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VR DISCOMFORT AND PREVENTIVE GAME DESIGN DECISIONS

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VR DISCOMFORT AND PREVENTIVE GAME DESIGN DECISIONS

The aim of this thesis is to examine the current generation virtual reality technology and software alongside the possible side effects some users experience while using them. Symptoms such as nausea and disorientation have been widely reported among users of virtual reality games and experiences. Although virtual reality sickness and simulator sickness have similar symptoms, their causes are different.

Virtual reality sickness is mainly caused by sensory conflict caused by contradictory sensations. In games utilizing virtual reality, the possibility and occurrence of these conflicts must be taken into account in order to improve user comfort. Since virtual reality peripherals give mainly visual information to the user, the majority of the discomforting factors can be minimized by controlling the visual stimuli given by the game.

In order to be able to observe the effectiveness and implementation of different game design methods, a test of three different virtual reality games was conducted. As a result of the test, it was confirmed that the movement on the periphery of the player's field of vision is the most harmful to the players comfort. Reducing the movement in the peripheral vision and the shortening duration of the game were found to be the most important factors in guaranteeing user comfort.

KEYWORDS:

Virtual reality, Motion Sickness, Game Design

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VR EPÄMUKAVUUS JA SITÄ EHKÄISEVÄT PELISUUNNITTELUN KEINOT

Tämän työn tavoitteena oli tarkastella nykysukupolven virtuaalitodellisuus laitteistoa ja ohjelmistoa sekä mahdollisia sivuvaikutuksia, joita osa käyttäjistä kokee niitä käyttäessä. Oireet, kuten pahoinvointi ja huimaus, ovat yleisiä käyttäjien keskuudessa. Vaikka virtuaalitodellisuuteen liittyvä pahoinvointi ja simulaattorien aiheuttama pahoinvointi ovat oireiltaan samanlaisia, niitä aiheuttavat eri tekijät.

Virtuaalitodellisuuteen liittyvän pahoinvoinnin syinä ovat pääasiassa ristiriitaisten aistimuksien aiheuttama hämmennys aivoissa. Virtuaalitodellisuutta hyödyntävissä peleissä näiden ristiriitojen mahdollisuus ja esiintyminen on otettava huomioon käyttäjämukavuuden parantamiseksi. Koska virtuaalitodellisuuslasit antavat käyttäjälle lähinnä visuaalista informaatiota, suurin osa pahoinvointia aiheuttavista tekijöistä voidaan minimoida kontrolloimalla pelin antamia visuaalisia ärsykkeitä.

Jotta eri pelisuunnittelullisien menetelmien tehokkuutta ja toteutusta voitaisiin tarkkailla käytännössä, suoritettiin kolmen eri virtuaalitodellisuutta hyödyntävän pelin testaus. Testin tuloksena huomattiin, että pelaajan näkökentän reunoilla oleva liike on pahoinvointia aiheuttavista tekijöistä haitallisin. Näkökentän reunoilla tapahtuvan liikkeen ja pelin keston todettiin olevan merkittävimmät tekijät käyttäjämukavuuden parantamisessa.

ASIASANAT:

virtuaalitodellisuus, liikepahoinvointi, pelisuunnittelu

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LIST OF ABBREVIATIONS

VR	Virtual Reality
2D	Two Dimensional
3D	Three Dimensional
FoV	Field of View
IPD	Interpupillary Distance
SDK	Software Development Kit
UI	User Interface

1 INTRODUCTION

Virtual reality (VR) software development for modern peripherals is a relatively new area of expertise. Although consumer grade virtual reality peripherals intended for gaming applications have been around since the early nineties, certain hardware limitations have prevented said products from reaching mainstream success. In 2012, the company Oculus launched a crowdfunding campaign for a new virtual reality headset called the Rift. The Rift aimed to overcome difficulties many previous products had struggled with and the campaign was a great success. This development has been cited as the event that started the resurgence in VR hardware and software development we are seeing today. (Handrahan 2012) The current generation of VR technology being still relatively early in its lifecycle, developers are still experimenting on design choices to produce the best user experiences.

One crucial part of optimizing VR user experiences is preventing possible side effects. These side effects are similar to those linked with simulator sickness, but are caused by different factors. Traditional simulators and VR peripherals are fundamentally different in their operating principles and produce very differing experiences for differing purposes. Although simulator sickness has been studied in the past, the notable differences between traditional simulators and VR warrant the need for VR specific study and design principles.

This thesis will go over the operating methods of VR hardware and highlight the possibly problematic limitations that might cause issues when designing user experiences. Knowing the capabilities of peripherals is crucial for developers when designing games that rely heavily on them. A peripherals capabilities will often influence many of the decisions made when designing a game for it.

Also to be covered are some of the more common symptoms users might experience when playing an unoptimized game. Most of the symptoms stem from a detectable cause and insight on these causes will help to design and optimize VR games to be as comfortable as possible. Experienced VR developers and hardware manufacturers are already aware of the discomfort causing properties of VR software and have shared some possible preventive game design methods. These existing solutions and the principles behind them will be studied in detail.

Lastly It will cover three games of different levels of production value and identify which design choices each example game used for preventing user discomfort. All of the selected games include player movement as a part of the experience and need to overcome similar obstacles in preventing player discomfort. Because of the similarities, comparisons between the three are made easier. With results from the testing, the effectiveness of different preventive methods can be observed and the most important factors can be identified. A findings table will be made to provide additional clarity.

2 VIRTUAL REALITY AND VR-PERIPHERALS

Virtual reality (VR) refers to an interactive computer simulation that aims to imitate reality by incorporating visual and auditory and sometimes haptic feedback technologies. A typical modern VR experience often features a visual component as well as motion and position tracking to create the illusion of being in a virtual space. (The Science of Virtual Reality 2018.)

A typical VR headset uses two screens, one for each eye. The picture on the screen is stretched to fit the users field of vision using a curved lens. Each screen displays a slightly different image, creating a stereoscopic 3D effect. The headset is held on the users eyes with a strap similarly how a pair of goggles would be.

Compared to their historical counterparts, modern VR devices have some added features to help make the simulated reality more believable. Most prominent of them are head and position tracking. With these features the user can turn their head to look around naturally in the virtual world. Added position tracking can make sure that the real-life head movements are replicated one to one in the virtual scene. Position tracking can also be used in a larger scale. Room scale position tracking allows for freedom of movement to a limited degree, usually confined to roughly a few square meters of space. VR peripherals can also include specifically designed controllers. VR controllers are often designed so that one can be used in each hand and they usually feature position tracking using the same method as the paired headset. This allows the user to interact with virtual objects similarly as they would with real world objects. (Chris Woodford 2018.)

The modern VR headset relies heavily on the high resolution and the small size of modern screens. Since the picture on a VR headsets screen needs to cover the entire field of vision of an eye, the high resolution is required to produce a comprehensible image for the viewer. A low-resolution screen will result in what is called the screen door effect, where the dark spaces between the pixels become visible to the user. It is also important for VR software and games to consistently maintain high enough frame rate as a low frame rate will result in compromised realism and a disorienting experience. Most modern VR headsets feature screens with higher than 60 Hz refresh rate to provide the smoothest possible experience. Although since VR headsets design necessitates the image being rendered twice, once for each eye, maintaining a high frame rate requires more graphical processing power than traditional software and games. (The Virtual Reality Society 2017.)

As of writing, three main models of VR headsets are widely used for gaming and software. The Oculus Rift, Htc Vive and the PlayStation VR. Although prototypes and developer kits of these devices have existed for a longer time, the consumer versions of all three were released in 2016. Also, it is noteworthy that they all operate on very similar principles and the differences between them are negligible when designing games. Their similarities can be considered an asset since porting software becomes easier because of it. The most notable differences are the button layouts on the controllers. (Paul Lamkin 2017.)

3 VR DISCOMFORT

Simulation sickness refers to a wide variety of symptoms one can experience from prolonged exposure to a simulated environment. Common symptoms of simulation sickness include nausea, disorientation, balance issues, sweating, vertigo, loss of color to the skin, vomiting, eyestrain and headaches. The prevalence of these symptoms varies from person to person depending on many factors. Although their symptoms are similar, simulation sickness is not to be confused with motion sickness. (Ashish Mohta 2018.)

Simulation sickness is not exclusive to VR and it has been reported among users of other types of simulations, such as flight or driving simulators. The primary mechanics behind simulator sickness and VR sickness are very similar and share a lot of the same symptoms. In both cases, the mismatch of sensory inputs is what causes the sense of disorientation and nausea (U.S. Army Research institute 2005). Other, more specific factors can contribute or add different symptoms that are more tied to the hardware in use.

Even though occurrence rate of simulation sickness varies widely depending on the factors at play, studies suggest that around 5 to 10% of the population are particularly vulnerable. Some differences have been observed in the susceptibility of different groups, but so far, the only distinction that can be made with some certainty is the difference between young and old age groups. It has been noted that younger people and children are much more resistant to simulation sickness whereas older people tend to be more vulnerable. The opposite is true for motion sickness. Young age groups suffer more from motion sickness than old age groups. (IEEE proceedings VR 2005.)

Exposure can play a key role in an individual’s vulnerability to simulation sickness. It has been reported that one can lessen their susceptibility to simulation sickness with prolonged exposure and experience (ARPost 2018). Counteractively, prior experience with an activity can be a worsening factor when performing a virtual version of said activity. This has to do with the brains expectations for sensory inputs. If a sensory input in a simulation differs significantly from what has been previously experienced in real life, simulation sickness is more easily triggered. For example, since most people have experience with walking, implementing a walking element to a VR game can prove quite difficult as even slight differences with real walking may result in disorientation. (Ben Lewis-Evans 2015.)

Despite the common ground between simulator and VR sickness, the two should be treated as separate issues. VR software differs from traditional simulators in one major way that makes it a more immersive experience. It takes up the users entire field of view (FoV). Because of this, the experienced side effects of image distortion and interruption are more potent than in a traditional simulation. The hardware itself can also cause physical discomfort in different ways, sometimes amplifying existing simulation sickness symptoms (Ben Lewis-Evans 2015.) Attributes in modern VR headsets, that inhibit the appearance rate of simulator sickness symptoms, include for example, smaller latency, higher framerate, and position tracking.

Even though VR discomfort and vulnerability to it vary widely from person to person, some uniformity can be seen between various experiences. There are a few common triggers that cause certain types of symptoms. Some of these triggers have to do with the simulation itself and some of them are caused by the limitations in the hardware.

3.1 Nausea

The most commonly occurring type of VR sickness is nausea. The mechanics behind VR induced nausea are partly like that of motion sickness. Traditional motion sickness is caused by a sensory conflict where the vision and the sense of balance receive contradictory information. (Ashish Mohta 2018.)

Motion sickness can be divided into three categories as follows. First type of motion sickness occurs when movement is felt but not seen. Seasickness while inside the cabin of a swaying ship is a classic example of this. In VR this can occur if the head tracking is compromised due to a software freeze or insufficient rendering speed.

Second type of conflict is movement that is seen but not felt. In VR this can occur when for example the player is moving in the virtual space while standing in place in the real world. The third type is when movement is both seen and felt but the stimuli don’t correspond.

Contradictory sensory inputs like this cause nausea in roughly one third of the population. The most common theory for this type of reaction is that it functions as a defense against neurotoxins. In a natural setting, sensory conflict occurs mostly when one is poisoned, thus the body's reaction would be to induce vomiting through nausea to get rid of the ingested poison. (U.S. Army Research institute 2005.)

3.2 Disorientation and balance issues

The sense of balance in humans relies heavily on vision as the dominant way of determining orientation and movement. Other senses like the vestibular system (inner ear) and the proprioception (muscles) aid in providing balance, but the sense of balance through vision is the one that develops first as a child and as such is the dominant one (Ben Lewis-Evans 2015.). The sense of vision also provides crucial information about movement. Because of how the eye is constructed, the periphery of the human visual field is more sensitive to movement compared to the other parts of the eye. In right conditions, this movement sensing property can cause one to feel movement even though they are not moving. This illusion in self motion is referred to as vection. It occurs when a large portion of the visual field moves and causes one to feel as if they had moved. For example, while sitting on a stationary train, seeing another train pass you in your peripheral vision, can make you feel like the train you're sitting in is moving even when it's not. This effect is also very noticeable in VR. Traditional screens most of the time don't extend far enough to be in users peripheral vision. A display on a VR headset on the other hand, extends to the users peripheral vision and is likely to cause vection in many users. (Unity3D 2018.)

The above factors combined, can make certain movements in VR disorienting. Games where the player moves or sees large moving objects in the periphery, can cause vection and result in a loss of balance. And since the player cannot see the outside world through the headset, they cannot rely on their vision to rebalance themselves. Although these conditions can be adapted to trough extended play, the player can experience after effects upon exiting VR, as the sense of balance readjusts itself.

3.3 Eye strain

The view through a VR headset, though convincingly similar, fundamentally differs from how one naturally views the world. When using a VR headset, the users eyes, rather than looking at objects in the distance, are focused to a screen that is very close to the eyes. Although the generated effect gives off the illusion of depth, the view is pre-focused to a certain focal point due to limitations in the hardware. This focus point is usually few meters in front of the user. Because of this, focusing on up close objects in VR can be very challenging and unintuitive, potentially leading to eye strain. In future devices, this could be solved with different methods. One method would be to mechanically move the display in the headset either closer or further away, depending on what the player is looking at. (Cale Hunt 2017.)

4 PREVENTIVE GAME DESIGN PRACTICES

Game design refers to the choices made to create a video game. Gameplay refers to the features of a video game, such as the way it is played, as distinct from the graphics and sound effects (Oxford Dictionaries 2018). This thesis will mostly focus on aspects of game design that have to do with gameplay, movement, camera and interaction with the game world, as those are most crucial elements to get right when designing a VR experience. If these elements and challenges regarding them are recognized and kept in mind, it is possible to develop around them. (Duffy 2007.)

4.1 Traditional game design in VR

Compared to a controller or mouse and keyboard, VR offers a fundamentally different set of controls as an approach to interacting with the game world. For movement, most conventional games feature a camera system that is controlled with directional inputs through button presses, mouse movement or analogue stick tilt. For example, for a player to look around in a first-person console game, they would have to tilt the right analogue stick to achieve this. In VR, control like this frequently induce nausea so looking around the virtual space should optimally be handled more intuitively through headtracking. Through headtracking, the players input on camera movement also becomes more precise and even fine movements are possible. On the other hand, like in real life, fast 180 or 360 degree turns become very hard or impossible to execute comfortably. If the game is played sitting down, turning a high number of degrees becomes even more restricted (Unity3D 2018). Movement in conventional games, much like camera controls, is achieved with button presses or analogue stick tilt. In VR, movement happens through position tracking. Again, this allows for a more precise and intuitive input method but omits the ability to do quick movements and in this case, moving outside of the assigned area.

Some common graphical effects can also become problematic when viewed through a VR headset. Games that are optimized for traditional displays often employ graphical post processing effects for various results. Many post processing options aim to emulate the effects one would see when looking at the world through a camera lens. Lens flares, depth of field or focus, bokeh effect, motion blur, lens dirt, lens distortion, chromatic aberration and film grain are some examples of these effects. Since the VR headset emulates the ability to view a virtual space through the users own eyes, camera related effects would not only be out of place, but sometimes even harmful for the players experience. For example, motion blur in VR would potentially induce disorientation or even nausea as blur in one's peripheral vision is one factor that causes vection. Flickering lights can also trigger vection as they can change how one perceives movement. (Ben Lewis-Evans 2015.)

4.2 VR game design

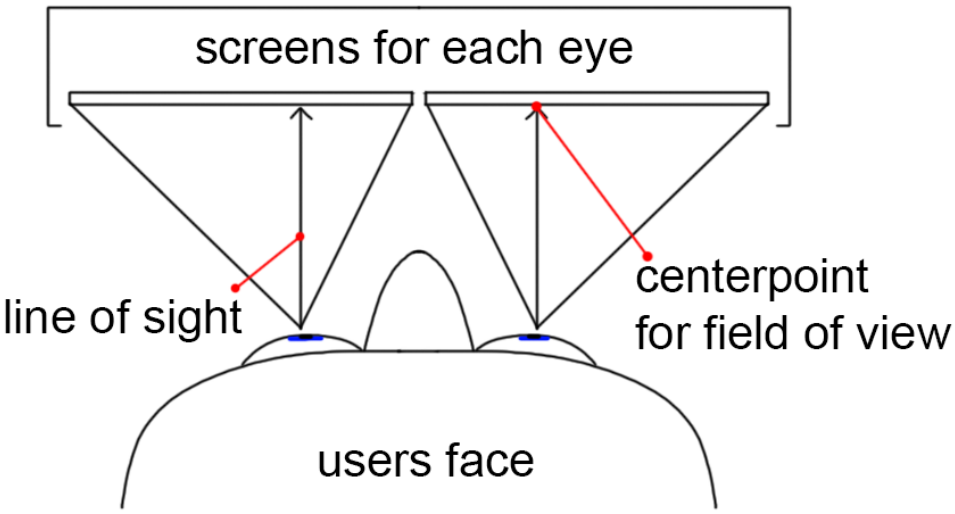
Although modern VR technology and related game development is relatively new, there are design practices that are recognized as being generally beneficial for VR development. These practices range from hardware related tricks to entirely new genres of games, designed to utilize the unique capabilities of the VR hardware. The various VR hardware manufacturers have also provided extensive guides for developers, detailing all the features of the hardware. Also, being provided are suggested practices on how to use the hardware in a way that provides the most comfortable experience for the end user. (Yasser Malaika 2015.)

4.2.1 Knowing the hardware

Developers can gain crucial insight about the hardware and it's features if the hardware guides are researched properly. Oftentimes, VR hardware comes with built in solutions for some of the harder aspects of VR development. For example, Oculus has provided a "Best Practices" guide for free use by developers. The Guide details how to get most out of the Oculus headset as well as general good practices for optimizing the VR user experience.

One built in feature detailed in Oculus' Best Practices guide is the distortion shader. Since the image on a VR headsets screen goes through a distorting lens to fit the users field of view, the image on the screen needs to also be distorted to accommodate. This distortion effect warps the image in a "fisheye"- like manner, enlarging the center and compressing the periphery. The result should be the user seeing an undistorted image stretched to fit their entire field of view. Although it is possible for developers to code this distortion shader by themselves, Oculus has strongly recommended using their existing distortion shaders, stating that “Approximating your own distortion solution, even when it “looks about right,” is often discomforting for users.” (Oculus 2017.)

The Best Practices guide also shares details on the Rifts premade projection matrices. A projection matrix in simulated 3D, describes the viewports field of view and the direction of said field of view. A projection matrix could be described as viewing the world through a window, the borders of the window determining the field of view. A transformed projection matrix could then be described as moving the viewing position to see a slightly different view of the world through the same window. This relates closely to VR with the fact that the view for each eye needs to be rendered with different projection matrix. The field of view for each half screen needs to be larger in the outer periphery to produce an effect that basically shifts the view of the scene inwards. The reason for this has to do with the interpupillary distance or IPD. The different transformation matrices are in place to accommodate for the fact that, despite the lenses themselves having adjustable IPD, each of the users eyes may not be directly in the front of the corresponding half screen. As seen in picture 1, field of view needs to be calculated to a point that is near the inner edge of the screen (Oculus Rift in Action 2013). The Best Practices guide advices taking advantage of the Rifts own projection matrices, urging developers to “Get the projection matrix exactly right and use the default Oculus head model. Any deviation from the optical flow that accompanies real world head movement creates oculomotor issues and bodily discomfort.”



Picture 1. Interpupillary distance and field of view.

Accurate and low latency headtracking is one of the key features VR headsets use to make the user experience as smooth as possible. To help with this, the hardware manufacturers incorporate premade software solutions to accommodate for the inevitable sensor inaccuracies. Predictive tracking is widely used software side correction that reduces the apparent “motion-to-photon” latency in VR headsets. Predictive tracking software works by taking the speed and acceleration of the current movement and calculating an estimate on where the tracked piece of hardware is going to be in the future. Utilizing this, the software can essentially render images ahead of time, thus reducing latency. The amount of prediction, it’s efficiency and its accuracy depend on the algorithm used (Road to VR 2017). The Oculus’ software development kit (SDK) includes its own implementation of predictive tracking. For other examples of latency aid, the Rift has a built-in latency tester. The Best Practices guide advices using this to aim for 20ms or less motion-to-photon latency to shield users from the disorienting effects of latency. Additionally, the latency should stay constant for the best experience. (Oculus 2017.)

It is widely recommended that VR games should maintain a consistently high frame rate to reduce the possibility of discomfort. The Rift, Vive and Playstation VR all support a refresh rate as high as 90 Hz, with the PSVR capable of even 120 Hz (Wearable 2017). Keeping the frame rate consistent is also just as important. As different frame rates can change how a player experiences movement, a consistent framerate is crucial in preventing disorientation. The Best practices manual states that a frame rate of at least 90 is necessary for a comfortable experience. Since consistent frame rate of 90 Hz while simultaneously rendering dual screens is hard to maintain, developers are advised to sacrifice graphical fidelity in favor of good performance. Both Oculus and Htc are also aware of the importance of performance and thus have placed comparatively high PC system requirements for their respective VR peripherals. (Ben Lewis-Evans 2015.)

4.2.2 Camera

The camera in a VR game will optimally work as similarly to the users own eyes as possible. Since VR is immersive and aims to emulate the feeling of being in the virtual world, when a VR camera behaves in ways that are not natural to the real world, both the users immersion and comfortability are compromised. Although there come times when manual manipulation of the camera may seem necessary from game design perspective, one should optimally design around having to do so.

As the headset tracks rotation from the front of the users head and not the center, it is important to use some sort of virtual head model to ensure that the pivot point of the virtual camera is in the correct place. Oculus' SDK for example, comes with a premade head model specifically for this purpose. A misaligned pivot point for the virtual camera in the scene might make the experience of just looking around uncomfortable and disorienting.

The head tracking also intersects with the position tracking with the fact that the camera of course moves with the position of the player. This camera movement should not be interfered with to keep the immersion and natural control of the camera as it is vital to the comfortability of the experience. Another thing to note about head and position tracking is that the orientational head tracking should never be taken away from the player, even when the position tracking might be compromised. Suddenly changing the rules with which the player operates the game, can be very disorienting to the user. (Unity3D 2018.)

Field of view is a common option in most conventional first-person perspective games and it lets the player change how wide their cone of vision is. A suboptimal field of view can cause dizziness even when using conventional monitors and it depends on the player how they want their preferred field of view to be. In VR games, the field of view is recommended to be kept as close to the real-world equivalent as possible. As the field of view changes how the player perceives movement, a wrong field of view can be very uncomfortable. For example, a too narrow field of view would give the player a vision akin to looking through binoculars. A narrow field of view also zooms the view slightly, enhancing the effect. When looking through a viewport like this, any head movement will feel very sensitive and seemingly cover more distance as objects move fast through the players field of vision (New Atlas 2016). Effects like these are direct motion ques that will cause vection and thus discomfort. Because of this same reason, the best practices guide advices against using a zooming camera. Although zooming features are common in conventional games, in VR "Zooming in or out with the camera can induce or exacerbate simulator sickness, particularly if doing so head and camera movements to fall out of 1-to-1 correspondence with each other." (Oculus 2017.)

As previously mentioned, the camera in a VR game should optimally be tracked one to one with the players movement. Because of this, some camera effects seen in conventional first-person games are highly incompatible with VR. One common effect is head bobbing. This effect essentially shakes the camera up and down when the player moves through the scene, emulating the head movement a person would make while walking in real life. Even in VR games that feature conventional movement, that would on surface benefit from this, this sort of effect would be very detrimental to the users comfort. Likewise, tilting the horizon with a similar effect would be also be uncomfortable to the user. Even in cases like player getting knocked back by and in game attack, or shaken by the level, uncontrolled camera movement should be kept to a minimum. The best practices guide urges developers to “Have accelerations initiated and controlled by the user whenever possible.” (Oculus 2017.)

4.2.3 Movement

Self-locomotion might not be essential for all VR experiences, but for a system that aims to imitate real life, it can greatly enhance the users feeling of immersion. Modern VR hardware usually comes with a way to implement “room scale” movement for the user, but this might not be the best option in some situations. Although room scale movement provides a rather discomfort free experience due to its similarity to real life movement, it requires a physical space for the player to move in. Also, it limits even the virtual area of movement to a few square meters. So sometimes, development of a different kind of movement system is required (Sam Pattuzzi 2018). In the case of porting conventional games to VR, this is something that cannot be bypassed. Non-VR games usually allow the player to move very freely in the virtual space. This is something that is not possible with the room scale tracking solution. And since moving around is something the player is going to do quite often, getting the movement system to be as comfortable as possible is essential.

Good development practices concerning VR movement share a lot of similarities with the previously mentioned good development practices for VR camera. Staying close to the one to one tracking is a generally good solution but not always achievable. Unlike camera movement though, self-locomotion in a virtual space allows for more design options due to a few factors. Many difficulties with VR movement have to do with the user feeling uncomfortable seeing motion cues while not feeling them. The answer to this is to design your movement system so that it mitigates those motion cues during movement.

Perhaps the most commonly seen movement option for VR is teleportation. This type of movement gets rid of the motion cues by not making the player actually move through the virtual space. A typical VR teleportation system works by pointing the controller and its marking reticle to a desired location and pressing the assigned teleportation button. This then makes the player teleport to the marked location. By itself, teleporting can still be disorienting so an additional camera effects can be added to help with this. Often seen accompanying a teleportation is a short fade to black between locations. This helps to sell the feeling of teleportation and not just moving very quickly through the space. It is also beneficial to limit the players ability to teleport rapidly. Rapid teleportations can create the illusion of normal movement and be discomforting to the user. (Yasser Malaika 2015.)

Although changing the field of view for the whole image has been proven to be disadvantageous, a different kind of field of view limit has been proven to decrease harmful movement in the peripheral vision during movement and thus prevent vection. The way to do this is to essentially block the players peripheral vision with in game objects to give them a solid point of reference (Ajoy S. Fernandes 2016). One example would be a virtual race car helmet. The player would see the edges of the helmet and it would help to block the movement sensitive peripheral vision. This sort of adjustment essentially tricks the sense vision to not register the movement it sees and thus decreasing the chance of sensory conflict with the vestibular system. There are many ways to implement such system and developers can design different kinds of field of view limiters to fit the theme of their game. Other examples would be a space ship cockpit, a big UI or a light cone from a flashlight. The latter working best in a dark environment.

When motion cues are taken to accord properly, a conventional analogue stick movement can be implemented to a VR game with less of a discomfort risk. Like described before, analogue stick movement in non-VR games works by tilting the left analogue stick to a desired direction to move the character in the same direction. The analogue stick camera works similarly but with the right stick instead. An analogue stick movement system in VR would essentially get rid of the need for the player to physically turn to face a direction, or to walk to change location. This has its advantages and disadvantages. The biggest advantages would be the ability to move more freely in the virtual world, not limited by the room scale model. The disadvantage being that this style of movement greatly diverges from the established one to one tracking model and can be hard to implement in a way that is comfortable for the user. When sitting still in real life while moving in the virtual space, the player is going to be exposed to a large amount of conflicting motion cues. because of this, extra attention needs to be put into diminishing the effects of these conflicts. The field of view limit helps with the motion cues in the peripheral vision, but the player can still be exposed to other kinds of motion cues in the central vision. The central doesn't see as much movement when moving forward but turning around can still be problematic. One possible solution to this is step turning. This effect makes the normally smooth moving camera turn in small notches. This Works in a similar way to the teleporting mechanic, but instead of changing location, it slightly changes the orientation of the camera. A fade to black when changing views is also beneficial here. (Sam Pattuzzi 2018.)

Self-locomotion in VR games isn't tied to just walking. Games can feature vehicles, moving platforms, moving stages and other factors that have the player moving without walking. Most of the motion cues and their side effects apply regardless of how the player is moving in the virtual space. The difference between walking and non-walking movement in VR arises from the fact that the illusion of non-walking movement is easier to sell. For example, in a VR spaceship game, the cockpit of the ship can act as a large periphery block and a stable focus point for the users eyes. Analogue based movement in a virtual vehicle is a relatively low discomfort risk option because of this. (Unity3D 2018.)

4.2.4 Gameplay design

It could be said that designing for the platform in mind is a core part of developing discomfort free VR experiences. When games are developed to take advantage of the unique advantages of the VR hardware, many problematic situations can be skipped entirely.

A generally good VR game design advice is to try to make the interaction in the game match the expectations of the user. The aforementioned walking is a good demonstration of this. walking is hard to execute in VR as it is an activity the user is most likely very familiar with and the brain has many expectations that are hard to match. It is important to keep in mind what kind of expectations the users might have in certain situations, and design interactions accordingly (Ben Lewis-Evans 2015). This is also why it is beneficial for the player to have some sort of avatar in VR. Since the player expects to see their hands even in VR, having models for them is considered a good design choice. Although having virtual hands comes with its own set of new expectations, there are ways you can manage these expectations. Developers at Valve have noted that having the player avatar be stylized or cartoony, rather than realistic, can result in a more comfortable experience for the player. The cartoony virtual hands would give some of the benefits by matching the player expectation of having hands, while also being a new enough experience that the brain would not know what sensory inputs to expect from said cartoony hands. (Yasser Malaika 2015.)

To avoid any unnecessary motion cues, UI design in VR should be stable and centralized. Having the UI be out of the peripheral vision and closer to the center helps to stay clear of possible problems that peripheral movement sensitivity causes. The UI should also be optimally anchored in place and not move, like seen in some conventional first-person games. A UI that is anchored into the world or objects instead of the player is also advantageous for the same reasons. (Medium 2017.)

A shorter play time can become an advantage when designing a VR game. With shorter exposure to potentially harmful stimuli, the risk of triggering symptoms decreases. It is a generally good idea to provide an opportunity for the player to play short sessions or design the game to be completable in a short time.

5 EXAMPLE GAMES

This part will examine three example games from different levels of production values. The chosen games all feature player movement of different types and thus need to overcome similar developmental obstacles. Different preventive methods found within the games will be identified and evaluated in order to discern how well they worked. In this test case, the testing will be conducted by the author of this thesis.

5.1 Science to stars

Science to stars is a VR game developed at Turku Game Lab for Tuorla Observatory. The Science to Stars project was collaboration between the University of Turku and the Turku University of Applied Sciences. It received funding from the Regional Council of Southwest Finland and was also part of a thesis by Aapo Peltola in 2015 (Aapo Peltola 2015). It uses the Unity game engine and runs on PC. The game centers around the international space station and features small tasks for the player to solve while flying around the it. The player assumes the role of an astronaut from the first-person perspective and is tasked with realigning the solar panels on the space station. The player has control of the various functions in the astronauts suit and can switch between two modes of action. In the interact mode, the player can interact with in game objects with their hands. In the flight mode, the player can maneuver the space suit with virtual joysticks that control the thrusters in the suit.

The camera in the game is both orientation and position tracked. The players spacesuit is a non-tracked, stationary game object and the player needs to sit still to stay inside the suit. The suit has a visor that the player can see through. The controllers are also tracked and in game they are represented as space suit gloves. Pressing different buttons on the controller allows the player to adjust the virtual gloves fingers accordingly. The virtual hands disappear once the player enters flight mode. The flight mode is accessed by pressing a button on the backside of the virtual glove. In flight mode, the controllers are to be held upright like one would hold dual joysticks. Tilting the controllers allows the player to go in different directions, turn and spin.

Since the game allows for such great degree of movement, there is a possibility for disorientation and nausea. As mentioned in the previous chapters, movement is a feature that often produces harmful stimuli. The game uses the spacesuit as the most notable trick to help alleviate possible discomfort. Since the spacesuit is stationary, it gives the player a solid focus point during motion. As seen in the picture, the spacesuits visor also restricts the players field of view so that the peripheral vision is not entirely visible. The amount of field of view restriction depends on how far the player is sitting from the visor window. This allows the player to essentially adjust the FoV to a personally comfortable level. The lack of objects in the scene is also a helping factor. Although flying could potentially be a disorienting activity, when there are not too many objects moving in the players periphery, its effects are lessened. Additionally, the game is relatively short, which works in its advantage. It takes only a few minutes to go through all the content. The short runtime effectively reduces the players exposure to the discomforting aspects that are present. During the short play session, a moderate amount of vection was felt by the tester, but the overall experience was not uncomfortable. After playing, a slight disorientation lasted for five to ten minutes.

Picture 2. The spacesuit visor and periphery blocking elements.

5.2 Gorn

Gorn is a VR action game developed by Free lives and published by devolver digital. The game is being developed in Unity and it runs on PC hardware with either Oculus Rift or the Htc Vive. The game is currently in "early access" stage on steam, and it receives new content updates as the development continues. The game was first released on steam on October of 2017. The game is a physics-based fighting game with a gladiator theme. The player is placed in a fighting arena with the task of defeating wave after wave of increasingly difficult opponents using weapons that can be found in the arena. The player can attack by physically swinging the different weapons, dealing more damage depending on the speed of the swing. Because the game is physics based, objects, weapons and enemies can be picked up and thrown to deal additional damage. (Freelives 2018.)

The game features player movement by walking. The players position is tracked in a room scale way, so they can move freely in the tracked area. To move further, the player can essentially drag themselves forward by extending their arm forward, pressing the grab button and pulling themselves towards that location. This can be done rapidly with both hands in a way that mimics the hand movements done while walking in real life. The movement achieved by doing this is relatively slow, which is advantageous quality to have in VR movement. On the downside, the movement is quite uneven in speed, compromising its comfortability. Also, to be noted is that the game uses a rather cartoony art style. Like mentioned in a previous chapter, a nonrealistic art style, especially in the players mode, can ease the possible discomfort. As seen in the screenshot, the players hands in the game are very stylized and usually covered by gloves or weapons. The game is played in rounds with short breaks in between. Each round consists of a limited number of enemies the player must defeat. The rounds get increasingly hard as the game progresses. Due to this structure, the game can be played in short sessions, with some additional in game break time.

Out of the three example games, this was possibly the most uncomfortable to play. Despite the slower pace, the lack of peripheral vision blocking elements and the stuttering movement caused disorientation and slight nausea. These side effects lasted for around 20 minutes.

Picture 3. Cartoony glove models.

5.3 Playstation VR Worlds

Playstation VR Worlds is a collection of five games developed by Sony Interactive Entertainment London Studio and released in October of 2016. It is one of the launch titles for the Playstation VR headset. Out of the five different games included, the one that will be focused on is Scavengers Odyssey, since it is the most relevant to this study due to it featuring player movment. Scavengers Odyssey is a first-person action game, where the player pilots a giant robot. The player sits inside the robots virtual cockpit and sees the action through the cockpits window. The game is controlled with standard first-person game controls using the dualshock 4 controller. The one notable exception being that aiming is achieved partly with the players head tracking, the targeting reticle following the players line of sight. The game game is mostly linear and features some combat, platforming and context sensitive actions for the player to do during its 40 to 60-minute runtime. (Playstation 2016.)

The player is supposed to sit down during play like one would in a cockpit. The players head is tracked and looking around and leaning in different directions is possible to get a better view of the cockpit or the outside. The player has models for virtual hands and body. As seen in the screenshot, the game features periphery blocking elements in the form of cockpit controls as well as big stationary UI elements. The character also moves very smoothly, and the robot doesn’t shake or bob when walking. Even the jumping feature has a very stable acceleration and arc. A more negative feature would be that the jumping portions of the game sometimes move the camera in uncomfortable ways, like turning the players view sideways or upside down. Since the game is set in space, the player can jump on surfaces that face different angles. These angled jumps rotate the players point of view in a way that can be disorienting. Although the stationary objects in the periphery help, these jumps made me slightly nauseous during play. Otherwise the game was a comfortable experience.

Picture 4 Stationary objects in the cockpit and large UI elements.

5.4 Comparison table and findings

For additional clarity, a comparison table with the main features for each game was made. From here it can be seen that the games used similar techniques in some areas and different in others. Gorn is the most notably different out of the three.

	Science to Stars	Gorn	Scavengers Odyssey
Control	-Virtual flight sticks -Position tracked hands	-Position tracked hands -Physics based interaction	-Gamepad control
Movement	-Omnidirectional flying -Smooth movement	-Simulated walking -Position tracking	-Piloting a vehicle -Jumping with vehicle
Camera	-Standard Headtracking -Restricted FoV	-Standard headtracking	-Standard headtracking -Stationary peripheral objects
Length of play	-Few minutes -Depends on players skill	-Short rounds -Limited amount of enemies per round	-Completable in less than an hour
Other methods	-Models for the players hands -Limited amount of of moving objects on screen	-Models for the players hands -Slow movement speed	-Limited amount of acceleration in movement -Big UI elements

Picture 5. Comparison table.

From these aspects it is possible to see how some design decisions are more effective than others. It seems that the most effective way to reduce VR discomfort is to limit movement in the periphery. In Science to stars, due to it’s space setting, these objects were almost completely absent and the experience was the most comfortable as a result. The player often sees only stars and distant objects in their cone of vision. This helps to make even otherwise disorienting movements feel much more comfortable. Same can be said about Scavengers odyssey and the large periphery blocking elements it uses.

The second most notable method was the game length and it is notable for two reasons. First reason is the aforementioned exposure time. Shorter exposure leads to decreased chance of discomforting elements causing symptoms. Had Science to stars lasted longer, the more unfavorable elements of it’s movement system would most likely have had more of an impact. Scavengers odysseys longer run time made the discomforting elements have more of an impact in the end.

The second reason for why game length is notable is the fact that shorter exposure time also diminishes the positive effects of less noticeable discomfort prevention methods. For this reason, some of the design decisions in Gorn didn't have as much of an impact. For example, the cartoony hands on the player character didn't seem to have a noticeable impact.

Overall, the findings suggest that when peripheral movement is restricted enough, the experience can remain relatively comfortable, even when including a lot of player movement. The less visual information there is about the player moving, the less of a discomfort risk the game has, even if it features player movement in a prominent way. The run time should also be optimally kept short. When designing a longer VR experience, it is important to keep in mind that the effect of discomforting elements will only worsen over time. A longer VR experience should optimally feature very controlled or restricted player movement and take into consideration even some of the smaller factors like player avatar.

6 CONCLUSIONS

The objective of this thesis was to provide info on VR sickness and shed light on possible methods to prevent it. The differences between simulator sickness, motion sickness and VR sickness were also made clear. An additional objective was to study which methods were in use in the three example games as well as how effective they were during a shot testing session.

After a brief introduction to the working principles of VR, the sickness causing properties of certain stimuli were introduced and explained. These stimuli could appear both in and out of simulators or VR and it was clarified which of the resulting symptoms were the most prominent if not exclusive to VR. Common symptoms to VR sickness were nausea, disorientation, balance issues and eye strain. The mechanics behind these symptoms and their unique ties to VR games were expanded upon.

After recognizing the problems and challenges of VR as a platform in part three, the fourth part was to provide possible solutions for these problems. It was shown that the hardware manufacturers were aware of their products shortcomings and had provided guidelines for developers in an effort to help overcome them. But as previously explained, VR discomfort has it's causes in both hardware and software. A software side overview of VR sickness prevention was added to cover this. Overall, this thesis has provided developers with advices for both VR sickness prevention in game design as well as hardware related knowledge to employ when developing content for VR as a platform.

In the final part, three example games were tested to see the previously covered developer insight in action. All the selected games featured player movement as a core part of the experience. Like previously mentioned, movement in VR is hard to produce without also causing discomforting stimuli to appear. As the example games had similar difficulties to overcome, comparisons between them were made easier. The comparisons revealed the camera and camera movement to be the most affecting factor for player experience. The second game, Gorn, was found to be the most uncomfortable to play, due to its lack of restricted FoV or limited peripheral vision. Smooth movement in Science to Stars and Scavengers Odyssey were also key features that lessened the impact of sensory mismatch. The short length was beneficial to all games as none of them caused unreasonable amount of discomfort. Many of the smaller changes and techniques like cartoony hands in Gorn, and player character model in Scavengers Odyssey seemed to have negligible benefits during the short playtesting session. The player is going to be looking at the scene and game objects most of the time and not enough attention is going to be directed at the player characters model for it to make a reasonable difference.

As a final thought it should be noted that, as development continues, the VR hardware will continue to evolve. Many of the limitations seen in current consumer models will most likely be improved upon in future releases. As the hardware improves, the developers attention can shift more to the software side.

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