.

5 EVALUATION OF VIEWPOINT SNAPPING

We conducted a user study evaluating the effectiveness of viewpoint snapping to reduce cybersickness. We assessed both its impact on user performance, as well as subjective measures of cybersickness levels and presence. We compared viewpoint snapping (VS) to a control condition without it (NVS) between two groups of participants. We hypothesized that viewpoint snapping would significantly reduce cybersickness, as assessed via the SSQ.

5.1 Participants

We recruited 28 participants (17 males, mean age of 26.4 years) for the study and divided them into two groups. The first group (5 female, 9 male) experienced the VS condition and second group (6 female, 8 male) experience NVS condition. The experiment was approved by the Carleton University Research Ethics Board.

We tried to recruit participants with a wide range of experience with HMD VR systems and equally distributed them between the two groups. Six participants had never used VR system before, while three used VR frequently (1 to 6 times per week). Of the remaining participants, five had experienced VR between 1 to 5 times ever, and the rest had experienced VR 6 to 15 times ever. We also asked about their experience with cybersickness. Six participants indicated that they had experienced some level of cybersickness previously. These participants believed that reasons for past experiences with cybersickness ranged from virtual movement when stationary, movement in a flight game, and technical issues like refresh rate, and jitter. Finally, none of the participants declared any medical conditions that would be relevant in our study (e.g., flu, taking nausea-related medicine, etc.).

5.2 Apparatus

5.2.1 Hardware

The experiment was conducted on a PC (i5-6500 3.2GHz CPU 3.2, GeForce GTX 970 GPU, 8GB RAM) with an Oculus Rift CV1 head mounted display. The input devices included an Eastern-Times Tech gaming mouse (ET7), and a keyboard. According to previous work [10], the mouse offers superior navigation speed, so we used it rather a joystick. The setup is seen in Figure 6. To avoid potential fatigue effects, or potential harm to participants (e.g., falling due to dizziness), participants were always seated. This also reduces any demand for postural control [23].

Figure 6: Hardware setup, and a participant taking part in the experiment. Participants were seated on a fixed chair to avoid any movement or real body rotation.

5.2.2 Software

We developed a custom virtual environment in Unity3D, as seen in Figure 3 and Figure 1. We used the available FPS level demo[9] as a base, and customized the game to add data collection, and to implement viewpoint snapping. We used Navmesh agents for the enemies, so that they would approach the player position (i.e., main camera). Navmesh is available via the Unity Engine AI system. We created two version of the environment, one with viewpoint snapping, and one without. As is typical of FPS games, the player view vector was coupled with the mouse to make sure they could not use their head for aiming. However, head movement could still rotate the viewpoint independently of the “aim” direction [3].

The player stood in the middle of the environment while streams of zombie enemies – 40 zombies at a time – approached them. Each stream was considered one trial and took approximately 2 minutes to reach the player from their starting points. In total, there were 10 streams of 40 enemies each (400 enemies in total). The starting positions of the zombies were consistent from one trial to the next. Since our study focused only on viewpoint yaw, camera pitch was disabled, and the zombies always appeared in positions that the participant could aim at them without the need to look up or down. The participant avatar was depicted holding a gun, as the task involved shooting the zombies. The movement was disabled; the participant was always positioned in center of the environment to ensure that viewpoint translation did not influence the results.

5.3 Procedure

Participants first signed a consent form. The experimenter then explained the purpose of the experiment. Participants were informed that they could quit the study at any time if they felt too nauseous. The experimenter then explained the details of the task.

The task involved shooting at the zombies that appeared around the participant. To shoot a zombie, the participant had to center the viewpoint on the zombie and press the left mouse button, much like most mouse-based first-person shooter games. If they successfully clicked the zombie (i.e., shot it), the zombie would disappear. Zombies were positioned pseudo-randomly and distributed to

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[9] https://www.assetstore.unity3d.com/en/#!/content/59359

appear outside of the field of view, necessitating a great deal of rotational viewpoint movement for participants to find and shoot them. Zombies would slowly advance from their starting position to the participant's position. If a zombie came within 3 meters of the participant's position without being shot, they still disappeared, but this was considered a miss (i.e., an error). Error rates were recorded as a performance-based dependent variable.

Every two minutes, the same nausea questionnaire used in the preliminary study (see Figure 2) appeared on the screen, and the participant rated their current nausea level from 1 to 10, similar to our preliminary experiment, and previous studies [6]. If they gave a score of 10, we advised them to withdraw from the experiment; 3 participants withdrew in this fashion. Otherwise, participants performed the task in VR for a total of 20 minutes, in either the VS or NVS conditions.

Participants completed the SSQ questionnaire [19] twice, once before the study (Pre-SSQ) and once after. Only participants who had a Pre-SSQ score of less than 7.48 (based on previous work [5]) were permitted to take part in the study. We also asked participants to sit and rest for 5 minutes before the study to ensure any effects from walking or running to study location would dissipate prior to commencing the study. Although some researchers [21] have used a second Post-SSQ test about 5 hours after an experiment, we excluded this third SSQ.

Following completion of the experiment and the Post-SSQ test, participants also completed the Witmer and Singer presence questionnaire [36]. We then interviewed and debriefed participants. Participants were compensated with $10 for their time.

5.4 Design

Consistent with past cybersickness studies [9], [11], [21], [32], our experiment employed a between-subjects design, with a single independent variable: viewpoint snapping (enabled: *VS*, or disabled: *NVS*).

The dependent variables included total SSQ, total Presence, error rate (count of trials where a zombie reached the participant), and nausea scores (measured on a 10-point Likert scale, as discussed earlier). We hypothesized that with viewpoint snapping enabled, cybersickness (as reflected by SSQ scores) and nausea scores would decrease, but that error rate and presence would be worse due to the inconsistent motion yielding greater difficulty.

6 RESULTS

6.1 Total SSQ

Cybersickness was quantified using the Simulator Sickness Questionnaire (SSQ), developed by Kennedy et al [19]. The SSQ consists of 16 symptom categories aggregated into three major components, Nausea (e.g., general discomfort), Oculomotor problems (e.g., eyestrain), and Disorientation (e.g., vertigo). The total score is obtained from sub-scores calculated in each of these three components [5]. Total SSQ is then calculated as (Nausea score) + (Oculomotor score) + (Disorientation score) ×3.74 [5], [19].

Results for total SSQ scores are seen in Figure 7. Overall, viewpoint snapping (VS) did indeed yield better (lower) SSQ scores compared to the non-viewpoint snapping condition with average scores of 29.8 and 48.1 respectively. We conducted an independent samples t-test to compare differences in total SSQ between the VS and NVS conditions. There was a significant main effect for viewpoint snapping on total SSQ ($t(26) = 2.3$, $p = 0.026$, power=.79). Viewpoint snapping significantly lowered cybersickness levels compared to the control condition, as measured by total SSQ.

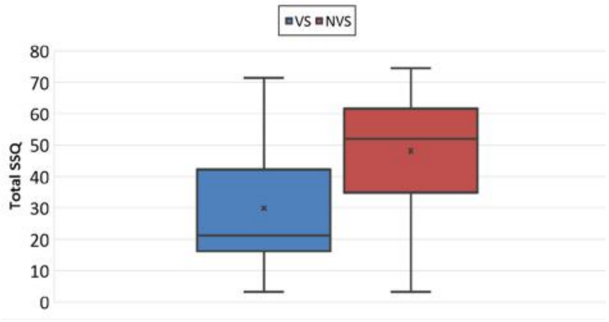

Figure 7: Box plot of total SSQ scores. Lower scores are better.

6.2 Nausea Score

Nausea scores were taken every two minutes. Nausea scores as a function of time are seen in Figure 8. Unsurprisingly, nausea levels increased over time due to the excessive viewpoint rotation necessitated by the experimental task. What is interesting is that viewpoint snapping again resulted in reduced symptoms as compared to the non-viewpoint snapping condition. We performed a repeated measures ANOVA to evaluate the effect of viewpoint snapping and exposure time on nausea scores. There was a significant main effect for viewpoint snapping on nausea scores ($F_{1,9} = 20.7$, $p = 0.0012$). The viewpoint snapping group had significantly lower nausea scores. The effect of time was also significant ($F_{9,9} = 7.8$, $p = 0.0027$). As seen in Figure 8, nausea scores increased with time. However, the interaction effect between viewpoint snapping and exposure time was not significant ($F_{9,9} = 0.9$, $p = 0.5$), suggesting that both viewpoint snapping conditions increased in nausea at about the same rate. It is possible that a longer experiment or a larger participant pool may reveal differences, as the trends appear to diverge slightly by the 20-minute mark in Figure 8.

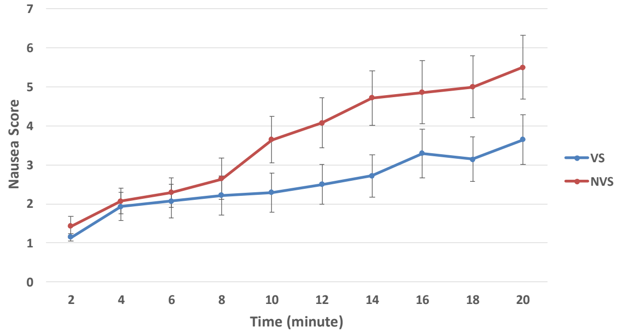

Figure 8: Total nausea differences as a function of time. Error bars show ±1 SE.

6.3 Error Rate

The total number of errors (i.e., number of times a zombie reached the player) was not significantly different between the two viewpoint snapping conditions. See Figure 9. An independent samples t-test was conducted to compare differences in total error between the VS and NVS conditions. The difference was not significant ($t(26) = 0.3227$, $p = 0.7$). While this does not allow us to categorically claim that error rate is *not* affected by viewpoint snapping (since one cannot "prove the null hypothesis" this way), we take this as a positive sign that any performance difference due to viewpoint snapping is potentially small.

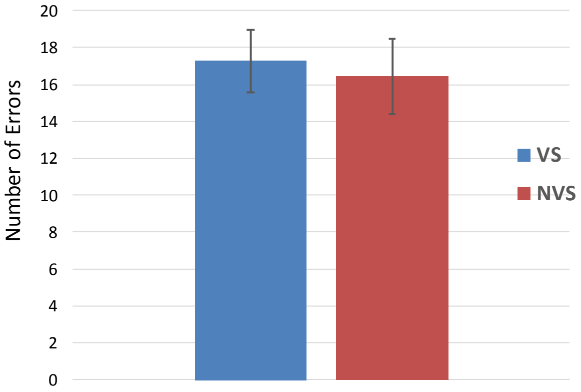

Figure 9: Error rate by viewpoint snapping. Error bars show ±1 *SE*

6.4 Presence

Similarly, the result of the 23-question Witmer and Singer presence questionnaire [36] revealed no significant difference between two groups in terms of presence, as confirmed by an independent samples t-test ($t(44) = 1.9$, $p = 0.06$). Note that presence was slightly (but not significantly) lower for the VS group (mean = 4.16, $SD = 1.2$) than the NVS group (mean = 4.89, $SD = 1.4$).

7 DISCUSSION

Overall, viewpoint snapping significantly reduced participant cybersickness levels (per the SSQ) by about 40%. As argued earlier, this makes sense and is consistent with our expectations based on past research on inconsistent camera movement and reducing optic flow [4], [31].

Of course, viewpoint snapping introduces a tradeoff between user comfort and naturalism/realism, much like other cybersickness reduction methods such as blurring, headlock, and field-of-view reduction (or "tunneling"). Interviewing participants after the experiment revealed some insights here. For example, 4 participants out of 14 in the VS condition mentioned that they initially found the snapping disoriented them. This may explain why this group had slightly (although not significantly) worse error and presence scores. However, after playing for a few minutes, participants indicated that they eventually got used to the snapping and it started to feel more comfortable. For example, one participant indicated that "at the start of the game it was annoying and frustrating to jump to different angles, but after 2 or 3 minutes I felt I could control my actions better".

The result that presence and error rates were not significantly worse with viewpoint snapping surprised us, as it was inconsistent with our hypothesis. Although we are hesitant to report such a null result, we are cautiously optimistic that this might suggest a limited impact of viewpoint snapping on objective user performance and presence in VR games. Further studies will help gather additional support for (or refute) this result, though, so we caution the reader against taking this result as definitive at this time.

Interestingly, two participants did not even notice the snapping occurring during the experiment. We note that both participants had very limited VR experience – one had had no prior exposure, and the other only had 1 to 5 prior VR experiences. After the experiment, when asked if they noticed the snapping, both indicated that thought that the snapping feature was part of the game.

We also note that three participants mentioned that the transition animation was distracting. The blinking of the screen made them dizzy and blurred their vision. Two participants mentioned this was particularly true for large rotation angles, which made it more disorienting and harder to aim. That said, our objective error results indicate limited impact on user performance.

Finally, as mentioned earlier, three participants withdrew from the experiment. We note that one of these withdrew from the VS condition at the 14-minute mark. The other two withdrew from the NVS condition, at the 4- and 7-minute mark, respectively. It is noteworthy that these withdrawals occurred more frequently and much earlier in exposure when viewpoint snapping was not enabled. This may indicate that viewpoint snapping can help increase VR exposure time prior to experiencing adverse cybersickness effects; but, this too needs further exploration in the future. Of course, the task we used in our experiment was an extreme example designed to elicit a cybersickness response.

7.1 Limitations and Future Work

As discussed earlier in Section 3.5, there is a potential confound in our preliminary experiment, from which we derived our rotational speed threshold at which to activate viewpoint snapping. As argued in Section 3.5, we suspect the impact of this potential confound is quite small. For our purpose, the 25°/s threshold appeared to be effective – our viewpoint snapping condition did reduce cybersickness, as expected. Nevertheless, future work will focus on establishing more reliable thresholds, since it is possible our current implementation unnecessarily activates viewpoint snapping at lower rotational speeds than is strictly necessary. A more well-established snapping threshold may yield better results.

Another limitation of our current evaluation is the fact that participants were stationary while performing the zombie shooting task. Testing the effectiveness of viewpoint snapping during free-roaming navigation is a clear opportunity for future studies, and would allow us to evaluate the effectiveness of viewpoint snapping in more realistic tasks. Other topics for future work include determining an empirically validated snapping range. We used 22.5° in the current experiment based on informal pilot testing. It is likely that "fine-tuning" this parameter by testing different snapping ranges (potentially dependent on rotational speed) will yield better results. Finally, we may further investigate viewpoint snapping in scenarios outside of rotational movements, for example, translation snapping for linear movement, both with and without rotation snapping.

8 CONCLUSION

In this paper, we proposed a novel method for reducing cybersickness caused by visual-vestibular conflicts in stationary VR gaming. This technique was motivated by previous research that found that optic flow and inconsistent movement/displacement can considerably reduce cybersickness. Based on this work, and our own preliminary experiment on cybersickness thresholds with respect to rotational speed, we developed the viewpoint snapping technique. Results of our experiment indicate that the technique did indeed reduce cybersickness, with potentially low cost in terms of user performance and presence. Moreover, there is slight reduction in level of verbally reported nausea experienced by participants. Overall, our results are promising and motivate us to further study the effects of viewpoint snapping in VR environments.

ACKNOWLEDGMENTS

Thanks to all participants who took part in the experiments. This work was supported by NSERC.

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