VR Rio 360: The Challenges of Motion Sickness in VR Environments

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Abstract. Motion sickness is a major concern that Virtual Reality (VR) manufacturers face and that has the potential to hinder this technology popularization. With related research since its inception in the 1960 s, motion sickness has been the subject of research by various institutions around the world. We have analyzed some of those studies and, along with the development of VR Rio 360, application developed by SIDIA (Samsung R&D Center in Brazil) for Samsung Gear VR, it was possible to investigate the factors that can cause this side-effect and also present possible technical solutions to reduce its occurrence in the application.

Keywords: Virtual Reality · Motion sickness · Cybersickness

1 Introduction

Virtual Reality (VR) is a mobile or computer simulated environment that gives an user a sense of immersion and presence through three-dimensional (3D) images with the support of visual, auditory and tactile feedback [1]. At this time, the relevance of VR is in the possibilities that this tool presents with applications that range from entertainment areas, such as games and movies, to medical and even military areas, with healthcare training and simulated air fighting, for instance. In the past five years, the technology behind VR and its multiple applications has developed quickly with the support of companies from the technology sector (e.g., HTC, Sony, Samsung, and Google). Due to that, VR has gathered the interest of content providers and researchers in the pursue of better and detailed studies regarding the current shortcomings of its applications.

Currently, one of the technology's biggest challenges is the discomfort caused by the continued use of its applications. In point of fact, experiencing discomfort as a side-effect of using these applications has been one of the biggest threats to widespread VR adoption over the past decades, as few people accept a technology that causes them to suffer while using it, and in some cases long after using it [3].

The current work presents definitions and discussions related to VR's discomfort issues, and also a case study related to the search for a solution for these problems in a application.

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1.1 Technology-Related Conditions

The discomfort that users feel while or after experiencing Virtual Environments (VEs) is often defined as motion sickness, simulator sickness or cybersickness. Although there are connections between the symptoms experienced in motion sickness, simulator sickness and cybersickness, their groups of symptoms can help to differentiate the three conditions [3].

Motion sickness refers to adverse symptoms and observable signs that are associated with exposure to real and/or apparent motion [11, 12]. It can be caused by any type of moving vehicle, including submarines, airplanes and trains, but it can also arise through playful activities such as a spinning chair, or a simple playground swing. Commonly known as seasickness, airsickness or car sickness, motion sickness appears to be more common in the age group between 4 and 12 years, where there is a predisposition to the condition [3]. Other factors that can increase the possibility of the condition's occurrence are related to user characteristics (i.e. experience, gender, field independence, age, illness, mental rotation ability, postural instability, susceptibility to motion sickness), personality factors (individuals low in extraversion, high in neurosis, and/or high in anxiety), and/or exposure schedules (e.g. duration, repetition). However, nearly all individuals experience it if exposed to enough motion stimuli [12].

Simulator sickness is a subset of motion sickness that is typically experienced by pilots who undergo training for extended periods of time in flight simulators. Possibly, the observed differences between the simulator's motion and the machine may be the cause of the condition. It is important to note that a simulator is not only a machine that creates a full environment, but it can also be represented by a head-mounted display with several sensors and motion indicators (e.g. floor vibration, surround sound, movement capture). Apathy, sleepiness, disorientation, fatigue, vomiting and general discomfort are the symptoms to which users can be submitted to after the use of simulators.

On the other hand, cybersickness is not caused by physical movement, but rather by the experience of seeing the movement in a virtual reality content/system while your body is stationary. It is a visually induced motion sickness resulting from immersion in a computer-generated virtual world – results from shortcomings of the simulation, but not from the actual situation that is being simulated [12]. Among the symptoms of cybersickness are nausea, eye strain and dizziness. Thus all of the conditions mentioned above can be used to explain VR sickness, since they do not cover the Virtual Reality-related discomfort separately.

1.2 Cybersickness Causes

Even today, there are many discussions about the underlying symptoms related to cybersickness. These debates contribute to the formulation of strategies for creating environments where the probability of problems can be overcome [3]. Over the decades, three theories on the cause of cybersickness have gained relevance: poison theory, postural instability theory, and sensory conflict theory [2].

According to poison theory, there is an evolutionary mechanism of survival that is activated every time the user undergoes consistent sensory hallucinations through the ingestion of some kinds of poison. Poison theory attempts to explain the reason that causes motion sickness and cybersickness from an evolutionary point of view [3]. The theory indicates that poison ingestion is responsible for physiological effects related to the coordination of visual, vestibular, and other input sensory systems. These physiological effects act as a premature warning mechanism that increases survival, causing a reflux of stomach contents. The improper exploration of some virtual environments can affect the visual and vestibular systems to the point where the body misrepresents the information collected and concludes that it has ingested some toxic substance, causing emetic responses (vomiting and nausea are mechanisms designed to expel everything that the stomach considers to be toxic). Poison theory research presents an interesting point of view within the occurrence of cybersickness, but there are gaps in both predictive analysis and conclusions about why people who are sensitive to virtual environments do not always have an emetic response. Other unexplained absences refer to why some people suffer from cybersickness in VEs with certain stimuli while others do not suffer from the same stimuli. It is believed that there is a pattern of visual stimuli and/or vestibular system stimuli that trigger motion sickness, and accidentally activate brain sensors for the detection of toxins. However, this interpretation fails to explain the amplitude of symptoms and the varied individual responses, while there is currently limited evidence for this theory [3].

Whenever the environment suddenly presents changes in its form, making it impossible to learn the strategies of postural control, we have postural instability as a result. In many VEs, the normal restrictions of body movement can not keep up with any visual changes, which causes a conflict in the strategies of normal postural control resulting in the symptoms observed in cybersickness [3]. And the longer the instability time, the more likely the severity of the symptoms to be higher.

Furthermore, one of the most widely accepted theory for cybersickness is sensory conflict theory [2–4]. It addresses the conflicts between the visual and vestibular senses, two sensory systems involved in VEs [4]. The senses are responsible for presenting information about the spatial orientation of an individual and the perceived movement and conflict between these informations can occur in virtual worlds. For example, the visual system tells the brain that the body is in motion at the same time that the vestibular system says that the body is stationary, which causes the conflict between the sensory systems [3].

2 Technology Issues

The technology used in the development of VEs has evolved substantially recently for the delivery of more exciting experiences. However, there are a number of disorders that have been related to the use of these immersive experiences. Those disorders appear mostly because of one or a combination of the following issues: position tracking error, system lag, flicker, binocular-occlusion conflict, and vection.

2.1 Position Tracking Error

One of the key elements of VR technology is that it allows tracking of the user's head and some members (e.g. hands and arms) in physical space with an accurate representation of the user in the virtual space. In addition, the information provided to the user from the head tracking presents the correct perspective when viewed in a VE. However, position trackers do not have 100% accuracy, and this inaccuracy will be a determining factor for the cybersickness symptoms condition [6].

Those tracking devices also have a propensity for creating relatively unstable information that can be called jitter (a slight irregular movement). For example, consider a jittery tracker connected to the user's head. If this tracker is used to refresh the user's vision, then the sight will be in constant and uncontrollable motion even when the user is completely still. These conditions cause dizziness and lack of concentration after using VR headsets [8].

2.2 System Lag

System lag is the time between the user's action and its actual representation in a VE. A fairly common example of lag in VR is an user turning his/her head 30 degrees to watch a car passing in a VE. If the lag is high, the computer will not update the screen at the same time and the user will have to wait for the images to be positioned where they should be. This lag brings a very big nuisance and can trigger cybersickness symptoms [9].

2.3 Flicker

Flicker plays a significant role in the oculomotor component of cybersickness. Although it can become less noticeable over time, it can still lead to headaches and eyestrain [15].

Flicker has two interesting characteristics: the first refers to the difference between the individuals and the dependence of the flicker fusion frequency limit, and the second is related to the probability that the flicker will be amplified as the field of view increases, since the peripheral visual system has a greater sensitivity to flicker than the fovea (a small depression in the retina of the eye where visual acuity is highest) [10].

For the purpose of flicker reduction, the refresh rate of a system should be increased. An update rate of 30 Hz is an initial value for the reduction of fovea perception. However, refresh rates should be higher for peripheral areas. As technology increases, higher rates in visual displays should become more popular and accessible [2].

2.4 Binocular-Occlusion Conflict

The term binocular vision is reserved for living beings who have a large area of binocular overlap and use it to code depth. Many complex visual tasks, such as reading, detecting camouflaged objects, and eye-hand coordination are performed more effectively with two eyes than with one, even when the visual display contains no depth [17].

In order to perceive depth, the human eye relies on cues. Monocular cues are the ones that provide depth information while viewing a scene with only one eye and binocular cues are the ones that depend on two frontal eyes. Furthermore, occlusion happens when one object is fully or partially hidden, making it seem that is farther away than the object that is hiding it.

In virtual reality environments, the binocular occlusion provides the notion of object proximity and scenario depth for the observer. The content is presented first to one eye while the other is blocked (occlusion), then the opposite process is done. For developers, the challenge is to ensure that this whole process is not perceived by users – any pause or delay can cause disorientation.

Then, the binocular-occlusion conflict occurs when occlusion cues do not match binocular cues (e.g. when text is visible but appears at a distance behind a closer opaque object, it can be quite confusing and uncomfortable for the user) [11].

2.5 Vection

When a visual scene moves independently of how an user is physically moving, there can be a mismatch between what is seen and what is physically felt. This mismatch is specially discontenting when the virtual motion accelerates because the otolith system does not sense that same acceleration [11]. The otolith system is responsible for linear acceleration and deceleration, including gravity, mechanoreceptors, in the form of hair cells, converts acceleration into neural signs [6]. Lateral movement can also be a problem, presumably because we do not often strafe in the real world [11].

3 User Factors and Content Criteria

Types of discomfort reported by VR users are mostly dizziness, nausea, eye strain, vertigo, disorientation and fatigue [2]. Mapping those factors can be decisive in explaining which individuals are more affected and the potential reasons. The idea is that the severity and occurrence of symptoms can be related with age, sex, race, disease, and even user positioning [3].

Older people are less susceptible to cybersickness symptoms. Greater susceptibility involve children between 2 and 12 years old – from that, the incidence falls rapidly year after year until the age of 21 [4]. Regarding gender, women have a wider field of vision, which increases the perception of flicker and, consequently, the propensity to cybersickness [2]. Illnesses like (but not restricted to) fatigue, hangover, and flu are powerful agents to cybersickness [2]. Users under the influence of drugs and alcohol may also have a higher susceptibility to cybersickness symptoms [3]. Furthermore, according to the theory of postural instability, the user's posture, where and if he/she is sitting are important factors – the scenario where the user is sitting while using a VR device represents the safest posture for use and reduces potential problems in postural control [4].

Prolonged exposure to VR experiences can also increase the chances of occurrence and intensity of cybersickness effects, which suggests longer adaptation periods. One way to accelerate adaptation to VE is to use devices for short periods of time [3, 4]. Therefore, it is important to have a projection of possible tasks and consider their duration.

Subjective signs of cybersickness have been reported for more than two decades [7]. A little over a decade ago a great example of approach on this issue was published [10] where the authors collected 16 electrophysiological parameters while their subjects were exploring a VE. During this challenge, there was an increase in the values of some parameters (gastric tachyarrhythmias, eye blink rate, skin conductance, respiratory sinus arrhythmia and delta power of the electroencephalogram (EEG)) while others reduced (heart period, fingertip temperature and photoplethysmographic signal, and EEG beta-power). Among these modifications, several (gastric tachyarrhythmias, eye blink rate, respiration rate, respiratory sinus arrhythmia and heart rate) presented a significant positive correlation with the subjective cybersickness score. In other work the authors observed that VR immersion results in an expansion of the low frequency but not the high frequency components of the heart rate variability [14]; in combination with the previously cited work, this may be a clue that cybersickness is connected with the increase of the cardiac sympathetic outflow. Two studies reported that VR causes moderate changes with short duration (<10 min) in the static postural stability calculated by the body sway amplitude [3]. These experiences did not change the dynamic postural stability, while postural stability in both studies was calculated immediately before and shortly after the challenge.

4 VR Rio 360: A Case Study

Rio 360 [5] is a VR application developed by SIDIA (Samsung R&D Center in Brazil) for Samsung Gear VR. Its focus is to explore Rio de Janeiro city and 12 tourist attractions. The application was released on Samsung's high-end devices, such as: Galaxy S6 flat, S6 edge, S6 edge+, S7 flat, and S7 edge.

At the beginning of the project development, it was observed that most users felt some degree of dizziness and/or lightheadedness while using the application. Aiming to adjust and improve the quality of implemented features, a set of experiments was conducted with internal users. The study's sample was composed by 10 participants, with ages between 25 and 40 years. Participants were invited to test the application's features on sessions that lasted 30 min (in average). They were asked to perform the same set of questions after each new version of the application was released, while following the steps listed below:

- Exploratory navigation;
- Identification of User Interface elements (e.g. connection buttons);
- Navigation and identification of landmarks (Fig. 1);
- Exploration and identification of the data available on the landmarks' information postcards (Fig. 2).

The study's main exploration points were: camera movement, distance between the camera and UI elements, and the application's motion design elements. By the end of each experiment, users' feedback related to the application were collected.

Fig. 1. VR Rio 360's map with a few landmarks [7].

Aproveite e visite a famosa Pedra do Pontal, e também as áreas preservadas de Grumari e toda a baía de Guaratiba.

Fig. 2. VR Rio 360's landmark information postcard [7].

During the study, the issues that participants reported more often were related to camera's movement (considered very fast) and also related to the application's elements, which were positioned too close to the user, making it difficult to understand the information they wanted to convey.

The study brought to light major device factors that technology manufacturers need to consider, which are: lag, flicker, calibration, field of view, and ergonomics in general. As far as lag is concerned, effective motion tracking that reflects changes in vision is critical, as are real-time graphic displays that operate close to 50–60 Hz. The flicker of the display (with different levels of perception between users) takes the user's focus and causes eye fatigue [4] – flicker fusion is an important property of the device and is even more critical for wider fields of view as peripheral vision is more sensitive to flicker [2]. Low calibration potentiates the symptoms of cybersickness due to differences in the physical characteristics of users – stereoscopic screens requires a slightly deflected view of the virtual world for each eye and this deviation should be related as closely as possible to the interpupillary distance (the space between the pupil centers of both eyes, that varies from individual to individual [4]) inherent to each individual, as such pertinent calibration is necessary for each user.

Furthermore, the study's results included the reduction of overall use discomfort in the application through a set of improvements. The table below summarizes the major differences between the application's initial and final version parameters (Table 1):

Table 1. Comparison between the application's parameters (initial and final).

Description	First release	Final release
Comfort distance	450 m	300 m
Float height	160 m	20 m
Float speed cap (maximum value)	0.5 m per frame	2.5 m per frame
Position delta multiplier	0.65 (frame)	0.45 (frame)
Minimum position delta	200 m	100 m
Horizontal acceleration	1.01 m	1.003 m
Maximum distance delta	1250 m	600 m
Position delta	0	110.5059 m
Delta time	0	0.013333 m

The following content provides a brief description of each parameter used:

- Comfort distance is the parameter that indicates the ideal distance between the interaction objects and the user – this distance is applied for navigation throughout the map and for interactions with the UI elements.
- Float height is the maximum height the user can navigate on the y-axis.
- Float speed cap is the maximum speed the user can reach while navigating the map.
- Position delta multiplier is a value to determine the updated position of the object in each frame through a multiplier.
- Minimum position delta is the lowest position value resulting from the calculation between the previous and current updates.
- Horizontal acceleration is the parameter responsible for establishing an acceleration limit value on the horizontal axis.
- Maximum distance delta is the factor that calculates which limit in the world space that the user can reach.
- Position delta is the value resulting from the difference between the updated calculation and the previous calculation of the object's position.
- Delta time is the time in seconds taken to complete the reading of the last frame [16].

Oculus Best Practices guide [15] does not define a specific value for each of the parameters described above – instead, it justifies how they should be handled in order to minimize user discomfort. The initial parameters used were created by the project's developers after studying Unity's documentation and script library, while trying to create a navigation control that would be easier for users to experience.

The major application improvements were related to Comfort distance, Float height, Float speed cap, and Maximum distance delta. Furthermore, after analyzing the developer and user adaptation sides, it is possible to say that Float Speed cap and Comfort distance were the most difficult values to adjust since they are related to the user's control over navigation and speed while going through the application's map. For the developers, the difficulty was in finding an adequate value while working with a map that was not in a 1:1 scale – VR Rio 360 worked with the map of Rio de Janeiro and the objects on larger scales so the user could access the sights faster, the objects could have the animations occurring faster and the UI could be in the user's field of view.

5 Conclusions

During its development, the VR Rio 360 application presented issues related to movement speed and user acceleration in the environment, which was causing discomfort symptoms related to cybersickness. In the application, the user's vision was set to first person, a factor that potentialized motion sickness symptoms, such as nausea, dizziness, vertigo. Studies suggest that these symptoms can be minimized with the usage of controllers. For sure the addition of components which can increase natural movements tend to reduce the motion sickness in the users. Nonetheless, other factors must be analyzed, such as type and quality of graphics used in VR applications.

Experts say that the sound can be 40% or more of the VR experience, if a user hears a sound that doesn't match a typical human experience in a world that feels like a human experience it tend to cause confusion and sound unrealistic [11, 18]. In this application, the sound while navigating the map was created in order to make a connection between the user and the city of Rio de Janeiro through Bossa Nova and other sound effects were used for feedback. Sound could play a greater role in reducing the effects of motion sickness by helping in the user's immersion levels – this approach can be a subject of study for future works.

An in-depth study on the relationship between the level of realism in virtual environment and the incidence of motion sickness, and also the possibility of controlling the vestibular system – so that the body that is at rest can navigate freely through the virtual environment without suffering with the side effects of motion sickness – could also be subjects for future studies.

The team's next steps prioritize studies on the cerebral areas involved with the visual system, the galvanic vestibular system, which commands information related to the position and movements of the head and the proprioceptive system, responsible for postural and body movement. These studies will be important to understand the functioning of the brain during the performance of these three systems simultaneously and thus, we can present effective alternatives in the fight against motion sickness.

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References

1. Desai, P.R., Desai, P.N., Ajmera, K.D., Mehta, K.: A review paper on oculus rift-a virtual reality headset. Int. J. Eng. Trends Technol. (IJETT) **13**(4), 175–179 (2014). ISSN: 2231-5381. www.ijettjournal.org. Published by Seventh Sense Research Group. http://www.ijettjournal.org/volume-13/number-4/IJETT-V13P237.pdf
2. LaViola, J.J.: A discussion of cybersickness in virtual environments (2000). http://www.eecs.ucf.edu/~jjl/pubs/cybersick.pdf
3. Davis, S., Nesbitt, K., Nalivaiko, E.: Comparing the onset of cybersickness using the oculus rift and two virtual roller coasters (2015). http://crpit.com/confpapers/CRPITV167Davis.pdf
4. Kolasinski, E.: Simulator sickness in virtual environments. Technical report 1027, Army Research Institute for the Behavioral and Social Sciences (1995)
5. Rio 360 VR App on Oculus Store. https://www.oculus.com/experiences/gear-vr/1105507662843899/
6. LaValle, S.M.: Virtual Reality. Cambridge University Press, Cambridge (2017). University of Illinois. http://vr.cs.uiuc.edu/vrbooka4.pdf
7. Regan, E., Price, K.: The frequency of occurrence and severity of side-effects of immersion virtual reality. Aviat. Space Environ. Med. **65**, 527–530 (1994)
8. Biocca, F.: Will simulation sickness slow down the diffusion of virtual environment technology. Presence **1**(3), 334–343 (1992)
9. Pausch, R., Crea, T., Conway, M.: A literature survey for virtual environments: military flight simulators visual systems and simulator sickness. Presence **1**(3), 344–363 (1992)
10. Boff, K.R., Lincoln, J.E.: Engineering data compendium: human perception and performance. In: AAMRL, Wright-Patterson Air Force Base, pp. 166–191 (1988)
11. Jerald, J.: The VR Book: Human-Centered Design for Virtual Reality. Association for Computing Machinery and Morgan & Claypool, New York (2015)
12. Brainard, A.: Motion sickness definition. Medscape portal, Neurology section (2017). http://emedicine.medscape.com/article/2060606-overview
13. Kim, Y., Kim, H.J., Kim, E.N., Ko, H.D., Kim, H.T.: Characteristic changes in the physiological components of cybersickness. Psychophysiology **42**(5), 616–625 (2005)
14. Ohyama, S., Nishiike, S., Watanabe, H., Matsuoka, K., Akizuki, H., Takeda, N., Harada, T.: Autonomic responses during motion sickness induced by virtual reality. Auris Nasus Larynx **34**(3), 303–306 (2007)
15. Oculus Best Practices 2017. https://static.oculus.com/documentation/pdfs/intro-vr/latest/bp.pdf. Accessed 9 Feb 2017
16. Unity Documentation Scripting API 2017. https://docs.unity3d.com/ScriptReference/index.html. Accessed 28 Feb 2017
17. Howard, I.P., Roger, B.J.: Binocular Vision and Stereopsis, vol. 29. Oxford University Press and Clarendon Press, Oxford (1995)
18. Fictum, C.: VR UX: learn VR UX, storytelling & design. Creater Space Independent Publishing Platform (2016)