Influence of Cybersickness and sense of immersion in Virtual Reality

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Abstract

Virtual Reality allows users to feel present in a virtual environment by stimulating the feeling of presence in the player. Although this technology has been around for the past thirty years, only recently, with the development of consumer grade head mounted displays, it has seen a boom in users and applications being developed for it.

The main concern regarding virtual reality are health issues, as this kind of technology, no matter the type of hardware, has always been eliciting symptoms of motion sickness in the users. This kind of visually induced motion sickness, known as cybersickness, has been studied extensively in the past but the exact causes are still unknown.
The purpose of this dissertation is to determine if there is a correlation between the lack of sense of immersion and the cybersickness.

In order to do so, previous studies regarding the subject have been run through an analytical framework designed by the author to determine which factors could have influenced the sense of immersion and which ones the eliciting of cybersickness.
Methods to increase the sense of immersion and reduce cybersickness include having the player in the virtual environment with their body rather than a controller, having a low number of UI elements on screen until the end of the most intense parts of a simulation, and having a virtual representation of the user’s body.

The hope is for this set of guidelines to be a valid reference both for future research and for developers to create more compelling and cybersickness-free experiences.

Introduction

Virtual Reality, also referred to as VR, is a technology whose aim is to stimulate the feeling of presence in a virtual world in the user. Due to its ever evolving yet imperfect technology, it is known to cause motion sickness symptoms. According to Llorach et al (2014) “Their high degree of immersion and presence provokes usually amazement when first used. Nevertheless, HMDs also have been reported to cause adverse reactions such as simulator sickness”.

Although simulator sickness is used in reference to motion sickness in virtual environments, there is a difference between simulator sickness and cybersickness, as according to Stanney, Kennedy and Drexler (1997) “After examination of eight experiments using different VE systems, that the profile of cybersickness is sufficiently different from simulator sickness”.

The motion sickness symptoms specific to these kind of virtual environments are often referred to as cybersickness, as defined by Rebenitsch and Owen (2016) “Cybersickness is an affliction common to users of virtual environments. Similar in symptoms to motion sickness, cybersickness can result in nausea, headaches, and dizziness. [...] Cybersickness is the onset of nausea, oculomotor, and/or disorientation while experiencing virtual environments in head-mounted displays, large screens, and curved screen systems”.

Virtual reality technologies have evolved from being rooms with displays surrounding the user, known as CAVE systems, to HMDs, which stands for Head Mounted Display, which are visors with high resolution displays positioned in front of the eyes of the user.
The subject of this research is the cause of cybersickness in virtual reality. The focus will be on how the design of the experience affects the user, especially in the field of games, and if there is a correlation between the sense of immersion, or lack thereof, and cybersickness.

According to Abrash (2014), ““While the causes of motion sickness are not well understood, there are good reasons to anticipate that many of the same factors that affect presence should affect motion sickness as well”.
Although VR technology caused users to feel motion sickness throughout its entire existence, it is necessary to analyse the possibility that certain design choices may reduce or even prevent motion sickness symptoms from occurring.

The way research will be conducted in this paper will be divided in two parts: in the literature review, an analytical framework composed of three questions will be applied to a number of experiments conducted by previous researchers. A variety of papers and journal articles has been written on this subject, and although some of the claims are not valid anymore as they refer to outdated technology, the research methods and the data gathered can still be useful when conducting new research.
Moreover, there will be an attempt to determine whether the motion sickness and the sense of presence were influenced by what Mel Slater (2009) defines Place Illusion and Plausibility Illusion.
In the analysis, the data gathered in the literature review will be analysed using Chertoff's theoretical model of presence.

This research presented in the paper might be beneficial in various fields. A general guideline on what design choices to make to avoid the user from experiencing cybersickness would be helpful in creating products which don’t require players to adapt to motion sickness symptoms. The current research demonstrates that users adapt to cybersickness after continuous use of VR (Chessa et al., 2016), which is not beneficial as it deters people from approaching this new technology.

Solving this issue would be advantageous for businesses as well, as the user base of potential consumers would greatly expand thanks to the removal of an adaption phase which not everyone is willing or capable of going through. According to Chertoff (2008) “ For businesses, the outcome of experiential design is higher earnings”.

Cybersickness has been the subject of countless studies and experiments, which have all contributed to finding a solution to this issue. Furthering research on this subject would not only greatly contribute to the development of VR technology, but also help understand the causes of motion sickness in other subject areas.

Literature review

For this research an analytical framework will be employed with the purpose of discerning what data needs to be collected from research. As a result of the analysis of sources from the annotated bibliography, three questions have been formulated which are useful when collecting data in the field of cybersickness and virtual reality. Additionally, Slater's Place Illusion and Plausibility Illusion will be used to further categorize research.

The first question concerns the year the experiment was conducted, with which hardware system and with what purpose.
The second question is about the design of the VR experience and if it elicited symptoms of cybersickness in the user, and if so if the fault was to be attributed to hardware limitations of design decisions.
The third question is about what percentage of users showed symptoms of cybersickness, when and which symptoms did they show.

Another factor will be whether the Place Illusion (PI) or the Plausibility Illusion (Psi) were happening, and the if the cybersickness was due to a lack of the former or the latter or both. According to Slater (2009) "PI is constrained by the sensorimotor contingencies afforded by the virtual reality system. Psi is determined by the extent to which the system can produce events that directly relate to the participant, and the overall credibility of the scenario being depicted in comparison with expectations".

According to Chertoff (2008) "the goal of the mediated environment designer should not only be creating an environment, but also creating an experience".
Per Witmer & Singer (1998), "Involvement is a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or

meaningfully related activities [...] Involvement depends on the degree of significance or meaning that the individual attaches to the stimuli [...] if the VE head-mounted display is uncomfortable, involvement in the VE will be diminished accordingly".

It can be said that Place Illusion relates to the capacity of the virtual reality hardware to make the user feel involved.

On the other hand, always according to Witmer & Singer (1998) "Immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences [...] When users interact naturally with a VE, able to both affect and be affected by the VE stimuli, they become more immersed in that environment".

According to Kolasinski's (1995) definition of situation awareness as "a state of knowledge capturing a user's perception of the elements in the environment, an understanding of their meaning, and an understanding of their predicted status in the near future", this leads to the association of Plausibility Illusion to the user's feeling of immersion and the capacity of the virtual environment to react in the way his situation awareness suggests.

It is possible to say that the creation of the environment relates to the Place Illusion, while the creation of the experience relates to Plausibility Illusion.

In a research by Lin et al. (2002), which was executed with the CAVE system to determine the effects of field of view in a virtual environment, the participants used a driving simulator and showed symptoms of cybersickness. It is not specified whether all participants showed symptoms of simulator sickness, but there was a pause after each test to let the feeling of simulation sickness fade away. As the participants showed increasing simulator sickness with the increase of the field of view, it is possible to attribute the fault to the hardware, due to a delay in the visual and vestibular conflict. Since the experiment featured a driving simulator, which resembles a real life situation, it is possible to determine that in this research the cause of cybersickness can be attributed to a lack of Place Illusion, as the hardware was not advanced enough to make the user feel immersed in what was a credible scenario which responded in the expected way to user input.

In a paper by Keshner and Kenyon (2009), where a CAVE system was used to determine how the motion in a virtual environment might affect postural stabilizing responses, the subject was asked to walk while the virtual environment was being moved around, with the visual scene moving on the sagittal plane and not rolling. Although participants did not show symptoms of motion sickness, the impairment of visual and vestibular pathways impacted postural stability. Considering how the purpose of the research was to study postural stability, it’s possible to say that the motion sickness was due to design decisions. In this case it can be seen how the test subjects experienced a virtual reality with a lack of both Place Illusion and Plausibility Illusion, as the virtual reality experience they were immersed in was not disorienting due to the hardware not being able to simulate an experience properly, but mainly due to the design of the experience.

In a 2014 research Llorach, Evans and Blat used the Oculus Rift DK1 Head Mounted Display to conduct a study which focused on the difference between using a conventional game controller versus positioning in the virtual world based upon the signal of the head mounted display. Most of the experiences were based on the VEPAB locomotion tasks, and the study finds that users who used the position estimation system (low sensory conflict) felt less simulator sickness that those who used the game controller (high sensory conflict). In this case the fault can be attributed to the refresh rate and input lag of the hardware. Symptoms were mostly nausea and disorientation, with some subjects still reporting simulator sickness hours after finishing the experiment. Although the "sense of presence was not enhanced by the possibility of 'real walking'" (Llorach et al., 2014), during this experiment it is possible to say that the lack of Place Illusion might have been one of the causes of motion sickness, as the scenario depicted was realistic but the hardware could not recreate it effectively enough.

Ohyama et al. (2006) conducted a research whose purpose was to examine the development of subjective symptoms and heart rate variability during motion sickness induced by virtual reality, using the CAVE system. The visual vestibular conflict was a design decision, and it was induced by rotating the floor while projecting random texture patterns. In the 14-minute long test, subjects had to track a virtual ball, in order to ensure an equal quantity of subject locomotion during both conditions. Subjects experienced the peak of motion sickness during the 2nd virtual reality stage of the test. It also should be noted that in order to determine microvascular blood flow the participants had to wear uncomfortable sensors that might have enhanced the feeling of motion sickness. In this particular case the experiment featured both a lack of Place Illusion and Plausibility Illusion. The virtual world created by the researchers was not immersive, as it consisted in random texture patterns on a wall, which did not solicit the feeling of “being there” in the test subjects. The hardware used for the experiment was also a limitation, as the sensors placed on the participants constantly caused a sense of unease and reminded them they were not part of the virtual world.

A paper from 2016 by Porcino et al. used the Oculus Rift head mounted display in a research with the aim of minimizing the effects of motion sickness in head mounted displays. The experience was designed to be a game where Dynamic Focus Selection was present without any form of eye tracking, and the cause of motion sickness, in this case, lies in the hardware. The Dynamic Focus Selection developed by Porcino et al. consists of a system of guidelines on how to minimize motion sickness, as usually everything is in focus and this creates discomfort in the user. Their model suggests using a region of interest to optimize the real time calculations in complex scenarios, and excluding objects outside the user's field of view. The Balk method was used to evaluate the symptoms, which classifies them in three general classes: Nausea, Oculomotor and Disorientation. In this test the one with the highest score was Disorientation, with the second being Nausea and last one Oculomotor. The game, developed on the Unity3d Engine, featured a spaceship whose aim was to destroy the asteroid coming towards it. The researchers who created this prototype focused heavily on designing the experience as to avoid causing any motion sickness in the test subject. It is then possible to say that this experiment featured a lack of Place Illusion, as in the end it was the hardware's fault if any motion sickness was felt by the players.

A 2003 research by Akiduki et al. used the CAVE system to explore the relationship between visual and vestibular inputs. The test presented two scenarios: one in which the floor projection would rotate at double the speed the head rotation of the subject, while in the other one the background image would synchronize proportionally to the subject motion. The induction of motion sickness was a design choice. Cybersickness was determined according to both Graybiel's and Hamilton's criteria, even though the score didn't change significantly. Participants experienced higher levels of motion sickness during the second phase. In the case of this paper, the motion sickness induced in the users can clearly be attributed to a design choice: the background projected on the walls would turn or rotate as the user moved his head, with the intent of inducing cybersickness. It is therefore possible to see the intentional lack of Plausibility Illusion in this peculiar experiment, as the motion sickness cannot be attributed to the hardware being lacking.

Akizuki et al. (2005) wrote another paper focusing on the effects of immersion in virtual reality on postural control, this time using a Head Mounted Display rather than a CAVE system. In the test, the visual scene was delayed after the head movement by about 0.2 to 0.8 seconds. According to Abrash (2014), the maximum latency possible is 25ms, and after that " the virtual world no longer seems nailed in place, and the human perceptual system is no longer convinced that it's looking at reality".

Users experienced light motion sickness after completing steps of inspection with the right hand in the VR world, but it's reported that they got used to it, which is the contrary of what happened with the CAVE system, where cybersickness got worse with time. It's interesting to note that instability did not occur during the use of virtual reality but immediately after. In this case it's worth noting how users felt more immersion although there was a lack of Plausibility Illusion. This is an example of how the Place Illusion depends on the hardware used, as the CAVE system as a virtual reality platform evidently still had limits that were overcome with the adoption of a more advanced system such as the Head Mounted Display.

Another study from 2008 by Horlings et al. explores the influence of virtual reality on postural stability during movements of quiet stance using VR glasses, which caused an input lag of 174 ms. Subjects had to stand with eyes closed, open without VR and in VR. The trials were taken with a few months of distance between each in order to avoid training effects entering the data. The study shows that virtual reality causes an increase in postural instability similar to that caused by closing the eyes. In this experiment the scene depicted in virtual reality was a realistic one, with buildings, a road and some palm trees and it did not have any elements that could be considered out of the ordinary. Since it was not the Plausibility Illusion that was missing, it's possible to say that what was lacking then in this experiment was Place Illusion, due to the mechanical limitations of the hardware. It's interesting to note that even though an year before Sharples et al. (2007) concluded that there was no significant difference between light and dark viewing conditions, "black foam was placed around the edges of the glasses and the room was darkened to ensure that gaze was maintained on the VR screen and the visual inputs were provided only by the glasses without any other peripheral visual inputs" (Horlings et al., 2008).

In 2007, a research by Sharples, Cobb, Moody and Wilson focused on the effects of virtual reality induced symptoms and effects (VRISE) across all four virtual reality display conditions: head mounted display, desktop, projection screen, such as the CAVE, and reality theatre. The design of the experiment consisted in 4 phases: pre-experiment questionnaire, pre-exposure assessment, during exposure monitoring and post-exposure assessment. The head mounted display was the one to cause most post-exposure disorientation. In experiment 3, which compared active and passive control conditions, SSQ scores were much higher in the passive phase. In this study, the researchers decided to run two experimental conditions, one in dark viewing and one in light viewing. The former had blacked out windows, preventing any natural light from coming in the room, while in the latter light would pass through. According to the researchers " Although there was an observed difference between disorientation in light and dark conditions, no significant differences were found".

As per Sharples, Cobb, Moody and Wilson "It has been suggested that degree of presence and self motion may impact severity of symptom [...] and therefore the level of presence experienced. [...] no significant differences were found." In this instance, the motion sickness is mitigated by the Plausibility Illusion, as the "subject in control reported fewer motion sickness symptoms than their passive yolked partner".

In 2007 Howarth and Hodder wrote a paper whose purpose was to quantify the habituation of people to the symptoms of motion sickness with the use of a head mounted display. The test was conducted on a video game called Killer Loop (Crave Entertainment, 1999), which was found to be a particularly nauseogenic stimulus, and participants used a "Power Pad" game controller to control their alter ego in the virtual environment. Subjects had to play the game constantly for 20 minutes, verbally rating their degree of malaise every minute. All but one participant showed reduced symptoms of VIMS over the days the experiment took course. Participant number 4 became more susceptible to the stimulus rather than habituating. A common symptom reported by all participants was nausea.

An important thing to notice about this study is that " the habituation which occurred was of a similar nature in all of the participant groups regardless of exposure interval, indicating that the number of exposures is a more important factor than the time interval between them"(Howarth & Hodder, 2007).

In this case it can be said that the cause of cybersickness relies on both the lack of Plausibility Illusion and Place Illusion. The head mounted display used for this experiment was rather outdated compared to the ones available now, and thus it had limitations that would prevent the test subject from feeling completely immersed in the simulation. The virtual environment itself was not ideal for a simulation, as a fast paced PlayStation 1 racing video game would probably elicit visually induced motion sickness even in people watching it run on a television screen.

In a research conducted in 1999 Hill and Howarth tried to discover if habituation to virtual nausea happened like it does in real life, with the use of a head mounted display. Another purpose of the research was to investigate whether participants exposed to a visual stimulus for longer would habituate to a greater extent than those who had less exposure, and this was found to happen. The research was conducted by having the participants play Wipeout (Psygnosis, 1995) on a Sony PlayStation system. Two groups were created: a “control” group and an “experimental” group. The participants in the first group would control the vehicle in the game, while members of the second one would spectate only. Both groups had to endure 20 minute sessions for 5 consecutive days. After the testing period had come to an end, the participants experienced significantly less nausea compared to the one reported on the first day. Some participants even refused to complete the test, which was “testament to the nauseogenicity of the stimulus” (Hill & Howarth, 1999).

The difference in score in the Simulator Sickness Questionnaire showed that “ there must have been physiological habituation to the appearance of motion, and that this habituation was greater in the experimental group than in the control group” (Hill & Howarth, 1999).

On the other hand, a study by Stanney and Hash (1998) found the following: “As measured by the Simulator Sickness Questionnaire, the active (i.e., complete control) condition reduced the severity of the symptoms experienced as compared to the passive (i.e., no control) condition, but did not do so as completely as the active-passive (i.e., coupled control) condition”. This validates what was discovered in the 2007 research by Sharples et al. about virtual reality induced symptoms and effects.

The cause of cybersickness in this experiment can again be attributed to both the lack of Place Illusion and Plausibility Illusion, as the hardware from 1999 was not adequate to elicit the feeling of presence and the Sony PlayStation 1 game WipeOut was not designed to be a convincing virtual environment.

Sugita et al. (2007) presented a paper that analysed the effects of visually-induced motion sickness (VIMS) by studying the linearity of the heart rate and the blood pressure by using causal coherence functions. According to Rebenitsch and Owen (2016) “ Visually induced motion sickness (VIMS) is nausea, oculomotor, and/or disorientation induced by any visual stimuli”, which does not necessarily take place in a virtual environment.

The video was projected on the back side of a screen by a DLP projector. The video projected was a clip from the “The Blair Witch Project” (1999), which is known to elicit VIMS in human subjects as it was shot with a hand-held camera swayed intentionally.

Rebenitsch and Owen (2016) found that “there have been concerns about the safety of these devices due to eyestrain and feelings of illness. A quick search of ‘‘movie theater motion sickness’’ reveals numerous results from people complaining of illness after attending movies such as [...] ‘‘The Blair Witch Project,’’ and particularly performances filmed with shaky hand-held cameras”.

First the subjects had to watch a still picture of a landscape for control, then a 15 minute long video from the film, then watch the picture again. Subjects showed symptoms of virtually induced motion sickness usually around the 10th minute mark of the video, with nausea being the main symptom.

This study did not feature a virtual environment, but it’s interesting to notice that the VIMS could be caused by a lack of Plausibility Illusion, as the continuous motion of the camera might be considered the virtual experience not responding in the natural manner to the expectations of the user.

In 2017 Chardonnet, Mirzaei and Merienne investigated all the features that can be extracted from the body postural sway when experiencing a virtual environment, with the use of a CAVE system, which is unusual considering the year the paper was written. In this test participants were immersed in the CAVE system while using a Flystick device. The subjects had to move in the virtual environment following a path at a speed higher than the normal walking one, to induce VIMS more easily, and the latency of the system would be around 40ms. After this, the participants had to stand on a balance board while looking at a fixed point on a wall. Then, the simulator sickness questionnaire was compiled and the test would be started again. The provoking of VIMS was an intentional design choice by the researchers. The results support the past findings that postural instability can be used as an efficient indicator of simulator sickness. It's interesting to see that in the article it's noted that females are generally more prone to motion sickness than men, as also supported by Jaeger & Mourant (2001) and Mourant & Thattacherry (2000).

The simulation that was set up for this study was purposefully designed to induce VIMS, with high latency, higher than normal walking speed and a rather bare virtual environment where the users had to collect floating yellow spheres. This can be considered both a lack of Place Illusion and Plausibility Illusion.

“The Perceptual Quality of the Oculus Rift for Immersive Virtual Reality”, a research conducted in 2016 by Chessa, Maiello, Borsari and Bex had the purpose of addressing two issues: the first one was whether head mounted displays such as the Oculus Rift could generate an acceptable level of immersion; the second one was to discover if the virtual reality experienced through Oculus Rift could cause cybersickness. The version of the Oculus Rift used for this experiment was the DK2, and a Google Cardboard and an LG 47” 3DTV were featured as well.

The Head Mounted Display featured in this experiment, the Oculus Rift DK2, features a 60hz refresh rate, although the optimal rate would be at least of 90hz (Abrash, 2014).

This investigation employed 4 different scenarios: one consisted of a train scenario where the player is moved along a circular path. The second was the skyscraper scenario, which put the player inside an elevator at the bottom of a skyscraper, which lift him up to the top and then let him fall to the ground. The third scenario was the RiftCoaster HD, which consists in a roller coaster tour through a castle. The fourth and last one was the obstacle scenario, which is a modified version of the train scenario with obstacles, to understand if the user is threatened enough to move out of the way.

The Oculus did not induce simulator sickness in the train scenario, although the researchers believe that the detail and the setting of the virtual world play a role in the user experience with a head mounted display. In the roller coaster scenario on the other hand, which induced the feeling of vection, some users reported symptoms of motion sickness. According to Chessa, Maiello, Borsari and Bex (2016), vection is “the visually induced self-motion perception that often emerges as a precursory symptom of motion sickness while viewing moving images in VR environments”; on the other hand, Rebenitsch and Owen (2016) define vection as the “the perception of the world moving away from the user”.

It’s also important to note that the study claims that short periods of virtual reality exposure mitigate the effect of motion sickness, as supported by Jaeger and Mourant (2001): “Length of time in the simulator was also found to have a significant physiological effect on the participants in the tested range of 13-23 minutes of exposure. Longer time intervals were associated with significantly greater symptoms of simulator sickness and perceived discomfort".

Although the experiment featured two scenarios similar in concept, the immersivity solicited in the subjects was higher in the RiftCoaster HD scenario, which was the one developed by professionals and not the researchers. This means that the enhanced graphics played a role in the sense of immersion and the Plausibility Illusion, although there was an increase in simulator sickness which "may be the consequence of increasing the veracity of VR simulation in HMD systems, which in turn leads to an increase in visual and vestibular conflict in users" (Chessa et al., 2016).

Clarke, McGregor, Rubin, Stanford and Graham (2016) made an interesting experiment trying to convert the classic Pac-Man game into a virtual reality game using the Oculus Rift DK2 head mounted display. The experience, called *Arcaid*, was designed to avoid inducing simulator sickness in the player. In the first iteration of the test, UI elements were not present and often the players felt lost and quickly sick. Subsequently, a targeting reticule and map stations were introduced and users showed greatly reduced feelings of simulator sickness. Experimentation found that removing control of the camera is also a cause of motion sickness, and it was also noted that having the menu constantly occupy the visual plane can cause eye strain. Out of 50 testers, only 4 reported symptoms of a low amount of motion sickness. The cause relied in the fact that these users played for a longer period than other testers, trying to complete the maze multiple times. As anticipated in "The Perceptual Quality of the Oculus Rift for Immersive Virtual Reality" by Chessa, Maiello, Borsari and Bex (2016), a correlation between exposure time and cybersickness exists.

The cause of motion sickness in this particular case could be attributed to a lack of Place Illusion, as the reason why users felt symptoms of simulator sickness relies in the extra time they spent in the virtual environment, which ultimately depends on the hardware's inefficiency.

In 2014 a paper by Smart, Otten, Strang, Littman and Cook focused on the connection between postural stability and optic flow, and deduced that when postural stability is degraded for prolonged periods of time, motion sickness ensues. For this experiment a pair of virtual glasses was used and since they were only partially immersive, the laboratory lights were turned off, although according to Sharples, Cobb, Moody and Wilson (2007) there are no differences between light and dark conditions. The participants had to complete balance checks before commencing the test. The experiment consisted of 5 trials, each lasting 10 minutes.

The first test, without computer-generated stimulus, had participants stand in front of a light while wearing a set of welding goggles. The second test had a star field moving in a sinusoidal pattern. The third test had the star field move based on the baseline motion of the participants. In the fourth test the motion was generated in real time by the participants, as their movement forward would expand the field of view and their backward movement would contract the field of view. The fifth test had the same process, except moving forward would contract and moving backwards would expand.

Of the participants who reported previous experiences of motion sickness, 40% became sick during the test. The study finds that “the ability to anticipate, predict and control the relation between perceptual information and action is critical for preventing motion sickness”(Smart et al., 2014), as suggested by Kolasinski (1995). The fifth test was the one with most participants becoming sick, especially in the oculomotor and disorientation subscales.

In this case, considering both the inadequacy of the hardware, which did not cover the user’s entire field of vision, and the nature of the virtual environment, which was not designed to be immersive, it’s clear a lack of Place Illusion and Plausibility Illusion.

A research by Gusev, Whittinghill and Yong (2016) investigated the effects that colour and colour blindness have on visually induced motion sickness in virtual reality using Samsung Gear VR. This experiment was conducted to further investigate the matter of the effects of colour on visually induced motion sickness, as two previous publications by Bonato et al. (2004) and Yuen (2007) had contrasting results, with the former affirming that colour had an impact on cybersickness, and the latter finding that colour had no effect.

The simulation, developed with the Unity3D engine, consisted of various spheres and cylinders that the user would find himself in the middle of. Using the touchpad of the Samsung Gear VR, it was possible to cycle through them and to use a variety of colour blindness filters. The use of an optokinetic drum has been known for inducing cybersickness on subjects, so the objective was to compare the length of exposure until motion sickness symptoms occur between those who view the simulation with the colour blindness disabled and those who had the colour blindness filter enabled.

The simulation was originally intended to run on an Oculus Rift SDK 2, but the hardware used in the end was a Samsung Gear VR with an Android based device. The user would control the rotation speed by swiping on the touchpad. According to the researchers, another vantage of the Samsung Gear VR consisted in the user not being tethered to a cable, but able to move his head freely.

Although the simulation was not tested on any participants, it’s conceivable that it would induce motion sickness due to a lack of Plausibility Illusion, as it’s known that “the use of an optokinetic drum or sphere induces motion sickness on test subjects” (Gusev, Whittinghill and Yong, 2016).

In 2001, a study by Jaeger and Mourant had the purpose of finding the differences between a static and a dynamic simulator system. The researchers expected “the more visually complex simulations to contribute to perceived discomfort” and that the “subject’s locomotor control [...] in the 3-D environment and the subsequent kinesthetic, proprioceptive, tactile, and vestibular sensory feedback will result in a reduction in simulator sickness outcomes” (Jaeger & Mourant, 2001).

The static simulator was mouse-driven while the dynamic was treadmill-operated. The test saw a total number of 60 participants, one third of which were females. The virtual reality system employed was an Head Mounted Display (HMD), with the static system requiring the pression of a button to move the player in the virtual environment, and the dynamic one calculating the rate of advancement by the walking cadence of the test subject on a treadmill. An interesting finding from this study is that “a textured visual environment resulted in higher reported simulator sickness than less complex imagery” (Jaeger & Mourant, 2001), which means that, in the specific conditions of this experiment, a higher level of Plausibility Illusion is correlated with increased simulator sickness.

A 2017 research conducted by Alshaer, Regenbrecht and O'Hare had the intent of understanding how the different ways of experiencing a virtual environment influenced the way the user felt immersed and estimated dimensions. The simulation, which was developed with the Unity3D engine, consisted of a configurable power wheelchair simulator which could be used with a variety of peripherals. Participants would experience the simulation first on an Oculus Rift head mounted display, and later with the use of a monitor display. The virtual environment, modelled with Google SketchUp, consisted of an empty hallway where the subjects would move through or around gaps. The participants were tasked with collecting stars which were put in between two poles which the subjects had to drive through. When it came to the feeling of realism, the most decisive factor for participants was the possibility to change the Field of View.

The sense of presence was much higher when using an Oculus Rift with a changeable Field of View, with up to half the participants not feeling any symptoms of motion sickness when having the possibility of looking around in the virtual environment.

The possibility for users to see a virtual representation of their body increased the sense of presence and helped in better judging the dimensions of objects in the simulation.

Although the virtual environment was not realistic, the sense of Plausibility Illusion and Place Illusion were quite high with participants feeling a strong sense of immersion in the simulation.

In 2017 Wood, Loizides, Hartley and Worrallo conducted a research featuring snowboarding in virtual reality with the Nintendo Wii Fit balance board. The prototype created for this test was a snowboarding simulator where the players had to snowboard downhill while moving left and right by shifting their weight on a Nintendo Balance Board. The hardware used for this experiment was an Oculus Rift DK2 Headset, with a field of view of 100 degrees and a refresh rate of 75 Hz.

The test was run both on the head mounted display and on a screen and keyboard setup. Reports indicate that the simulation, when experienced with an HMD, was completed in a much shorter time, as well as being more fun and enjoyable. According to Wood et al. (2017) "there was also mention of the HMD making the balance problems worse due to participants being unable to see their feet". This is compatible with what Alshaer et al. (2017) found in their research regarding how a virtual representation of the user body helps with the sense of presence.

This experiment featured almost no occurrence of motion sickness, with only one participants out of seven reporting symptoms of nausea, disorientation and balance issues. In this case it's possible to say that both the Place Illusion and Plausibility Illusion seem to have been maintained, maybe thanks to the use of the Nintendo Wii Fit board.

Methodology

As a game designer who has the intent of developing VR experiences, I was greatly interested in what could “make or break” an experience for the user. There have been many studies about motion sickness and virtual reality which approached the problem from a medical point of view, immersing participants in virtual simulations which would cause motion sickness on purpose without resembling what a properly designed virtual experience would feel like. It is then my purpose to compare the simulated environment ran in the previous tests to the theoretical model of presence created by Chertoff, Schatz, McDaniel & Bowers (2008), which offers an exploration on the mitigation of breaks in presence (BIP) when it fails to be maintained.

According to Chertoff, Schatz, McDaniel & Bowers (2008) “A managed experience is achieved when experiential design is strategically applied to environments or activities in which groups or individuals will interact”. He then proceeds to affirm that “by utilizing experience a more personal connection to the environment can be achieved. [...] Such a personal connection would lead to a strengthening of the factors that contribute to the emergence of presence”. A theoretical model defining various “types of experiential stimuli the presence contributing factors used” is then used to categorize causes of Breaks in Presence.
The categories used in this model are the following: External interference, Internal interference, Inconsistent mediation, Contradictory mediation, Unrefined mediation.

According to Chertoff et al. (2008), an External Interference happens when the external world interferes with the simulation, such as when an user is participating in a virtual simulation but “he can hear people in the next room discussing their lunch plans”.

An Internal Interference arises when the internal world interferes, for example an user being distracted by something while he's in a virtual simulation.
Inconsistent Mediation is the result of a virtual environment failing to consistently maintain its output media, such as a program freezing or lagging.
Contradictory Mediation takes place when the virtual environment reacts in a way that contradicts participants' expectations, such as an object not being interactable with because it was not yet programmed.
For Unrefined Mediation to happen, the mediated environment has to evoke an excessive number of schemas or data, as to generate an information overload.

My research consists in analysing previous research to gather information about what usually causes motion sickness and how to avoid repeating the same mistake. Various kinds of papers have been written about this argument, ranging from purely medical ones to papers dedicated to game design. There is a copious amount of data available for me to analyse with the framework afore mentioned, in the hope of collecting the one that is needed to guide in the creation of a virtual experience with minimal to none cybersickness.

Analysis

At this point the next step is to analyse the data gathered from the literature review and run it through Chertoff's theoretical model. It is important to do so in an effort to understand what design decisions have been made in the past that caused motion sickness in the participants. Some of the papers analysed have been published almost 20 years ago, others have used technologies which are not available for the public, while others have used virtual systems which are completely different from the HMDs that are so widespread nowadays. According to Rebenitsch " Technology improvements have, or likely will in time, rendered some of the hardware issues mute, but not all. There are inherent restraints on virtual environment systems", so whether the claims this papers made are still valid or not, it's still useful to analyse the design process behind the tests conducted to have an approximative understanding of what causes motion sickness in virtual environments.

The analysis will start with CAVE systems, which have been a widespread technology for simulating virtual reality in the 90s, and are still a "popular and important for research and as testbeds for a variety of simulations"(Crecente, 2016). The Computer Automatic Virtual Environment, known as CAVE, is a virtual reality system that uses projectors to display images on walls and floor (Cruz-Neira et al., 1992).
In a test which involved a driving simulation, an increase in field of view has been correlated to an increase of simulator sickness symptoms, as demonstrated by Lin et al. (2002). The cause of motion sickness in this instance could be attributed to a break in presence due to both Inconsistent Mediation, for the hardware was not up to task, and Unrefined Mediation, as such a wide field of view probably caused a sensory overload.
It's possible to deduce that arbitrary changing the field of view of the player is a bad design choice. It still needs to be clarified if a change in field of view resets the habituation process,

although in Alshaer et al., (2017) a change of field of view increased the sense of presence, but the hardware used in this test was an head mounted display.

In various tests the rotation of the floor projection would rotate at double the speed of head rotation or synchronize with the speed of the participants' body and this induced motion sickness in the participants, which would suggest that having an increase in the speed of visual cues correspond to head movement might cause motion sickness. In this case it's clear that a Contradictory Mediation is happening, as the virtual environment is responding to action in a way that the user did not anticipate.
Moving the visual scene around the sagittal plane also caused slight motion sickness, which can be attributed to an Inconsistent Mediation as the hardware is not advanced enough to avoid a conflict between the visual and the vestibular system. Video games, especially flight simulators such as War Thunder (Gaijin, 2016), suffer greatly from this limitation.

After intense exposure to visual cues, tracking a virtual ball caused cybersickness, which means that putting players which are moving in virtual reality in a situation saturated with visual cues and then asking them to move in a coordinated manner might be too excessive. This break in presence is due to an Unrefined Mediation, with too much data overloading the user with information.

In a test conducted by Chardonnet, Mirzaei and Merienne (2017), it was found that having players move around at a speed higher than the normal walking one caused visually induced motion sickness. In this case the lack of immersion can be attributed to a Contradictory Mediation, as the feedback received by the player does not correspond to his action.

A Head Mounted Display, also known as HMD, is a “visor display that places two small screens, or a single screen that renders two separate images, before the eyes” (Rebenitsch, 2016).

A paper by Llorach, Evans and Blat (2014) demonstrated that letting the player move using his own body elicits much less visually induced motion sickness than when the movement is controller based. The movement being dictated by a controller can be considered a Contradictory Mediation, as the user experiences movement in the virtual environment but doesn’t feel his body moving in real life.

In another paper by Porcino et al. (2016), a model for Dynamic Focus Selection was used, which helps with mitigating the effects of motion sickness by having only the objects in the user's field of view be in focus. This model could help mitigate the breaks in presence caused by Unrefined Mediation, as an excessive number of objects in focus does not resemble everyday life, as humans focus on single objects, therefore the overload of information in the virtual environment causes a break in presence.
Technology aimed at following the player's gaze is already in development, with examples such as Tobii Eye Tracking (What Is Eye Tracking?,2015).

In 2005 Akizuki et al. demonstrated that motion sickness can be induced by a lag between the visual scene and the head movement, which suggests that using the latest generation hardware should help in preventing motion sickness. Abrash (2014) demonstrated that a maximum lag of 20ms can be tolerated. The presence of an higher level of input lag creates a break in presence by Inconsistent Mediation, as it's the hardware that is at fault for lagging behind.

Research by Howarth and Hodder (2008) and Hill and Howarth (2000) demonstrated that habituation to virtual reality greatly reduces motion sickness, even in simulations which cause motion sickness in most participants. Such an habituation process could help in dealing with the hardware's shortcomings, thus reducing breaks in presence caused by Inconsistent Mediation.

According to studies from Clarke et al. (2016) and Porcino et al. (2016), it's possible to deduce that it's better to leave parts with a high number of visual cues at the end of the virtual reality simulation. Virtual Reality games such as Space Pirate Trainer (I-Illusions, 2016), do this by having the visual field filled with information before and after the gameplay section, but aiding the user with minimal visual cues while he's actually playing. This is done in order to avoid a break in presence caused by Unrefined Mediation, which occurs when the player is overloaded with information, and Internal Interference, which takes place when the subject is distracted from the simulation.

Chessa, Maiello, Borsari and Bex (2016) report that users showed symptoms of motion sickness only in the part of the test that was created by professional game designers, which means there are still many things to be learned about motion sickness in virtual reality (Rebenitsch & Owen, 2016). The scenario created by professionals in this case had a much richer graphics style than the other ones, suggesting that certain kinds of visual fidelity might actually be considered Unrefined Mediation and thus not suitable for virtual reality. This is supported by Abrash (2014) "No one knows yet which art styles work in VR. Detailed scenes that look great on a screen can look like cheesy stage sets in VR – and simple scenes can seem startlingly real".

Interesting results were found in a paper written in 2016 by Clarke, McGregor, Rubin, Stanford and Graham, from which it's possible to learn a few things about experience design: it's important not to remove UI elements from players and to avoid having the menu occupy the visual plane constantly. Other tips include leaving the camera in control of the player.
In a study by Smart, Otten, Strang, Littman and Cook (2014), it's claimed that the ability to anticipate, predict and control the relation between perceptual information and action is critical for preventing motion sickness.
This implies that leaving the player the control or giving him enough warning should reduce motion sickness. In this case it's possible to see how implementing these guidelines would be

useful in avoiding breaks in presence caused by Contradictory Mediation, thanks to the simulation responding in a predictable manner, and Unrefined Mediation, with the user not being overloaded with information he didn't perform a task to request.

A paper by Gusev, Whittinghill and Yong (2016), which investigates the effects that colour and colour blindness have on visually induced motion sickness, develops a simulation which could be used to test such theories but never applies it on any subjects. Further research on the correlation between colour blindness and visually induced motion sickness could help when dealing with breaks in presence caused by Inconsistent Mediation.

According to studies by Wood et al. (2017) and Alshaer et al (2017), a virtual copy of the subject's body in the simulated environment can help the user better estimate dimensions in the virtual environment, thus enhancing the sense of presence and decreasing the amount of symptoms of cybersickness experienced. For the user, having the possibility to see a representation of his body while being immersed in virtual reality would help with Internal Interference, as the subject would not be distracted by the fact that looking down he would see his legs missing, decreasing his postural stability.

Conclusion

In this paper a variety of research has been analysed, featuring both papers that used technology from the past such as CAVE systems and extremely recent ones where the latest versions of consumer head mounted displays were used to run experiments.
An analytical framework was created to study these papers and to extrapolate only the data necessary to find a correlation between motion sickness and sense of immersion.
The analytical framework consisted of three questions, regarding the hardware, the design and purpose of the test, and the percentage of users who reported symptoms of motion sickness.
After this, the analytical framework had the objective to determine if Place Illusion and Plausibility Illusion were taking place or not.
The studies that underwent analysis in the literature review were taken from a variety of fields, with some focusing on the correlation between cybersickness and postural stability, such as Llorach et al. (2014), between motion sickness and heart rate, such as Sugita et al. (2007), or purely on visually induced motion sickness and ways to mitigate its effects, such as Porcino et al. (2016).
The aforementioned studies were then analysed with Chertoff's theoretical model of presence (2008), to try and understand what caused breaks in presence.
The analysis of this studies concluded that there are a variety of factors influencing cybersickness and the lack of immersion.

In CAVE systems, causes of cybersickness and breaks in presence have been found to be linked to an increase in field of view, to an increase in speed of visual cues with the head movement, and to moving the scene along the sagittal plane.

Other causes can be linked to having players move in a coordinated manner in a simulation which is saturated with visual cues, as well as having the players move around in the virtual scene at a walking pace higher than the one they have in real life.

In HMDs, it was found that having players move in the simulation with their own body rather than a controller elicits much less cybersickness. A game developed by Porcino et al. (2016) tested Dynamic Focus Selection, a model for the simulation to only focus on the objects the player is looking at, to not overload the user with information.
Other findings were that a lag between the head movement and the visual scene higher than 20ms causes symptoms of cybersickness.

The Analysis of some papers demonstrated that habituation greatly reduces motion sickness, as it probably conditions users to deal better with the hardware shortcomings to make them feel immersed. It was also found that leaving parts of the simulation with a high number of visual cues towards the end helps by not overloading the user with information.

An interesting finding was that in some cases the parts of the simulation created by professional game designers with rich graphics would be the ones inducing motion sickness in the users, so a set of specific art guides when creating 3D environments for virtual reality must be set in order to mitigate motion sickness.

The constant presence of UI elements on the visual plane was also found to elicit symptoms of motion sickness, as well as taking away from the player the ability to control the camera. The possibility for the player to anticipate the relation between perception and action was also found to be critical and not to be removed.

The last important finding was that having a virtual copy of the body of the user inside the simulation would greatly enhance the sense of immersion, the postural stability and reduce the amount of symptoms of cybersickness.

As it’s evident from the data analysis, which only focused on the way the tests were conducted, this paper did not address the medical aspects of motion sickness in virtual reality, as it maintains a focus on the design choices and hardware limitations that influence the cybersickness perceived during a virtual reality experience.

The purpose of this research was to create a set of guidelines for future developers to design virtual environments which would not elicit symptoms of cybersickness while still making the user feel immersed.

There is a high number of papers that focus on the subject of cybersickness, as it concerns both the medical and the technological fields and its causes are still relatively unknown. In the future, with the intent of expanding the scope of this research, more papers could be taken in consideration and passed through the analytical framework in order to collect more data about what could be beneficial or harmful when designing a VR experience which does not elicit symptoms of motion sickness.

As it has been demonstrated already, different types of hardware elicit different symptoms of motion sickness, with new technology causing much less malaise than older one (Rebenitsch, 2016).

It is a realistic assumption that technology will have evolved by the time this research has concluded, and since VR is now a consumer product with new HMDs entering the market often, it is possible that what was perceived as a bad design choice in a test was nothing more than an hardware limitation soon to be overcome.

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