Gaming Background Influence on VR Performance and Comfort: A Study Using Different Navigation Metaphors

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Abstract. Navigation metaphors in Virtual Reality environments have consistently challenged researchers and developers due to the difficulty of implementing locomotion techniques with high levels of comfort, sense of presence, efficacy and able to fit different narrative environments. In this context, several studies have linked cybersickness to the performance of navigation metaphors, concluding that navigation metaphors based on natural locomotion and with kinesthetic feedback (such as walking-in-place) are more comfortable than those based on indirect locomotion (such as flying). In this paper, we present the results of a study where 41 individuals were asked to navigate a VR environment with two different navigation metaphors. A primary performance metric (karmapoints) derived from the game mechanics introduced in the virtual environment was recorded. Additional subjective metrics about comfort (related to cybersickness) were also recorded through questionnaires. Our results show that participants with a more intense "gamer" background outperform those without such background in both navigation metaphors, regardless of their previous VR experience. Likewise, high level gamers felt less comfortable with the walk-in-place metaphor, which challenges the more accepted explanations of the causes of cybersickness.

Keywords: Virtual reality · Games · Interaction · Navigation

1 Introduction

From the early 2000s, we have witnessed a significant increase in the amount of Virtual Reality (VR) software, devices, and platforms. The scope of this paper is limited to VR systems based on Head Mounted Displays (HMDs).

One of the most challenging design decisions that VR developers face is how users will interact with the Virtual Environment (VE), i.e., the artificial world

M. Antona and C. Stephanidis (Eds.): HCII 2019, LNCS 11572, pp. 646–656, 2019.
https://doi.org/10.1007/978-3-030-23560-4_47

filled with assets designed to host the virtual experience. Even when hundreds of interactions are available (e.g., grabbing an apple from the tree, shooting a tank cannon, etc.), locomotion (the navigation ability of users) remains the most common user action. According to Bowman's taxonomy of interactions in Virtual Reality [1], locomotion can be understood at three different levels:

– Travel: Control of the user's viewpoint and motion in the three-dimensional environment.
– Way-finding: Cognitive process of determining a path based on visual cues, knowledge of the environment and aids such as maps or compasses.
– Navigation: Together, travel and way-finding make up the overall interaction called navigation.

In games and simulators designed for traditional screens, interaction typically occurs through devices such as keyboards, mice, joysticks, game pads or touch screens. Actions performed with these devices are mapped on a quasi-standard set of reactions inside the environment. For example, pushing forward on a joystick, pressing the W key, pressing the UP arrow key or pushing forward on the mini-stick of a pad, are actions typically linked to the forward motion of a character, a vehicle or other virtual avatars. These unwritten assumptions define what is called "an intuitive control schema."

When trying to adapt these intuitive controls (which have been perfected for more than 60 years of gaming and simulation history) to the VR medium, developers found that traditional navigation methods are not entirely suitable to this emerging platform. At the root of the problem is cybersickness, a phenomenon that typically manifests itself as disorientation, eye strain or nausea, among others [12]. Cybersickness is inherent to VR but strongly linked to simulator sickness. It is also common in 3D non-stereoscopic screen environments [11], but has different origins and symptoms [14].

To avoid cybersickness, various locomotion metaphors have been proposed based on natural movements, real or fake, such as redirected walking, walk-in-place or arm swinging. These approaches, far from traditional navigation techniques for games and simulators, are designed to reduce the negative effects of VR. However, as a result of the alternative kinesthetic way of operation, they also reduce performance, mainly in usual gamers, as a collateral effect of the loss of control [13].

In this paper, we compared cybersickness and user performance with two different groups of users: High Intensity Gamers (HIG) and Low Intensity Gamers (LIG). Our results show that both groups of participants experienced higher levels of cybersickness when using a head-bobbing (HB) navigation metaphor. Significant differences were also observed between groups in terms of performance both with natural locomotion (HB) and artificial locomotion (touch-pad based indirect walking, TP).

2 Previous Work: Cybersickness and VR

Cybersickness or VR-induced sickness is a phenomenon derived from the use of Virtual Reality through a Head Mounted Display (HMD) [2,3]. It is a polysymptomatic sickness [4] which means that it causes different symptoms in different people. The most common symptoms include nausea, oculomotor disorders and disorientation [5].

There are several explanations of the causes of cybersickness. The most accepted theory is the Sensory Conflict Theory (SCT). In the words of Mousavi et al. [15], "the theory is based on the premise that discrepancies between the senses which provide information about the body's orientation and motion cause a perceptual conflict which the body does not know how to handle. With cybersickness and motion sickness, the two primary senses that are involved are the vestibular sense and the visual sense. These sensory conflicts arise when the sensory information is not the stimulus that the subject expected based on his/her experience". In cybersickness, those discrepancies come from vection, i.e. the perception of a fake self-movement through visual feedback even when there is no actual movement [16]. By linking vection to interaction, the possibility of "real walking" can be provided through navigation metaphors such as redirected walking, walk-in-place or stepper, among others, which reduces discrepancies between the visual and the vestibular systems [17]. Therefore, the use of traditional game controllers like joysticks or game pads with mini-sticks that simulate indirect walking (similar to flying) should improve vection and consequently, cybersickness [9].

3 Empirical Evaluation

A total of 41 individuals (29 males and 12 females) participated in our study. The average age of the participants was 24.22 years old. Participants included students and staff members from Florida Universitaria, an external campus of the Universitat Politècnica de València in Spain. IRB approval was obtained and all participants gave written informed consent for the study.

3.1 Procedure

In order to determine the influence of locomotion techniques in different psychological and physiological aspects of the user, a Virtual Environment was developed where participants had to navigate and perform various tasks. Data were collected before, during and after the VE session. Since our study involved intra-group comparisons, each individual experienced the virtual environment twice, each with a different navigation metaphor. The order of the conditions was randomized to minimize learning bias.

The experiment was divided into three stages:

1. Pre-VE questionnaires: Collection of demographic data such as participants' gender or age. Additionally, participants had to identify themselves as Hight Intensity Gamers (HIG) or Low Intensity Gamers (LIG) based on how often they played video games, the places where they played, and the gaming devices they owned.

2. Virtual environment. Performance data while experiencing the VR environment (time, distance, etc.)
3. Post-VE questionnaires: Participants completed the ITC-Sense of Presence Inventory questionnaire [7]. The Negative Effects factor was considered as a metric to identify cybersickness symptoms.

3.2 Experimental VE

The VE used in our experiment took the form of a maze filled with karmaspheres (which give the player karmapoints) and various hazards such as fire or poisoned puddles (which take karmapoints away from the player) that "harm" the player unless a shield is activated. The shield is a field of energy that protects the player against any hazard but makes him walk at a slower pace. The goal is to find the exit of the maze within the allotted time (3 min) and the maximum amount of karmapoints.

When first entering the virtual environment, the following audio instructions were played:

Hello and welcome to our maze. You have been selected to participate in a competition where there can only be one winner. You will have 3 minutes to find the exit of the maze and throughout your journey, you must collect as many karmaspheres as you possible. Karmaspheres can be picked up by simply touching them. Each karmasphere you collect will increase your Karma score. But, beware, there are elements that can make you lose karma. Exposing yourself to risks may cause the loss of karmapoints. Fortunately, we will not let you face the hazards of this maze totally unprotected. You have a shield that can protect you from all the risks you may find throughout your journey. While active (by pressing the trigger button at the bottom of your controller), no karma will be lost. However, your shield will slow you down and you will not be able to collect any more spheres. The shield is powered by a battery which is discharged with each use, but recharges automatically when the shield is not in use. If the battery becomes completely empty, you will not be able to activate the shield until it recharges. Before entering the maze, you will have the opportunity to become familiar with how to interact with our virtual space by entering the training area. In this area, you will have to approach three target points marked with lights in the following order: green, yellow and red, and capture your first karmaspheres. Immediately after collecting the last karmasphere at the red light, you will be teleported to the actual maze and the competition will begin.

To explore this scenario you will use:

- *Touchpad. Touch it (gently) to move in the direction of your line of sight*
- *Walk-in-place (Walk on site). The system detects the movements of your head up and down, so, maybe, you should exaggerate your steps slightly.*

Remember, you must leave the maze before the time runs out, and earn the greatest amount of karma. Are you ready? Good luck!

The "Training Room," is a small environment with a neutral and minimalist design to reduce the user cognitive impact of the first encounter with our virtual environment (Fig. 1). The room is designed to practice the three basic interactions available in the VE: locomotion, picking up spheres and activating the shield. Participants were asked to navigate to three different spot lights located on the floor in a specific sequence: green, yellow, red. This task allows users to practice the specific locomotion technique assigned to their group. Karmaspheres are included to practice the catching action and the option to test activation/deactivation of the shield (pressing the trigger button in the controller) is also available.

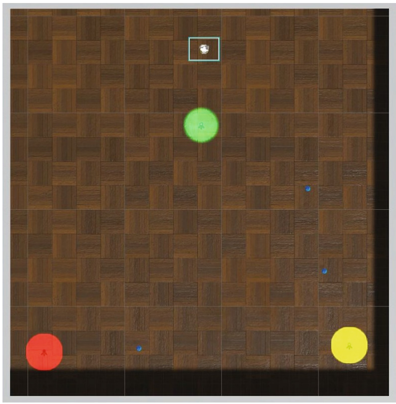

Fig. 1. Top view of the training room (Color figure online)

After completing the training, a new scene is loaded in the VE. The user is placed in a larger room called the "Risk Room" (Fig. 2). This room has a maze structure, which makes navigation more challenging. Along the path that leads to the exit, participants will encounter three different hazards. The hazards are strategically designed to trigger behavioural presence signals and evaluate risk perception as the primary goal of our study. A detail of a participant' view with a fire hazard and some karmaspheres is shown in Fig. 3.

3.3 Hardware Elements

The virtual experiences were implemented on a HTC Vive system [18], composed of two standard tracking cameras and a headset. The system was supported by a high performance laptop with Intel i7 CPU, 16 GB RAM and NVIDIA 1050Ti

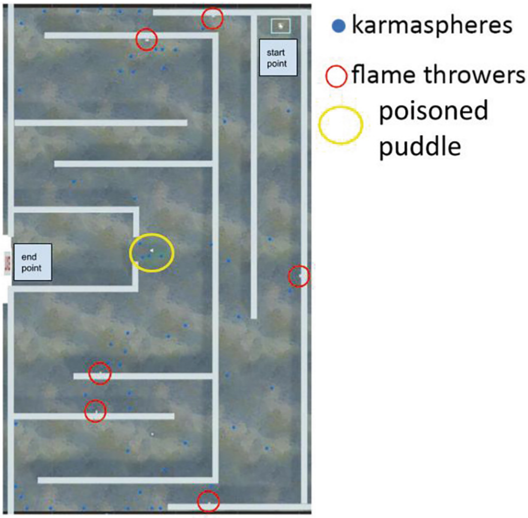

Fig. 2. Top view of the VE

GPU to ensure high graphic performance and avoid the appearance of visual glitches such as rendering delays or similar issues that could affect the users' perception.

The commercial version of the Vive has a refresh rate of 90 Hz. The device uses one screen per eye, each with a display resolution of 1080×1200. The headset and the controllers include more than 70 infrared sensors and contain an internal gyroscope and accelerometer. These sensors are used in combination with two stationary "lighthouse" base stations that can track the user's movement with submillimeter precision. The lighthouses emit infrared light and are effective within a $4.6\,\text{m} \times 4.6\,\text{m}$ tracking space.

The HTC Vive's headset also has a front-facing camera that allows the user to observe her surroundings without removing the headset. The camera can be used to identify any moving or stationary object in a room. This functionality can be implemented as part of a "Chaperone" safety system, which will automatically display a virtual wall or a feed from the camera to safely guide users away from obstacles or real-world walls.

3.4 Locomotion Techniques Implementation

In our experiment, two different locomotion techniques were implemented: head bobbing and indirect walking. Head bobbing is a technique based on the detection of head movements that an individual makes when walking, even when walking in place. Using HTC Vive's sensors, we were able to accurately detect those movements in the real world and translate them to the locomotion pace of the virtual avatar. Furthermore, since our head moves faster when we run, faster

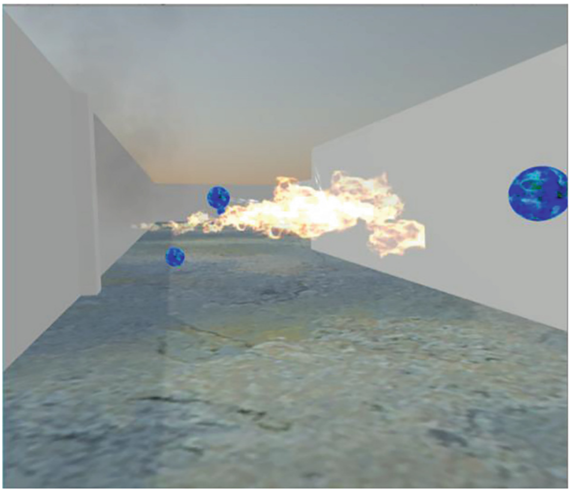

Fig. 3. First person view of the VE

movements are registered even if user runs in place. Consequently, faster movements are applied to the avatar. Although some commercial implementations of this technique add arm tracking (through the controllers) to provide a more robust input system, it was not considered in our study due to the additional energy consumption and effort required from participants.

Indirect walking is a navigation metaphor that is similar to the way we move in a traditional video game. By pushing down the touchpad in the controller, the users' avatar moves in the direction he is facing (the HMD determines the gaze orientation). This technique has a fixed speed and cannot be increased. We conservatively set it at 2 m/s, based on the results by So et al. [6], which suggest that cybersickness symptoms increase quickly at speeds higher than 3 m/s.

3.5 Metrics

The following parameters were used as performance indicators (values were tracked for both walk-in-place metaphor and indirect walk metaphor):

- Karma (K): The final amount of karmapoints earned (and not lost) by participants. Each karmasphere equals 1 karmapoint.
- Time (T): The time (in seconds) that the individual spent from the beginning of the experience until the exit point was reached.
- Shield (TS): The amount of shield used. It is a factor obtained by multiplying the time (in seconds) that the user keeps the shield active by the intensity of activation (how far the trigger button was pressed).

The ITC-SOPI questionnaire [7] was used to assess cybersickness. The Negative Effects factor in this questionnaire provides a simple alternative to the classic

SSQ [5], including information about adverse physiological symptoms such as “I felt nauseous,” “I felt dizzy,” “I felt I had a headache,” or “I had eyestrain.”

Finally, participants were asked to identify themselves as High Intensity Gamers (HIG) or Low Intensity Gamers (LIG), based on how often and for how long they play video games, and the places and the priority of gaming in their lives. We prioritized qualitative over quantitative evaluation to avoid negative social bias.

4 Results

Our sample (n = 41) was split into two main groups: HIG (High Intensity Gamers; n = 30, 73.17%) and LIG (Low Intensity Gamers; n = 11, 26.83%) (Table 1).

Table 1. Demographic variables for each gaming subgroup

Variable	HIG	LIG
Age	22.8 (sd = 6.04)	28.09 (sd = 10.7)
Male	86.66%	27.27%
Female	13.33%	72.73%

4.1 Performance

Karma value was the only factor considered as a performance indicator. Since users had to maximize their activity in the maze to obtain the most karmapoints without going over the 3 min limit, Time and Distance do not necessarily reflect better performance. Our results show that a participant’s previous experience in video games generally translates into better performance in the new medium, with alternative interactions. In terms of average karmapoints, the HIG group scored nearly the double amount of points (AVG = 17.13, sd = 6.84) than the LIG group did (AVG = 9.675, sd = 8.96). In terms of the two different navigation metaphors (HB for Head-Bobbing and TP for TouchPad based indirect walking), our results show a similar distribution (see Fig. 4).

All variables were normally distributed (Kolmogorov Smirnov $p > .05$), and a t-test to both subgroups revealed statistically significant differences for both conditions: HIG KarmaTP and LIG KarmaTP ($p = 0.0415$) and HIG KarmaHB and LIG KarmaHB ($p = 0.0139$). No significant differences between karmapoints under each navigation condition were found in intra-group analysis.

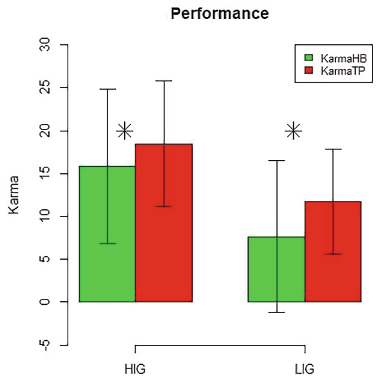

Fig. 4. Karmapoints per intensity of gaming profile and locomotion metaphor

4.2 Cybersickness

As an indicator of cybersickness, we analyzed the Negative Effects dimension (SOPI-NE) of the ITC-SOPI questionnaire. The values in this scale range from 1 (strongly disagree) to 5 (strongly agree). Higher scores are related to a higher sense of cybersickness.

In our study, the HIG subgroup scored slightly lower in the SOPI-NE (AVG = 2.261, sd = 0.86) than the LIG subgroup, SOPI-NE (AVG = 2.371, sd = 0.959). Differences in navigation conditions per subgroup are shown in Fig. 5.

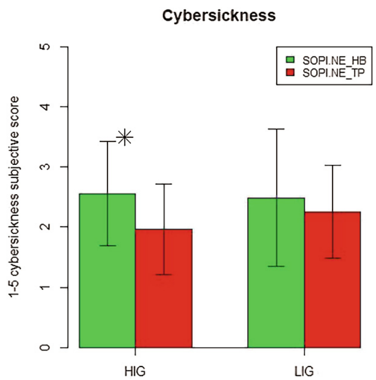

Fig. 5. SOPI Negative Effects per gaming subgroup and navigation metaphor

No significant differences between subgroups were found for the navigation conditions. However, an intra-group analysis revealed significant differences in the HIG group between head-bobbing navigation and touchpad indirect walking navigation (p = 0.006998). The difference is not significant in the LIG group (p = 0.5904).

5 Discussion

In our gamified VE, High Intensity Gamers performed consistently better than Low Intensity Gamers with similar prior VR experience, regardless of the navigation metaphor used to explore the maze. This sheds light on the transferability of gaming skills between different locomotion techniques, which is counter-intuitive since users had never experienced a walk-in-place metaphor before.

Both groups of participants performed better with the more artificial locomotion technique, the indirect walking based on touchpad. Despite being considered less comfortable in terms of cybersickness (caused by vection), this technique offers a better sense of control, as described by Bozgeyikli et al. [8].

Regarding the cybersickness assessment based on the ITC-SOPI Negative Effects factor, no significant differences were found between HIG and LIG, which suggests that prior gaming experience does not prevent cybersickness symptoms. However, by studying each group individually important differences were found in the HIG subgroup between the two locomotion metaphors. Specifically, users felt significantly more uncomfortable with the walk-in-place technique than they did with the touchpad based indirect walking. This result is interesting because it contradicts prior research on cybersickness [9,10] which claims that indirect walking is supposed to cause more vection due to the evident mismatch between visual and vestibular systems. No differences in cybersickness were found between navigation metaphors in the LIG subgroup.

6 Conclusions and Further Work

In this paper, a VE (a maze) with various gamified interactions was implemented to determined the effects of two different navigation metaphors related to the gaming profile of users on cybersickness and performance. Our results show that High Intensity Gamers performed better than Low Intensity Gamers in both locomotion methods. More significant differences were observed between locomotion techniques in the HIG group. Participants in this group reported feeling significantly worse with the walk-in-place technique, even when considered more comfortable than the one based on touchpad. Our findings suggest that prior gaming experience may play an important role in cybersickness, which naturally calls for further studies on gaming background: what genres of games do users play? On which platforms? For how long have they been playing games?

References

1. Bowman, D.A., Koller, D., Hodges, L.F.: A methodology for the evaluation of travel techniques for immersive virtual environments. Virtual Reality **3**(2), 120–131 (1998)
2. LaViola Jr., J.J.: A discussion of cybersickness in virtual environments. ACM SIGCHI Bull. **32**(1), 47–56 (2000)

3. Sharples, S., Cobb, S., Moody, A., Wilson, J.R.: Virtual reality induced symptoms and effects (VRISE): comparison of head mounted display (HMD), desktop and projection display systems. Displays **29**(2), 58–69 (2008)
4. Nichols, S., Patel, H.: Health and safety implications of virtual reality: a review of empirical evidence. Appl. Ergon. **33**(3), 251–271 (2002)
5. Kennedy, R.S., Lane, N.E., Berbaum, K.S., Lilienthal, M.G.: Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. Int. J. Aviat. Psychol. **3**(3), 203–220 (1993)
6. So, R.H., Lo, W.T., Ho, A.T.: Effects of navigation speed on motion sickness caused by an immersive virtual environment. Hum. Factors **43**(3), 452–461 (2001)
7. Lessiter, J., Freeman, J., Keogh, E., Davidoff, J.: A cross-media presence questionnaire: the ITC-Sense of Presence Inventory. Presence Teleoperators Virtual Environ. **10**(3), 282–297 (2001)
8. Bozgeyikli, E., Raij, A., Katkoori, S., Dubey, R.: Locomotion in virtual reality for room scale tracked areas. Int. J. Hum.-Comput. Stud. **122**, 38–49 (2019)
9. Frommel, J., Sonntag, S., Weber, M.: Effects of controller-based locomotion on player experience in a virtual reality exploration game. In: Proceedings of the 12th International Conference on the Foundations of Digital Games, p. 30. ACM, August 2017
10. Merhi, O., Faugloire, E., Flanagan, M., Stoffregen, T.A.: Motion sickness, console video games, and head-mounted displays. Hum. Factors **49**(5), 920–934 (2007)
11. Davis, S., Nesbitt, K., Nalivaiko, E.: A systematic review of cybersickness. In: Proceedings of the 2014 Conference on Interactive Entertainment, pp. 1–9. ACM, December 2014
12. Biocca, F.: Will simulation sickness slow down the diffusion of virtual environment technology? Presence Teleoperators Virtual Environ. **1**(3), 334–343 (1992)
13. Albert, J.M.: User-centric classification of virtual reality locomotion methods. Doctoral dissertation (2018)
14. Stanney, K.M., Kennedy, R.S., Drexler, J.M.: Cybersickness is not simulator sickness. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 41, No. 2, pp. 1138–1142. SAGE Publications, Los Angeles, October 1997
15. Mousavi, M., Jen, Y.H., Musa, S.N.B.: A review on cybersickness and usability in virtual environments. In: Advanced Engineering Forum, vol. 10, pp. 34–39. Trans Tech Publications Ltd., December 2013
16. Rebenitsch, L., Owen, C.: Review on cybersickness in applications and visual displays. Virtual Reality **20**(2), 101–125 (2016)
17. Llorach, G., Evans, A., Blat, J.: Simulator sickness and presence using HMDs: comparing use of a game controller and a position estimation system. In: Proceedings of the 20th ACM Symposium on Virtual Reality Software and Technology, pp. 137–140. ACM, November 2014
18. HTC Corporation 2018. HTC Vive (2018). https://www.htcvive.com. Accessed 16 Dec 2018