How can the control and interaction principles be improved for games in Virtual Reality?

A QUALITATIVE STUDY TO CREATE INTERACTION DESIGN GUIDELINES THAT LIMITS THE EFFECT OF CYBERSICKNESS IN VIRTUAL REALITY

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How can the control and interaction principles be improved for games in Virtual Reality?

Hur kan kontroll- och interaktionsprinciperna förbättras för spel i Virtual Reality?

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2015-06-10
Abstract

With new VR devices entering the consumer space, the interest in the industry is growing immensely. There is currently limited information regarding controls and cybersickness in VR and the available recommendations are narrow in their nature. The goal of the thesis was to find new control and interaction guidelines that limit the onset of cybersickness, to be used by those who wish to create games in Virtual Reality.

A literature review in the area of cybersickness was followed by a qualitative study. 22 participants played 4 selected VR games of different nature and were interviewed after each gaming session. The data was used in a qualitative framework designed to create policies. The resulting guidelines covered areas of cybersickness, presence and ergonomics. They validated several existing guidelines, extended some and created new ones. The new guidelines state that it is preferred to strive for controls that mirror real life, that presence has implications on interaction design and that new inputs should be implemented in a pedagogical manner. In addition some ergonomic aspects of head mounted displays were uncovered.

Keywords: virtual reality, VR, interaction, controls, cybersickness, design, interaction design, immersion, presence, guideline, framework analysis
Sammanfattning

I takt med att VR-marknaden växer ökar konsumentintresset för teknologin mer och mer. Det är i dagsläget svårt att få tag på information angående kontroller och cybersjuka i Virtual Reality och de rekommendationer som finns är begränsade. Målet med uppsatsen var att hitta nya riktlinjer för interaktion och kontroller inom VR med fokus på att underlätta för designers att skapa spel som begränsar cybersjukans påverkan.

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1 Introduction

1.1 Introduction to Virtual Reality
For every major technology device there exists a convention of interaction. The PC has the keyboard and mouse; game consoles have a gamepad with a layout few manufacturers stray from. These conventions are developed through research and product development.

In the last years Virtual Reality (VR) hardware have advanced and the interest for the devices has increased immensely. Due to this increase there is not yet an established convention for how to design VR experiences. The input is strongly linked to Cybersickness (CS) and a badly designed interaction can make the user feel more than frustrated; it can make him/her feel sick. Several VR devices are entering the market and more and more people are trying it out, increasing the importance of finding out what enhances and what diminishes the VR experience.

1.2 Purpose and research question
Since previous work in the field of VR games has been limited there are few interaction guidelines available to create games for the medium. The recommendations that do exist are specific and mostly learned through trial and error. Based on this a general approach has been applied with the intent to make an explorative study in the field of interaction for games in VR. The research question is:

How can the control and interaction principles be improved for games in Virtual Reality?

The overall research methodology is to collect information from existing recommendations and data from users experiencing a set of VR productions, which then will be analyzed to create guidelines.

1.3 Delimitations
The thesis focuses on interaction and control guidelines of current consumer VR. No interaction conventions from professional simulators will be used. The analysis is based on data from subjects using a Samsung GearVR, a Samsung Note4 and a Samsung GamePad. No hardware variable, like field-of-view or display refresh rate, is included in the study. And while the report is including elements of cybersickness the analysis is limited to a qualitative nature. In addition, no game design elements are included.
# 2 Vocabulary

<table>
<thead>
<tr>
<th><strong>CAVE</strong></th>
<th>Cave Automatic Virtual Environment; images projected surrounding the user on the floor, walls and ceiling.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cybersickness (CS)</strong></td>
<td>The symptoms of motion sickness induced inside a VE.</td>
</tr>
<tr>
<td><strong>Control schema</strong></td>
<td>The mapping of the controller, deciding what type of input has what type of output.</td>
</tr>
<tr>
<td><strong>Controller</strong></td>
<td>A device used in order to enable or to accelerate the interaction.</td>
</tr>
<tr>
<td><strong>Field Of View (FOV)</strong></td>
<td>The angle of the visual field. A single eye has a FOV of 140 degrees. Two eyes’ FOV overlap each other, giving a total of about 180 degrees.</td>
</tr>
<tr>
<td><strong>First Person Controller (FPC)</strong></td>
<td>The controller component of a first person shooter, e.g., steering the character in 6DOF while looking out of the eyes of the character. On PC and console this is in most cases implemented with a mouse and keyboard or a gamepad using both thumbsticks.</td>
</tr>
<tr>
<td><strong>Game</strong></td>
<td>An activity with a player, procedure, rules, objectives, conflict, boundaries, resources and outcome. See section 3.2.3.1 for detailed description.</td>
</tr>
<tr>
<td><strong>Head Mounted Display (HMD)</strong></td>
<td>A visual display strapped to the user's head, staying in place when the user rotates and moves the head.</td>
</tr>
<tr>
<td><strong>Immersion</strong></td>
<td>The illusion of being physically within a VE experience.</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td>The act of communicating with a device through an interaction schema.</td>
</tr>
<tr>
<td><strong>Interaction schema</strong></td>
<td>The designed way to communicate with a device. Can include one or several controllers such as gamepads, cameras, sensors or physical buttons.</td>
</tr>
<tr>
<td><strong>Motion sickness (MS)</strong></td>
<td>A set of symptoms that arise in certain conditions in real life. Several theories as to why these symptoms arise exist. This is the same as being seasick on a boat, or feeling ill when reading in a car.</td>
</tr>
<tr>
<td><strong>Presence</strong></td>
<td>The illusion of being part of a virtual environment. The more immersive a VE experience, the greater the sense of being part of the experience.</td>
</tr>
<tr>
<td><strong>Simulator sickness (SS)</strong></td>
<td>Cybersickness, but happening while inside a</td>
</tr>
</tbody>
</table>
VE that induces vection

<table>
<thead>
<tr>
<th><strong>Six degrees of freedom (6DOF)</strong></th>
<th>3DOF with the addition of three axes that stand for space coordinates, enabling positional tracking.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Three degrees of freedom (3DOF)</strong></td>
<td>The possibility to track rotation of three perpendicular axes, i.e. pitch, yaw and roll.</td>
</tr>
<tr>
<td><strong>Thumbstick</strong></td>
<td>The control which gives input in XY coordinates, usually one for left and one for right thumb on a gamepad</td>
</tr>
<tr>
<td><strong>Vection</strong></td>
<td>Illusion of self motion due to a large part of the visual field moving</td>
</tr>
<tr>
<td><strong>Vestibular</strong></td>
<td>The sensors of the inner ear that tracks acceleration in 360 degrees rotation and forward/backwards up/down vector.</td>
</tr>
<tr>
<td><strong>Virtual Environment (VE)</strong></td>
<td>A virtual model that a user can interact with, communicating information through the human senses. Currently mostly the visual sense.</td>
</tr>
<tr>
<td><strong>Virtual Reality (VR)</strong></td>
<td>The result of having immersion inside a virtual environment.</td>
</tr>
</tbody>
</table>
3 Background
The study covers several connected areas presented in this section. At first the basics of interaction principles is explained. A brief description of VR is then presented along with a short history presentation of both the hardware and application areas. In order to understand the unique aspects of VR and the importance of the study, the concept presence (the sense of ‘being there’ in the virtual environment) along with cybersickness (a common side effect of prolonged use of VR-products) is then introduced before ending the chapter with a summary of the current consumer VR devices and their input possibilities.

3.1 Interaction principles
Desktop computer games have for many years in almost all cases been used with a keyboard and a mouse. Gaming consoles have had gamepads that consist of a combination of control pads, thumbsticks and/or buttons. Flight simulators have popularly been played with a joystick and car games with a steering wheel.

Interaction conventions exist for popular devices, be they technical or non-technical. These are interaction schemas that after a time become familiar and behave as expected. They come into existence for different reasons like ergonomics or, like the QWERTY keyboard, mechanical limitations (Stamp 2013). Sometimes they are developed over time sometimes they explode into being like swipes and pinches for smartphones. As the market develops the same type of interaction principles will develop for VR.

3.2 What is VR?

“What is real? How do you define ‘real’? If you’re talking about what you can feel, what you can smell, what you can taste and see, then ‘real’ is simply electrical signals interpreted by your brain.” – Morpheus, The Matrix 1999

The quote by Morpheus is arguably one of the first forays that laymen had with what is called Virtual Reality (VR). Something that was artificial yet seemed to be real. VR is the result of when technology can simulate physical presence inside a Virtual Environment (VE) by stimulating the senses, most often the visual sense. Currently most devices attempt to convince the user that it is an alternate reality by projecting a stereoscopic image to the user, effectively presenting a 3D view (Hale and Stanney 2015).

3.2.1 History of hardware
Most research articles mention Sensorama, a device built by Morton Heilig (Heilig 1961), as one of the earliest VR devices. It is a static device that features stereoscopic visuals and sound, wind, aromas and functions to tilt the body. While being an impressive piece of technology it was never a market success. Shortly after Sensorama Ivan Sutherland developed the first stereoscopic Head Mounted Display (HMD) in 1968, showing others the capabilities of HMD that the world later would think of as standard VR (Sutherland 1968). Shortly after this the military raced ahead
in the development with their focus on large machines simulating helicopters, airplanes and tanks. The purpose of these simulators was, as is shown in 3.2.2, to replace training time in their real world counterparts. In order to prepare the pilot as thoroughly as possible the interface of the simulators has been developed to be extremely realistic. To decrease the inducement of CS many have also developed rigs that can stimulate the vestibular system mentioned in section 4.1.3. These have always been very expensive machines and are not open to the mass market (Johnson 2005).

### 3.2.2 Application domains

Even though Sensorama is considered one of the first consumer experiences of VR the first professional use of the technology, a helicopter simulator, was developed by the U.S. Military in the second half of the 1950s. Until recently the military has been the leading researcher and developer of the VR systems for use in training. Already as early as in the 1970s it was clear that the cost benefits of using the VR systems are significant. The hourly cost has historically been 10-30 times higher in real airplanes versus in a VE and in tanks as much as 15 times. This caused a great demand for research resulting in the military being responsible for much of the academic VR literature (Johnson 2005).

Entertainment parks are another area where VR has been used commercially. Disney founded a VR studio in 1992 in order to create theme park attractions. They offset the high cost with a large number of users for each device. They created several attractions for Disney Quest, their indoor interactive theme park in Orlando, such as Aladdin, Hercules and Pirates of the Caribbean shown in Image 1 (Mine 2003).

![Image 1 Attractions in Disney theme parks. Aladdin, Hercules and Pirates of the Caribbean (Mine 2003)](image)

### 3.2.3 VR Games

Having briefly covered what has been driving the research and development of VR systems the focus will now turn to games. Games have not been instrumental in the technological development as of yet but almost half of the future industry is projected to be game-related (TechCrunch 2015). A definition of what a game is will follow before covering the brief history of VR games, following up with the games that exist today.
3.2.3.1 Definition of a game

There are many definitions for what a game is. The description below stems from Tracy Fullerton and is chosen because of its practicality and consists of eight components, listed in Table 1 (Fullerton 2008). Zimmerman & Salen lists eight other definitions, which is quite similar to the one below, in their book Rules of Play (Zimmerman and Salen 2005).

A game has at least one **player**. A player is someone who voluntarily takes part of the game. They activate themselves over time, making decisions in order to win the game. They temporarily accept the arbitrary rules of the game and also that they have to finish tasks in a worse way than how they would do them outside of the game. Take Monopoly for example. To finish the game as quickly as possible a player would throw more than one dice throw per turn. The player would buy any street on the board and would walk of out jail immediately. But when a player plays a game the limiting rules are accepted.

The **objective** clearly states what is required to win a game and give each player a direction of how to structure his or her decisions. This sets games apart from other forms of entertainment, for example movies and concerts, where the audience simply enjoys the experience during an allotted timeframe. To use the previous example of Monopoly, the game is finished when there is only one player left in the game, i.e. they have a monopoly.

**Procedures** are methods of play as it is allowed by the rules. These are the actions that the players are allowed to, and sometimes have to, perform based on what the rules of the game depict. They influence the gameplay greatly and encourage behavior that can be far from the optimal path. In Monopoly there is for example a procedure where the player have to throw the dice on every turn and then walk the amount of steps shown on the dice.

**Rules** explain the nuts and bolts of the game. They define what each kind of object does and a player can and cannot do. They inform the players of what will happen when certain situations arise, e.g. when someone does not have enough cash on hand in Monopoly. The rules are defining and made to be followed but there is seldom a judge. Often there is only an unspoken agreement between the players that if a person does not follow the rules he/she is not playing the game.

**Resources** are items that are needed to complete the game. They can be used by the player to achieve the objective(s). They are also scarce which makes them valuable for each player. In Monopoly, streets and money are obvious resources. The playing pieces that are not used are not useful at all – according to the rules each player can only have one piece – and so they are not a resource in the game.

**Conflict** is created by the rules and procedures that the game has set upon the players. These rules and procedures usually make it more difficult for the players to finish directly. In solitaire internal conflicts are created by the player’s choices, each one coupled to tactical advantages and disadvantages. In multiplayer games
such as Monopoly it also encourages conflicts between players in order to reach the goals.

Boundaries are implied in the sense that everything that happens in this game is happening only in the space defined by the rules and procedures and not in real life. In Monopoly, the players take with them any of the playing items when they leave, and they do not arrive to the game with a handful of monopoly money to begin. Fullerton mentions Johan Huizinga who states that the space where the game takes place is “a temporary world where the rules apply rather than the rules of the ordinary world” (Fullerton 2008). The important part here is to note that it is temporary and distinct. Different instances of the same (or another) game do not have worlds that overlap.

Outcome should be uncertain at the start of the game yet be defined in its inequality, for example a winner and a loser. It is especially important that the outcome is unknown as it is one of the driving forces for people playing the game. Often when the outcome is known, the players will stop playing. If someone has all but one street in Monopoly, the other(s) usually forfeit. If a chess player has calculated that there is no way for him/her to win, that player usually surrenders. This is a big difference from other forms of entertainment like films, for example, where attendees in some cases know what will happen; yet are still entertained.

3.2.3.2 Earlier VR games

In the 1980s a short VR period in the gaming industry started and continued into the 1990s. There were several devices on the market where one of the earliest ones was the SegaScope 3-D Glasses for Sega Master, as seen Image 2, released in the end of the 1980s. It uses a shutter system, syncing the image displayed on the TV and shows the correct image for each eye, which effectively shows a stereoscopic view (Sega n.d.). The controller that was used for SegaScope 3-D Glasses was a the same gamepad, the type mentioned in 3.1, as was used for all Sega Master System games. See Image 2 for photos.

Nintendo followed and released Nintendo Virtual Boy in 1995. Similar to other consoles the player interacted by using a gamepad, as mentioned in 3.1, shown in Image 3. This was one of the first controls with two control pads that enabled the user to navigate in 3D, a design that would later turn out to be standard design for many controllers developed for consoles. The system came with defects such as non-ergonomic design and a lacking gaming experience, delivering poor visual quality and producing eyestrain due to its monochrome display. Because of this, it is
one of Nintendo’s biggest flops to date (DigitalSpy 2014). Soon after this, in the middle of the 1990s century, VR hardware began to disappear from the market.

![Image 3 Nintendo Virtual Boy (Wikia n.d.)](image3)

### 3.2.3.3 Interaction in current VR Games

The number of VR games that are available to the public is relatively small. All of them implement interaction schemas that take advantage of the input from head tracking. The head then controls the rotational angles of the in game camera, effectively moving the camera when the head of the player is rotated. Unless this match between head and camera rotation is executed well, as can be seen in section 4.1.6 and further in 4.2, CS is likely to occur.

VR games can be divided into two roughly sets: those with a stationary camera and those with a moving camera. Some games are an iteration of the knowledge of desktop computer games and a moving camera is present in many of these, like *Dreadhalls* seen in section 5.2.4.3. In this game the player uses a slightly modified thumbstick layout that is the standard interaction schema for console games, as presented in 3.1.

Due to the milder experience of stationary cameras many games have chosen this design. They usually involve either a top down view like *Nighttime Terror*, seen in 5.2.4.4, or simulating a person in a naturally static environment. An example of this is the environment of a shooter in a gun-turret, like *Gunner* for Samsung Gear VR (nDreams 2015). These games have the potential to be a comfortable experience for the majority of people due to their lack of sensory mismatch, as further discussed in 4.1.3.
3.2.4 VR and presence

One of the unique aspects of VR is the possibility to completely immerse the user into the virtual world. This is not covered in detail in this report but it is important to know that the effect exists. Immersion can be explained as the feeling of being somewhere else. The feeling of being part of this world is called presence and this is as Michael Abrash (2014) calls it “the magic of VR”. He explains it in a talk on Steam Dev Days:

“Presence is when even though you know you are in a demo room, and there is nothing really there, you can’t help reaching out to touch a cube. When you automatically duck to avoid a pipe that is dangling from the ceiling. When you feel uneasy, because there is a huge block that is hanging over your head. When you are unwilling to step of a ledge. It’s taking of the HMD and being disoriented, finding yourself back in reality. It’s flipping the switch deep in your lizard brain, to make you believe, that you are some place interesting.”

-Michael Abrash, Steam Dev Days 2014

3.2.5 VR and cybersickness

Cybersickness (CS) was relatively unknown until the first flight helicopter simulator was constructed by Bell Aircraft Corporation in the 1950s (Johnson 2005). A large number of the participants of the helicopter simulator experienced uncomfortable symptoms, commenting for the first time that the problem might be the mismatch between their senses. Miller & Goodson performed a study in 1958 which is often cited: “One of these men had been so badly disoriented in the simulator that he was later forced to stop his car, get out, and walk around in order to regain his bearings enough to continue driving” (Johnson 2005).

CS can be severe and as is shown in section 4.1 it will likely be an issue of VR for a long time. As is shown in section 4.1.6 the controls, closely related to the hardware of the devices shown in the next section, play an important role.

3.2.6 Current consumer VR hardware

Several types of VR hardware exists like simulators mentioned in 3.2.1 and glasses in 3.2.3.2. Other types of setups are CAVE systems (Cruz-Neira et al. 1993) that projects imagery on walls in front of the user. But the devices that are soon to enter the current market are HMDs, which are strapped to the users head. The binocular versions are heavily favored due to the sense of depth they can deliver (Cinoptics 2015, Oculus 2015, Razer 2015).

A true sense of presence, indeed an enjoyable VR experience, requires hardware that can project a believable reality on the display. A few years ago there were no capable consumer device but in 2012 Oculus performed a Kickstarter campaign for their VR headset. In their campaign video Palmer Luckey describes how he wanted a new type of experience but could not find any product that could deliver it. Instead he did it himself. With the following release of the Oculus Rift in 2012, Oculus delivered a device with good enough hardware at a consumer price of $300. This put the VR industry into a new gear (Kickstarter 2012).
Since then several headsets have emerged. A short list is presented in Table 2, bringing up some of their defining aspects. There are two categories that suggest what market they are aiming for. These are where the processor is located and what kind of tracking they offer. They can have their computing power on a PC, console or cell phone. Using a mobile phone to render and display the game has implications such as increased portability due to lack of wires but also severe restrictions in battery life and limited computing power, which PC and consoles have not. The tracking can differ between three degrees of freedom (3DOF), six degrees of freedom (6DOF) and/or whether they are other body parts like hands or feet. The better the tracking, the more immersive an experience the device can offer. But the more hardware in the device the higher the cost will be.

<table>
<thead>
<tr>
<th>Device</th>
<th>Compute center</th>
<th>Tracking</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oculus Rift DK1</td>
<td>PC</td>
<td>3DoF for head</td>
<td>The very first headset of the new heydays</td>
</tr>
<tr>
<td>Oculus Rift DK2</td>
<td>PC</td>
<td>6DoF for head</td>
<td>Improved version of DK1</td>
</tr>
<tr>
<td>Oculus Rift Crescent Bay</td>
<td>PC</td>
<td>6DoF for head</td>
<td>Improved version of DK2</td>
</tr>
<tr>
<td>Open Source VR</td>
<td>PC</td>
<td>3DoF for head, possibly hands</td>
<td>Open source VR platform. Will offer integrated Leap Motion for hand tracking</td>
</tr>
<tr>
<td>Project Morpheus</td>
<td>PS4</td>
<td>6DoF for head and hands</td>
<td>Developed by Sony to offer new kind of console games, takes advantage of existing Sony controllers like Move and Eye</td>
</tr>
<tr>
<td>HTC Vive</td>
<td>PC</td>
<td>6DoF for head and hands</td>
<td>Tracking head and hands, in a 225 sqft area</td>
</tr>
<tr>
<td>Google Cardboard</td>
<td>Mobile</td>
<td>3DoF for head</td>
<td>Cheapest one to date, $5 on amazon and compatible with almost any mobile</td>
</tr>
<tr>
<td>Durovis Dive</td>
<td>Mobile</td>
<td>3DoF for head</td>
<td>Higher end version than Google Cardboard</td>
</tr>
<tr>
<td>Samsung GearVR</td>
<td>Mobile</td>
<td>3DoF for head</td>
<td>Specifically for Samsung Note4. Offers improved sensors and a touchpad for user to interact with phone</td>
</tr>
<tr>
<td>Samsung GearVR2</td>
<td>Mobile</td>
<td>3DoF for head</td>
<td>Specifically for Samsung note Improved version with USB jack and fan remove condensation from optics</td>
</tr>
</tbody>
</table>

Table 2 VR HMDs available or soon to be available on the market
3.3 Input in Virtual Reality

As mentioned above there are, or soon will be, several consumer devices for sale. The manufacturers have focused on the output of the display and only a few of them offer more input than a 6DOF head tracking. While this might be enough input for some games there is a demand for more diverse set of input in order to create better experiences.

While there have been research around military and commercial flight simulators mentioned in section 3.2.1, their interfaces are very complex due to the fact that the goal of those simulators are to replicate real life as closely as possible. Because of this the area of simulators will not be looked at when searching for extensions of the interaction design principles. Instead the focus will be on input devices that are or soon will be available for the general mass market.

3.3.1 Gamepad

Gamepads that are similar to the popular console designs are available, for example the Samsung GamePad EI-GP20 (Samsung 2015). This device has the ability to connect through Bluetooth. Regular gamepads from gaming consoles are also used on several platforms. There are advantages of using a familiar control but it makes it easier for designers to bring with them "luggage" from other platforms.

3.3.2 Head tracking

In section 3.2.6 several current devices that will offer head tracking are presented. As can be seen in section 4.2 it is strongly recommended to use this input to control the camera. Many games use this input as either an indicator of what the user wants to select, in menus or in game, but also in other ways like aiming in shooter games. Due to the fact that the head tracking makes up for the majority of the input available on many devices found in Table 2 it can be crucial to make games that take advantage of it instead of requiring the user to connect an external controller.
3.3.3 Other

A common sight when people try out a VR headset for the first time is that they want to use their hands to touch things. It is what their mind tells them feels natural. But this feature is currently restricted by hardware as most headsets currently cannot track the hands. There are several products that attempt to solve this. One is the Leap Motion that tracks the space in front of the headset, seen in Image 4. It uses two cameras to gain a sense of depth. It has to be mounted on the headset, needs an USB outlet, and the scan area is limited to a cone originating from the device. The Leap Motion is sensitive enough to track all ten fingers with the precision of 1/100th of a millimeter, which might or might not be required to make compelling games. It is sold separately from the HMD (Leap Motion 2015).

Another solution to the input of the hands is the STEM which works by offering two hand controllers and three portable tracking units, all connected to a base station. Ideally four of these are placed on the hands and feet while the last one is strapped to the head. The base station seen with all controllers in Image 5 is sending out an A/C field. The field is used to track the units and controllers while pulsing at around 8kHz. Being a novel system that is compatible with most platforms, it will ship in summer of 2015 at a cost of 580 USD for the full package (Sixense 2015).

One of the most recent hardware devices is the HTC Vive. It is developed as a joint product between Valve and HTC and offers a high-end experience of 6DOF, due to release in 2015 (HTC 2015). By setting it up with a PC, clearing a space of about 15 by 15 feet, placing sensors in the corners and strapping in, the player can enter an immersive world. The entire package with HMD, handheld controllers and base stations are seen in Image 7. With handheld controllers the hands, as well as the head, are tracked in the room.
Some systems are trying to provide input in another way, by tracking the feet. Virtuix OMNI is an omnidirectional, low-friction treadmill connected via USB to a computer. Put on special shoes, connect an Omni POD to these shoes, and step into the Virtuix as shown in Image 7. After being strapped in the device can be used as an input in any game that uses a 360-degree input, like an FPS game shown on external monitors or a VR game presented through a HMD. The Virtuix is due to ship in Q3 2015 it works especially well in cohesion with VR since it offers intuitive in-game locomotion of the camera (Virtuix Omni 2015).
4 Review of literature

4.1 Cybersickness

CS is one of the major issues of VR to date. It has been known by the military since the 1950s and extensive academic knowledge exists in the subject. But the new devices mentioned in 3.2.6 have made it increasingly easier for organizations and people alike to create content for VR. These content creators generally do not possess extensive knowledge of CS due to the difficulty of finding concrete and definite implementation strategies. So far, not much easily digested info exists about how to address the issue (Owlchemy Labs 2014). In his talk Carmack (2015) raises the issue of cybersickness as one of the main problems of VR adoption and other researchers label it as highly limiting to the VR experience (Johnson 2005). In order to better understand what CS is and how it can be countered by well-planned interaction principles this chapter will briefly explain CS, why it happens, the popular theories and how it relates to user interaction.

4.1.1 Definition

The paper will use the term Cybersickness (CS) as McCauley (1984) defines it: “The experience of symptomatology during and after the use of a Virtual Environment (VE) that would not ordinarily be experienced if the same activity were carried out in the real world.” (McCauley, 1984).

Often the term CS is used to talk about uncomfortable symptoms in VR. Another similar term is Simulator Sickness (SS) used extensively by the military. There are some contradictory reports on how exactly CS and SS relates and although the term is often used interchangeably, there is some agreement CS can be used in all VEs while SS is used in moving VEs (Hale and Stanney 2015, Stanney et al. 1997). For the purpose of this thesis the information regarding SS will be considered to be applicable on CS and CS will be the term that is used from here on.

4.1.2 Symptoms and susceptibility

Even though it sounds intuitive most scientists do not consider the word cybersickness to be semantically correct. CS is not a sickness as much as a collection of symptoms that arise due to a normal response to unusual stimulus (Hale and Stanney 2015).

When being under the effect of CS several symptoms may arise depending on the individual susceptibility. Known symptoms of CS after exposure to VR include eyestrain (<40% of exposures), nausea (<30% of exposures) as well as drowsiness, salivation, sweating, headache and dizziness/vertigo (Kennedy et al. 1993).

The aftereffect has the risk of lasting for a long time. Symptoms such as flashbacks and disorientation have been reported as long as twelve hours after the experience (Hale and Stanney 2015). The individual difference in susceptibility of CS is large, however, and some participants of VR constantly report very little, if any, symptoms. Even so CS has been shown to impact a substantial percentage of the people who experience VR (Johnson 2005).
4.1.3 Underlying physiology

In order to better understand why CS exists and how to better counteract it, it can be helpful to look into some basic knowledge of the underlying physiology of the involved senses. These senses are the vestibular and the visual system due to their effect of the user’s illusion of self-motion.

The vestibular system, seen in Image 8 is responsible for giving information about movement and orientation of the head. It consists of three semicircular canals providing details about angular acceleration. Due to their perpendicular placement the three semicircular canals can detect rotational motion in all of the XYZ axes and deliver this information to the brain for processing.

It also contains the utricle and saccule, which detects linear acceleration. One of the most important functions of the utricle and saccule is to give a person feedback regarding the person’s orientation with respect to gravity. Similarly to the semicircular canals, they are positioned relative to each other to cover acceleration up/down and forward/back, while being unable to detect sidewise acceleration (Gleitman et al. 2000).

Even though the vestibular system will usually receive inputs in movement, it can only detect acceleration. As it is perfectly natural to be in motion without acceleration, in a car for example, the body can perceive it is moving without the vestibular system being stimulated. This impression of self-motion while being stationary is called vection and most people have experienced it. It is common for a person to believe their train car is leaving the platform when in fact the adjacent train car is moving (Riecke and Feuereissen 2012). In such a situation vection is induced through visual cues from the real world but it can also be produced by displays simulating the real world. Vection is a common recurrence in VR, especially in simulators, when a person believes he/she is traveling somewhere. They have the sense of velocity but are in fact stationary (LaViola Jr. 2000).

4.1.4 Theories of cybersickness

After explaining the senses involved in CS, the theories, which are trying to explain why it occurs, will be discussed now. As it is shown below the theories are trying to explain why symptoms arise when the senses conflict. One theory suggests that it is because the subconscious does not know how to deal with the sensory conflict. The other theory states that this conflict gives rise to instability in the posture of the body and when this occurs then CS symptoms will arise, but that a sensory conflict need not be the origin of the symptoms. No matter which theory is correct researchers want to find a working theory in order to be able to predict when CS will occur to
more effectively avoid it. So far no one theory has been accepted as the de facto standard.

4.1.4.1 Sensory conflict theory
Historically the historically most accepted theories why people get motion sick is the sensory conflict theory. It is the oldest theory and it is cited virtually in all research reports by its name, and it is employed in most authors’ results (Johnson 2005). The authors best explain the theory:

Under natural conditions of self-propelled locomotion, all of these sensory components of the basic orienting system transmit correlated information with regard to the position and motion of the body. But in a wide variety of situations, the harmony that normally exists between these receptors can be disrupted so that the inputs from one or more of these functionally related receptors conflicts with the other inputs, and, as a result, the combined influx is incompatible with stored expectations.

... motion sickness occurs when the sensory information about bodily movement, provided by the eyes, the vestibular apparatus and other receptors stimulated by forces acting on the body, is at variance with the inputs that the central nervous system expects to receive (Reason and Brand 1975)

To better understand what it means an example is going to be presented. Propose that a person is sitting in an airplane flight simulator. The VE gives a visual indication of flying in the air, straight forward, in constant speed. In this case the same forces that are acting on the simulated body, gravity and an opposing force from the chair, are acting on the real body. So far there is little if any sensory mismatch. But if a 180-degree roll of the virtual plane were to be initiated, turning the VE upside down, the visual system would signal that the body is turning upside down. The brain would expect the signals from the vestibular system to match the signals that the visual system is delivering. It would expect angular rotation during the roll and a shift of gravity. Since the person is inside a VE only the visual sense delivers these signals, the body is sitting stationary in a room. A sensory conflict occurs and according to the sensory conflict theory, this is why cybersickness occurs (Reason and Brand 1975)

4.1.4.2 Postural instability theory
The other of the two major theories is the postural instability theory, which is getting increasingly popular. According to Johnson (2005) who made a thorough review of the current research on CS it is the theory which currently is most accepted. The theory is not focused on the sensory pattern or the expectations, but rather as a response to the moving, or simulated moving, unfamiliar environment around the user (Riccio and Stoffregen 1991).

The postural instability theory stems from the notion that maintaining postural stability in the environment is a primary behavioral goal for humans and animals. The symptoms of CS, they argue, results from prolonged postural instability. In the situations where these symptoms arise the subject is always unfamiliar with the environment. Regardless whether it is an animal at sea, someone in a VE or a pilot in a plane. In the situations where the participant in question is unfamiliar with the
environment they will be unable to maintain postural control. For example, compare the movement patterns between walking on ice and walking on concrete. Even though they are flat surfaces both humans and animals walk on them differently. According to Riccio and Stoffregen (1991) this is because all of us try to attain postural stability. But this had to be learned. In the beginning everyone was very much like Bambi, not knowing how to handle the environment. Whenever the environment changes to something unfamiliar postural instability will be attained. The lack of postural control results in the symptoms that induce CS until the subject adapts and the unfamiliarity dissipates. The theory states that the severity of the CS symptoms scales directly with the duration of how long one is exposed to postural instability. When there is enough experience the subconscious will create a correct control strategy, when this is achieved postural stability is attained (LaViola Jr. 2000).

In order to reduce the MS symptoms, one only needs to reduce the level of postural instability. One easy way is to lie down flat on the floor where almost everyone has postural stability (Johnson 2005).

4.1.5 User interaction and CS

After having understood the two major theories of why CS is induced, next is to inspect what can be done in order to decrease these symptoms. In this area there are usually three categories of variables that are discussed. These three areas are hardware variables, user variables and task variables (Kolasinski 1995, Johnson 2005, LaViola Jr. 2000). All of the devices that are mentioned in section 3.2.6 are working hard to alleviate the hardware variables that impact the most and this report will not cover them. User variables that are popularly mentioned are age, sex and previous exposure to CS. It is noted that sex can matter slightly, that age has some impact and that previous exposure to CS is a good indicator if it will happen again (Kolasinski 1995, Johnson 2005).

Task variables are highly interesting and it is possible to gain a lot of information from previous studies. Most of these factors are an effect of the specific system design and so it is in the hands of the designer to make sure that they give users as high a chance as possible to have a comfortable experience.

Session duration is one of the most important variables. Several studies have shown that longer time spent inside the VE increases probability of severe discomfort (Kolasinski 1995, Johnson 2005).

Abnormal rates of acceleration, both linear and rotational, is reported to be very uncomfortable. This is likely due to the fact that the vestibular system mentioned in section 4.1.3 is in conflict with the visual sense (Kolasinski 1995, Johnson 2005).

Unusual maneuvers, in effect abnormal visual stimuli, can be very unsettling. Flying backwards or having the visual field being played up in reverse time is reported to be unsettling. In addition a freeze/reset command is often present in simulators, a feature developers implement in case of crash or other reasons. These are strongly CS inducing for the participant and the recommendation is not to use them. Kolasinski (1995) suggests that for HMDs the screen should be black when they put it on and black when they take it off in order to reduce the amount of abnormal visual stimuli (Kolasinski 1995, Johnson 2005).

Active head movement increases susceptibility to cybersickness. The more head movements the participant performs the more likely the participant is to elicit

Position of the subject can be important. It has been reported that a supine position is the most effective when trying to reduce CS. One reason for this is that it limits the amount of head movement that the subject can perform in addition to giving a lot of postural instability. Sitting or standing has also been measured, with a slight favor to standing even though it contradicts the postural instability theory (Kolasinski 1995).

Vection, the illusion of self-motion while stationary, is also an important factor that has been concluded to be more likely to produce CS. It is unclear what exactly the correlation is between CS and vection but it is likely that displays that produce strong vestibular effects produce the most CS (Kolasinski 1995).

4.1.6 The relevance of controls
From the section of 4.1.1 and 4.1.5 it is clear that the interaction between user and games is more relevant than ever. A bad interface does not only provide low usability, it can literally make the user feel ill. The controls are obviously central in providing a comfortable experience and as has been shown in the previous sections of this chapter there are many variables to consider when discussing CS. Some have a direct connection to controls and it can be assumed that in order to discourage the induction of CS the following should be kept in mind when designing the control schema

– Low or non-existent mismatch between vestibular and visual senses
– Low requirement of active head movement
– Avoid maneuvers not seen in real life
– Low induction of vection
4.1.7 Simulation Sickness Questionnaire

Having discussed CS and its relevance to controls it is time to present how CS is quantifiably measured. For this purpose the Simulation Sickness Questionnaire (SSQ) developed by Kennedy et al. (1993) can be used. It is the standard measuring method of CS in the academic area (Johnson 2005, Kolasinski 1995). It is a questionnaire that has to be filled in immediately after an experience in a simulator and consists of input from 16 different symptoms in a 4-point severity scale (none, slight, moderate, severe). Based on this input the SSQ delivers the three subscale scores of Nausea, Oculomotor Discomfort and Disorientation. The Total Severity score combines all symptoms into one score. Each scale has a score of zero as “not affected at all” and increases as symptoms increase (Kennedy et al. 1993). Each subscale scores symptoms are listed in Table 3.

<table>
<thead>
<tr>
<th>Nausea</th>
<th>Oculomotor Discomfort</th>
<th>Disorientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>General discomfort</td>
<td>General discomfort</td>
<td>Vertigo</td>
</tr>
<tr>
<td>Increased salivation</td>
<td>Fatigue</td>
<td>Fullness of the head</td>
</tr>
<tr>
<td>Sweating</td>
<td>Headache</td>
<td>Dizzy (eyes open)</td>
</tr>
<tr>
<td>Nausea</td>
<td>Eyestrain</td>
<td>Dizzy (eyes closed)</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>Difficulty concentrating</td>
<td>Nausea</td>
</tr>
<tr>
<td>Stomach awareness</td>
<td>Difficulty focusing</td>
<td>Difficulty focusing</td>
</tr>
<tr>
<td>Burping</td>
<td>Blurred vision</td>
<td>Blurred vision</td>
</tr>
</tbody>
</table>

Table 3 The components for each subscale in SSQ

One of the major benefits of using the SSQ is that it covers a wide variety of symptoms with one questionnaire. In addition, it quantifies the results in an easily comparable way (Johnson 2005).

Due to the fact that the data the SSQ is based on are from healthy and fit pilots the SSQ should not be used on people who are not in their usual state of fitness level. In addition the SSQ is not designed to be used both before and after a simulator experience. The difference in scores is not reliable according to the authors (Kennedy et al. 1993). Even so, researchers are so comfortable with the SSQ that there are numerous academic experiments that do just this (Johnson 2005).
4.2 Current VR Interaction Advice

The previous sections went through academic literature and found important aspects to have in mind for all types of interaction with VR. It is clear that one of the pitfalls of VR, CS, can be linked to the interaction and that it needs to be kept in mind during the interaction design.

The general recommendations for designers and developers from the industry can be found in a few resources of high credibility in the field. Oculus is the leading hardware manufacturer in the field and the company that reignited the current VR industry as mentioned in section 3.2.6. The company keeps a document updated called Best Practices Guide available at their homepage. This is a highly recommended reading which lists information in the areas of rendering, minimizing latency, optimization, head-tracking and viewpoint, positional tracking, acceleration, movement speed, cameras, CS, degree of stereoscopic depth, user interface, avatar, sound, content and health and safety (Oculus 2015).

In addition there are several video presentations from various conferences that are of interest at this stage, recommended to watch for anyone new to VR development. The person who made the first Oculus prototype, founder and CEO Palmer Luckey gave a talk at Oculus Connect that contained information regarding interaction with VR games (Luckey 2014). In addition Oculus's current CSO, Chief Scientist Officer, Michael Abrash talked at the famous Steam Dev Days about interaction with VR as well as presence, mentioned in section 3.2.4 (Abrash 2014).

These three sources also cover topics that are not relevant in this study. The advices that will be taken into account are those that cover the area of controls, interaction and/or CS. Analyzing advice from these areas yields three general recommendations presented below.

4.2.1 Minimize vestibular mismatch

As was noted in section 4.1.6 one of the guidelines from the academic literature was to aim for none, or low, vestibular mismatch in order to decrease the risk of inducing CS on the user. Similarly many recommendations from these sources reiterate that it is best to synchronize visual and vestibular senses to as high a degree as possible. “The display should respond to the user’s movements at all times”, “Make accelerations short (preferably instantaneous)”, “Unexpected vertical accelerations can create discomfort”, “Avoid […] rotating or moving the horizon line or other reference frames” (Luckey 2014, Oculus 2015).

4.2.2 Stationary camera is most comfortable

As was noted in section 4.1.6 vection can induce CS. As further described, “Locomotion is hard”, “Stationary position is most comfortable” and “VR may be best with slow movement and lots of up-close interactions” (Abrash 2014, Luckey 2014, Oculus 2015). Luckey notes as well that “Forward movement is very comfortable, but less so to the sides and to the back”. This ties back to section 4.1.5 that unusual maneuvers, like going backwards, is CS inducing. A stationary camera seems to be the best option if CS is to be minimized, and a forward moving camera the best option if there has to be locomotion.
4.2.3 **New interaction conventions are waiting**

All three sources are acknowledging that new types of interaction are waiting to be discovered. “We are going to have to rethink the kind of interactions we are going to have”, “a whole new vocabulary will have to be developed”, “There’s a lot left to be done […] Especially the interaction between input and game design in VR” all projects the need of new, more suitable interaction conventions (Abrash 2014, Luckey 2014, Oculus 2015).
5 Study

This study was performed with the goal to extend upon the known control and interaction guidelines presented in section 4.1.6 and 4.2. In order to produce data the decision was made to perform a study around multiple short gaming sessions. Both quantitative and qualitative data was gathered through forms and interviews. The qualitative data was then analyzed through a proven framework of iterative nature. The framework produced several guidelines, some new and some a reiteration of already existing knowledge from academic and industry resources.

In section 5.1 the original plan of the study as is presented. This plan was then put in action and the actual execution is presented in section 5.2.

5.1 Method

The test plan is presented below. The plan covered aspects of the study such as type of test, equipment to be used, what participants to search for and how to recruit them, schedule of the actual test, tasks participants were to perform, how data was to be analyzed as well as the expected result.

5.1.1 Type of test

The type of test was planned to be two-fold. Primarily it was a qualitative study in regards to controls and the users experience. It was decided that several different designs of interaction was to be tested and that every user should play every game. The device of the test was to be a Samsung Note 4 in a Samsung GearVR headset as seen in Image 9. As such it is impossible to capture the screen and see how the users actually performed in game. Instead qualitative data was to be collected by interview questions after the sessions. Between each test a mix of semi-structured questions as well as structured questions regarding their experience, with focus on interaction and controls, were to be asked.

5.1.2 Participants

The aim was to recruit 20 participants without any regards for age or profession. To get a diverse test group the goal was to get 50% males and 50% females. Since glasses do not fit inside the headset people who wore glasses were however not suitable for the test. Due to the nature of the it is also important that they were not to be ill at the time of the test, as mentioned in section 4.1.7. In addition, in order for the
participants not to have developed increased resistance to CS those who have tried VR in the past two years were advertised not to join.

To recruit people the plan was to put up posters on notice boards at KTH - Royal Institute of Technology as well as post it on suitable locations on Facebook.

5.1.3 Structure of the test
The plan was for the schedule to look like the following:

1. Greet them
2. Give them a brief explanation of the study.
3. Ask them to sign consent form for recording audio and to use results in the study and for the company.
4. Walk through the schedule
5. Explain that this will be a study that focuses on the controls of games. As such, they should keep that in mind (not graphics etc.)
6. Start the tests. After each test
   a. Have them fill in SSQ digitally
   b. Perform interview
   c. Collect ratings
7. If there is time in the end, ask deeper on any sticking points
8. Thank them for their participation

5.1.4 User tasks
Each user were planned to try out four different games and spend three minutes in each environment, playing the game. After each game they were to be interviewed on each experience as well as fill out forms with structured questions.

These questions made up the structure of the data as well and were planned to be the following:

- Semi-structured
  - What did you think of the controls?
  - Given the chance, would you have changed anything?
  - Did any elements feel particularly good?
- Structured, quantifiable
  - Fill in SSQ
  - How intuitive they feel the controls is on a five-scale rating. From "Not intuitive at all" to "Very intuitive".

5.1.5 Equipment
- 4 VR games which all have different control schemes.
  - 2 prototypes that was developed during the thesis
  - 2 games from Oculus Store
- A consent form
- A Samsung Gear VR
- Samsung Galaxy Note 4
- Computer to type the answers to the open ended questions
- Computer to record SSQ between tests
- Microphone to record the interviews
5.1.6 Data analysis
As is recommended by Lantz (1993), data preparation is necessary in order to reduce the amount of data to work with. The transcripts from the interviews will be pruned and data not relevant to the research question removed. A qualitative analysis will be performed on the data using Framework analysis by Ritchie & Spencer (1994). In particular, the instructions from a branch of Framework analysis that focused on Applied policy research (Ritchie and Spencer 2002).

It should be noted that several other frameworks are available. Some popular for qualitative analysis are Thematic analysis, Interpretative phenomenological analysis and Constructivist grounded theory (Silverman 2011). The reasons for choosing the Framework analysis are threefold. Firstly it is designed to create policies that are similar to the goal of this study. Secondly it is transparent where every step along the way is saved. This was preferred if backtracking was ever needed. Thirdly it works well for shorter timeframes; the data collection is performed at one point in time and then analyzed in several iterations. Other frameworks, like the Constructivist grounded theory, requires iterations of analysis in between data collection. This was judged to be too time consuming.

In addition the data from the SSQ will be used to weigh the qualitative data while it is processed in the framework. Due to the transparency of the framework this is deemed possible (Ritchie and Spencer 2002).

5.1.7 Expected result
The expected result is for the Framework analysis to produce several new guidelines around control and interaction for VR games. It is expected to validate or extend several of the known guidelines.

5.2 Execution
The execution of the prepared plan is presented below. The areas previously mentioned and the result for each is presented in the order they took place. Unfortunately the design of the test was such that the data about SSQ that was collected was judged to be illegible. See section 5.2.1 for further information.

5.2.1 Data excluded from the study
In order to use the data of CS in the analysis phase all users filled in a SSQ form after every game as mentioned in section 5.1.3. They were instructed to fill out these directly after the game experience as is recommended by Kennedy, et al. (1993). It was discovered that the onset of SSQ was relatively slow, sometimes developing a few minutes after a game session ended. This was discovered when participants exclaimed that they felt really ill in the middle of the interviews. The author believes these unexpected situations were encountered due to the fact that the playing sessions were too short for the symptoms to be noticed. The SSQ was designed from data gathered from military grade simulators with sessions likely much longer than three minutes. After this discovery it was decided that the connection between SSQ-score and game experience was unreliable. This meant that the data was unfit for the analysis and all SSQ related data was excluded from the study.
5.2.2 Equipment
The equipment that was used for the test was

- A schedule, printed. Appendix 9.1
- A consent form, printed for the user to sign. Appendix 9.7
- An ink pen for users to sign the test
- Illustrations of the controls for each game to be tested. Appendix 9.2
- A Samsung Gear VR (Samsung 2015)
- A Samsung Note 4 (Samsung 2015)
- A Samsung Smartphone Gamepad (Samsung 2015)
- A MacBook Pro to have users fill in forms on, saved to Google docs
- A Zoom microphone of model H4N was used to record the interviews
- A pair of B&W P5 headphones
- Cookies and soft drinks

The hardware from Samsung was shown previously in Image 9.

5.2.3 Participants
As was noted in section 5.1.2 there were some qualifications for recruiting people. This was accomplished: no people were ill at the time of test and none had tried VR in the past two years.

The users were recruited with the help of posters printed on A4. The first poster that was printed is placed in Appendix 9.3. It was quickly realized that there was great competition for student's attention at the places where posting was allowed. Two more iterations of the posters were made and distributed, see Appendix 9.4 and 9.5. The posters were distributed across two university campuses nearby: The Royal Institute of Technology and Stockholm School of Economics. In addition, the posters were distributed on Facebook in social and academic groups. 22 participants completed the test, 9 of them female and 13 male. The average age was 26.3 (SD = 5.2). This age was relatively high considering universities were the main marketing area. Upon inquiry it was discovered that that friends had seen it and referred them, about half were students of some sort. The average gaming experience was exactly “Moderate”, on a three-point scale between “None-Moderate-Extensive”.

5.2.4 Selected games
In the study a total of four games were used, selected based on several variables. Firstly it had to be possible to acquire them, limiting choices to either commercially available or in-house developed software. Among those who were commercially viable the games also had to be popular and so games that were promoted by Samsung in the Oculus store was chosen. Secondly, in order to get opinions from as many types of interactions as possible all of the games have different ways of interaction, as is presented in the following sections 5.2.4.1 to 5.2.4.4. Finally the games were also evaluated based on how they complemented each other in the terms of the recommendations found from the academics and industry in previous chapters. In particular it was of interest to have games with different levels of vection (section 4.1.6 and 4.2.2), vestibular mismatch (section 4.1.6 and 4.2.1), requirement
of head movement (section 4.1.6) and if the game presented any novel ways of interaction (section 4.2.3).

<table>
<thead>
<tr>
<th>Name</th>
<th>Camera</th>
<th>Controls</th>
<th>Year</th>
<th>Developer</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dreadhalls</td>
<td>Stationary</td>
<td>FPC</td>
<td>2013</td>
<td>White Door Games</td>
<td>Gamepad</td>
</tr>
<tr>
<td>Nighttime</td>
<td>Moving</td>
<td>Top-down-shooter, aiming with head</td>
<td>2015</td>
<td>VR-bits</td>
<td>Gamepad</td>
</tr>
<tr>
<td>Terror</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kneebend</td>
<td>Stationary</td>
<td>Physical knee bends</td>
<td>2015</td>
<td>Resolution</td>
<td>None</td>
</tr>
<tr>
<td>Solitaire</td>
<td>Moving</td>
<td>One-button-interaction, aiming with head</td>
<td>2015</td>
<td>Resolution</td>
<td>Gamepad</td>
</tr>
</tbody>
</table>

Table 4 The games which was used in the test

Three aspects from earlier guidelines were taken into control when the games were selected. These are level of vestibular mismatch, vection and novelty of interaction found in sections 4.1.6, 4.2.1 and 4.2.2. Due to the duration of the sessions the games were also required to deliver a gaming experience in three minutes. More details as to how each game relates to previously found guidelines are mentioned in each subsection.
5.2.4.1 Kneebend

In Kneebend the objective is to travel as far as possible in an obstacle ridden straits. The controls of the game are of low complexity. The player start in a menu with nothing in it but a high score label and a button that says “Start Game” seen Image 10. When looking upon said button, it counts down from 5 to 0 after which the game begins. The player is transported to the straits, seen in Image 11, and gets a starting velocity. Objects in two different heights will be put in the path of the player and the objective is to get as far as possible by navigating beneath or over them. The player transports him-/herself between the two heights by either doing a knee bend or by
standing up. So if the player is on top level he/she should initiate a knee bend. The camera will go down. When obstacles appear on a collision course the player should stand up. The camera will then go up. Every game the player gets three lives and when he/she has collided into three obstacles, the game is ended and the menu scene appears. Then the player has to start over.

Noticeable aspects as mentioned earlier are vection (forward locomotion, mentioned in section 4.1.6 and 4.2.2) as well as vestibular mismatch (instant acceleration up and down, mentioned in section 4.1.6 and 4.2.1). However, since the vestibular mismatch is initiated by knee bends this might serve to decrease the CS inducing effect. In addition, the control schema of using knee bends could be said to experiment with new interaction conventions as mentioned in section 4.2.3.

Finally the game exposed the participants to unusual maneuvers (mentioned in section 4.1.6) through the collision of obstacles. They came from afar and if the participant did not dodge they continued and collided with the camera, virtually being in the participants face.

5.2.4.2 Solitaire

The gameplay is similar to most Solitaire game and is played with the gamepad controller seen in Image 9. Any one of the four button acts as a pick up/drop down action. The same button is used to indicate if the player wants to flip a card, either in a tableau (piles in bottom) or the stock (the stack which holds leftover cards which one can circle through during the play). The camera in the game is completely stationary.

The player uses the head to indicate which cards they wish to do something with. As seen in Image 12, the circle in the middle of the screen is the crosshair that indicates where the player is aiming. It stays in the center of the screen while the player moves the head in order to change selection.

Noticeable aspects are a stationary camera (mentioned in section 4.1.6 and 4.2.2) and also a relatively high requirement of head movement, contradicting the guideline mentioned in section 4.1.6.
5.2.4.3 Dreadhall

Dreadhalls has controls of a FPC. In addition it utilizes the input possibilities that a HMD provides and offer the players the possibility to look around with the head. It requires a gamepad to play, enabling the player to move 3DOF of position with the left thumbstick and 1DOF rotation wise, the yaw, with the right thumbstick. The last 2DOF of rotation, roll and pitch, are controlled through the input of the head. Actions are performed by pushing one of gamepad’s four main buttons. The objective of the game is to escape the maze, depicted in Image 13, surviving by only running. There are no weapons available. There are some novel controller ideas that take advantage of the HMD, such as the interaction of presenting the map when the player looks down below as is shown in Image 14.

As with most FPC games the player is able to rotate the yaw with the right thumbstick. This induces vestibular mismatch (rotation with right thumb, mentioned in section 4.1.6 and 4.2.1). In order to counter this the team that created Dreadhalls have developed a “comfort mode” which the player can toggle on or off. In comfort mode the camera does not rotate smoothly. Instead it snaps around in fixed 30-degree angles at a time. The regular version was evaluated in this study in order to test out the standard FPC controls that many of the VR games have implemented.

Previously mentioned aspect besides vestibular mismatch is vection (forward locomotion and strafing to the sides, mentioned in section 4.1.6 and 4.2.2). In addition, the game exposed the participants to unusual maneuvers (mentioned in section 4.1.6) by letting them walk up to and literally press their virtual face to the walls.
5.2.4.4 **Nighttime Terror**

*Image 15* *Nighttime Terror*, player is up in left corner firing (The Rift Arcade 2015)

*Image 16* *Nighttime Terror*, player is almost in center of screen, aiming at white enemy rabbit with crosshair (The Rift Arcade 2015)

*Nighttime Terror* is a top down shooter game. The objective is to survive with the character at the same time as the player is killing as many monsters as possible. It is played from a “god mode” perspective, with the camera is static raised approximately 20 meters above the ground, see Image 14 and Image 15. With the gamepad the player control the character on the ground, running around with the left thumbstick. In the middle of the screen a crosshair projected indicating where the player is aiming. When the player presses any button the character fires towards the crosshair no matter where the character or the crosshair is located as is shown in Image 15. As
monsters die harder monsters spawn. Periodically upgrades are dropped down which the player have to run over and collide with in order to pick up.

Regarding earlier guidelines Nighttime Terror has a stationary camera (no locomotion and no vection, as mentioned in 4.1.6 and 4.2.2) and uses the head movement as a new type of input, experimenting with new ways of interaction as mentioned in section 4.2.3.

5.2.5 Collected data

Two forms were prepared for the test. One was the user information form. This collected the data of age, sex and gaming experience. Every participant filled it out once. See Appendix 9.9.

The second form was the one that was presented to them after every game. The first page consisted of a drop down list that represented the game they had just played, a field that asked for their user ID and a list of the 16 symptoms that make up the SSQ mentioned in 4.1.7. Each symptom had a multiple choice selection ranging from none to Severe. All of the fields had to be filled in in order for them to press continue when they were done. See Appendix 9.9.

The second page of the second form consisted of three semi-structured questions:

- What did you think of the controls?
- Given the chance, would you have changed anything?
- Did any elements feel particularly good?

These were only here to give a natural pause in the form input and for the interviewers sake. No information was entered in the text boxes presented; the conversation was recorded on a standalone microphone.

The questions were chosen to be open ended and as non-leading as possible. The goal was to get the participant to talk for a minimum of three minutes about each game. If they were not talkative and had not gone through some of the questions above then the interviewer specifically raised those questions.

As the interviewer became more knowledgeable about the different aspects of the experience certain questions could be raised. For example: “what did you think about the interactions between you and the environment?” and “how did you feel about the aiming?” Great care was taken not to lead the user along but to gently probe. Some participants were not very talkative and so sometimes it stopped before three minutes. In some cases participants talked for much longer. The goal was always to get some sense of what the participant thought about the controls and about anything that felt uncomfortable, in order to connect to the research questions.

5.2.6 Test procedure

Each test was designed to be about 40 minutes long, giving the interviewer time to take extra notes and prepare for the next participant. The extra time also gave some leeway for participants who responded in greater lengths to the interview questions. Prior to each participant arriving the interviewer made sure that the devices were charged and that the software worked as expected.

After each participant arrived they were greeted and offered cookies and drinks that had been acquired in advance. Then the schedule for the test session,
available in Appendix 9.1, was presented and walked through. This included telling them about the agenda and explaining the time structure.

After the introduction was made they were handed the consent form shown in Appendix 9.7. While this was read through and signed the user form (it captured age, sex and gaming experience) was prepared for them. In addition the game order for that user was decided with the help of an evenly distributed random function and noted down for use throughout the test.

When the participants had signed the consent form they were informed about VR, why the study is being done and what the expected result will be. In addition, they were informed that they could partake of the results of the study when it was done if they so wished. The participants were also informed of what type of data that was interesting and why. Examples of what was not interesting was given, for example graphics, but they were told to rather say too much than too little.

After this they were informed about how the hardware worked, how the mobile fit into the HMD and how by showing stereoscopic 2d images an effect of 3D was achieved. The device’s volume controls and focus wheel was explained, as well as instructions on how to adjust the focus. The gamepad was shown and it was made certain that the user understood how to use it.

The participants were also told about a bug that exists and which, seemingly without any consistency, shows up. The result of the bug is that the camera in game does not move according to head movements – it is completely static and does not rotate at all. This causes the visual field to stay the same when the player rotates the head, making for instant nausea for most people. The participants were made aware of this bug, that it is not a feature, and was instructed to inform the interviewer if they noticed this behavior.

At this point the participants filled in the user form. During this time the interviewer prepared the first game. For every game that was to be tested the interviewer navigated through the menus and started the gameplay. After this the controls were explained using the control-scheme sketches in conjunction with verbal instructions, see Appendix 9.2, and the participant were handed the devices. If it was the first time they put on the HMD they were given time to adjust the straps and focus wheel in order to get a sharp image.

The participants then started to play the game for three minutes. During this time the interviewer prepared the post-game-form and filled in the administrative information. When the participants were done playing they were immediately asked to fill in the SSQ questionnaire. At page two, the interviewer started a microphone and the interview started. The interview always started off with the first question “What did you think of the controls?” Depending on the depth of their answers this question might have been followed up with more questions such as "Given the chance, would you have changed anything?" and “What elements felt particularly good?” Depending on how talkative the participant were even more specific questions might have been asked such as “What did you think of the interaction with the environment?” but once again, the interviewer was careful not to ask any leading questions. After this, the next game was prepared and the process was repeated.

After all four games had been played the player was subsequently thanked for their participation and that they were welcome to contact the interviewer with any questions that might arise.
5.2.7 Post test
Each interview was transcribed to text, resulting in on average 1-1.5 A4 pages for each person. This was done continuously during the two-week period that the testing covered. The questions and all forms were prepared in English but most of the participants were Swedish and preferred to speak Swedish. The interviewer translated the questions to English and some nuances could presumably have gotten “lost in translation”. As was planned and recommended by Lantz (1993) a process of data reduction was initiated to remove the, for the study, unnecessary data. The focus of this study are as stated in the research question the interaction and controls and so anything that did not have to do with this, directly or indirectly, was removed from the transcripts. Popular topics that arose were among others graphics and gameplay features.

5.3 Data analysis
As mentioned in section 5.1.6 the framework that was used is Framework analysis (Ritchie and Spencer 2002). The framework is a fundamentally iterative one that makes the researcher cycle through the data several times. Using the data that was gathered the framework is described below, along with the results from each step where applicable.

5.3.1 Familiarization of the dataset
The first step is about immersing oneself in the data that exists. This started already during the interviews by not asking questions, probing the participants where suitable and then transcribing the audio to text. After this the transcriptions from the interviews were printed out and read though several times in order to get a feel of the content.

5.3.2 Identifying a thematic framework
The next step was to generate thematic frameworks by creating themes and subthemes from the data. The opinions in the interviews were color-coded based on how they were interpreted. They were then categorized into five different categories as seen in Table 5. After these rough themes were set they were cut out and placed in five separate piles. These piles were removed from the table, clearing space. Now, each pile was reviewed and notes were written down at the insets of each piece of paper, summarizing paragraphs and opinions into keywords. After each piece of paper had yet another categorization in form of keyword, they were once again placed on the table but in a new set of piles only based on their keywords. If a pile did not exist that it ought to go to one was created and given a heading. This was a highly dynamic process as subthemes emerged, were split even further, and sometimes merged with another theme.

<table>
<thead>
<tr>
<th>Immersion</th>
<th>Head Input</th>
<th>Feedback when using controls</th>
<th>Rotation</th>
<th>Misc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
After all piles from the initial color-coding had been used to create new piles, and each slip of paper assigned to one of these, the themes in the themes in Table 6 had been discovered. After this each slip in each pile was again questioned. Does this piece of data fit into this heading? What about the other headings? This process was redone until the author did not move any more slips between old and/or created new piles. This deemed to be enough information to confidently create labels. The themes and subthemes that emerged are shown in Table 7.

<table>
<thead>
<tr>
<th>1 Patterns of comfort</th>
<th>Aim with the head</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Head movement in total distance/activity</td>
<td>Too much head movement</td>
</tr>
<tr>
<td>1.2 Head movement in abs angle from center</td>
<td>Navigation queasiness</td>
</tr>
<tr>
<td>1.3 Queasiness from controls</td>
<td>Immersion</td>
</tr>
<tr>
<td></td>
<td>Immersion controls</td>
</tr>
<tr>
<td></td>
<td>Immersive controls more like real life</td>
</tr>
<tr>
<td></td>
<td>Limit weaknesses with game design</td>
</tr>
<tr>
<td></td>
<td>New unintuitive controls</td>
</tr>
<tr>
<td></td>
<td>Extreme head angles</td>
</tr>
<tr>
<td></td>
<td>Game design</td>
</tr>
<tr>
<td></td>
<td>Feedback wanted in head input</td>
</tr>
<tr>
<td></td>
<td>Feedback wanted in new controls</td>
</tr>
<tr>
<td></td>
<td>Feedback wanted through game design</td>
</tr>
</tbody>
</table>

Table 6 Themes after second iteration

<table>
<thead>
<tr>
<th>2 Patterns of presence</th>
<th>Aim with the head</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Controls</td>
<td>Too much head movement</td>
</tr>
<tr>
<td>2.2 Visuals Interaction with environment</td>
<td>Navigation queasiness</td>
</tr>
<tr>
<td>2.3 Other</td>
<td>Immersion</td>
</tr>
<tr>
<td></td>
<td>Immersion controls</td>
</tr>
<tr>
<td></td>
<td>Immersive controls more like real life</td>
</tr>
<tr>
<td></td>
<td>Limit weaknesses with game design</td>
</tr>
<tr>
<td></td>
<td>New unintuitive controls</td>
</tr>
<tr>
<td></td>
<td>Extreme head angles</td>
</tr>
<tr>
<td></td>
<td>Game design</td>
</tr>
<tr>
<td></td>
<td>Feedback wanted in head input</td>
</tr>
<tr>
<td></td>
<td>Feedback wanted in new controls</td>
</tr>
<tr>
<td></td>
<td>Feedback wanted through game design</td>
</tr>
</tbody>
</table>

Table 7 Themes and Subthemes for analysis

5.3.3 Indexing

At this stage it was time to index the data, to apply the newly created labels. All the transcripts were once again printed out anew. They were read through and each paragraph was noted with the number that corresponded to the label that somehow described the content. A paragraph could have any number of labels.

5.3.4 Charting

After the indexing the transcripts all data was moved into one table. Each row consisted of one game played by one user. Each column was one of the nine subthemes. Each row was filled in with the paragraph and all the data that had been categorized into the different themes and subthemes. If some paragraphs had several labels attached to them they would be split up if there existed a clear separation between the labels. If not, it would be entered into both of them. After this was done the goal was to print these and draw conclusions.
5.3.5 Mapping and interpretation
As mentioned by Ritchie & Spencer (1994) it is often by the relations of labels inside each case (in this study: each game played by a user) where the researcher can see relations and connections between different themes. Due to the size of the chart it was hard to get any sense of connection at all. It spanned several pages in width and in height, totaling 136 pages in its raw form. The chart was therefore condensed with the goal to get as much data on as few pages. The relation between labels and interviews was removed in the process, after which it only existed labels with quotes from users belonging to each theme; see Appendix 9.6 for a small sample. After this process had been done for all of the games, a total of 24 pages were printed. Now once again the data was color-coded based on trends, connections and structure. Why had this happened? What did the designers try to achieve when they got this result? Why didn’t it work the way they thought it would?

As is mentioned by Ritchie & Spencer (2002) this part is the most difficult to describe. It appears that the analyst works in a mechanical way, making obvious connections, but in reality each step requires leaps of intuition and imagination. The process of immersion in the data triggers associations the origins of which the analyst have trouble recognize.

5.3.6 Defining Concepts
Using the color-coded tables that had been prepared in the previous step it was now time to try to come up with recommendations to counter these situations. While each of the games tables had been printed out separately, they were now joined in one. Colors were compared across games and sometimes across themes; new connections were made between quotes. The connecting quotes were drawn out and listed in clumps in a huge word document, after which they were reflected over by the author. General guidelines were then based on these quotes. The result is presented in the following section.
6 Results
The goal of the analysis was to extend the currently known interaction and control guidelines to help game designers make better games in VR. With the help of a qualitative theoretic framework several of the already known guidelines have been reinforced and new guidelines have been found.

Even though the sense of presence was not supposed to be investigated the effect was often mentioned in the interviews. Coupled with the observation that participants behaved differently while under the sense of presence it is clear that it gives rise to some new concepts, and could have a powerful impact on certain interaction elements. Therefore presence was incorporated into some of the more general guidelines.

Whatever the circumstances this paper advocates being aware of the implications before decisions are cemented. All choices are trade-offs and while VR is new, while so little is known, it is important to test often to understand what the trade-offs are. With this in mind the guidelines are presented in the next section.

6.1 Strive for controls that mirror real life
When a person performs an action in real life there is usually some sort of response. If they were to grab a door and pull it the door would open if unlocked. If locked it would indicate that state with haptic feedback.

There are two ways this can be represented in VR. The first is a perfect representation of the real world. If one were to perform an action in the real world and the same action in VR, the feedback would be exactly the same. This could be possible by either a huge physical rig or more likely a direct connection to the brain like in the movie The Matrix (IMDb 2015).

The other alternative consists of mapping an action to an event that is inconsistent with the real world mapping. Opening doors with a button is an inconsistent mapping. Locking head and body rotation is an inconsistent mapping. These inconsistencies are inevitable for most games with the technology that exists today. But nonetheless it is important to realize what kind of simplification that is chosen and what kind of implications arise because of that particular simplification.

The more realistic controls the less implications.

6.1.1 First Person Controllers
One example is First Person Controllers as seen in FPS games. The common controls for these type of games on PC or console is to have locomotion on the left thumbstick or keyboard - back, forward, left and right strafe – and aiming with right thumbstick or mouse. There’s 3DOF in one control center and 3DOF in the other.

In Dreadhalls the controls consist of a 3DOF on one thumbstick, 1DOF on the other and 3DOF by rotating the head. This

“The right thumbstick to look around felt off, and gave a feeling of uneasiness”

“I would have liked separated rotations for head and body, it feels weird to not have it like that”

“I thought it was confusing that there were several ways in which you could move your head. Several different things that affect the steering of my character. I was confused and not really happy with the way it was”
means that there are two ways to move the visual field: the head and the thumbstick.

In addition the camera in-game is not decoupled from the body’s forward vector. The player effectively steer the characters walking direction with the head. So if a player is running straight and turns the head to the right, the character turns right. This is an inconsistent mapping, in real life the body and head rotation are decoupled. Players do not expect this inconsistent mapping in the game and many participants found this unnerving.

This mapping also makes it cumbersome to use the head to steer the character in an effective way. As some participants reported, if they wished to turn to the right with the help of the head they had to keep looking in that direction after the turn. When they turned the head back to their naturally forward position (in real life) then the character would turn back, back to the old direction, forcing them to use the thumbstick.

6.1.2 Other estimations in gameplay

In the game Kneebend there was due to hardware limitations a simplification in how people moved up and down. Instead of accurately tracking the exact height of the head the software tried to judge whenever a shift up or down was initiated using the accelerometer. This resulted in two situations that are worth mentioning.

Firstly, it meant that the exact movements that the participants made were not fully represented in the VE. As long as the system recognized the knee bend it did not matter if the participant made a shallow or a deep one.

Secondly it sometimes missed the knee bend. This result in either the participant moving and the visual field not, or even worse – the visual field moving while the participant was stationary. This feeling of not being where you thought you would be seemed to severely affect the experience.

6.1.3 Interactions with objects

For the games that had a first person view, i.e. Solitaire, Dreadhalls and Kneebend, there was some kind of interaction with the environment. Solitaire used a button to pick up cards. Dreadhalls used buttons to pick up objects and open doors, and Kneebend used the gaze to initiate the start of the game. Some participants commented on how intuitive they experienced the interaction. The conclusion is that using buttons to pick up cards was not as intuitive as hand moving gestures but still more intuitive than using a button to unlock a door.

6.1.4 Recommendations

When their experience in VR behaved in an unexpected way many of the participants experienced a “bad” feeling. Some explicitly reported that it broke their sense of presence or immersion. Often they said that it was the main source of nausea. Others still mentioned that it would have been more enjoyable in a

"In general, when there were movements in real life which did not correspond to any movements in the game it felt bad"

"The connection between Virtual Reality and Reality doesn’t feel natural. I would have liked more 1:1 connection in VR and R."

"When my position did not match where I wanted to be I was completely thrown off"
more intuitive or natural way. Whatever the reason it is clear that when making a game the designers should take great care into crafting experiences that relies on controls as similar to expected behavior as possible. A true one to one relation between the VE and the real world is very rarely possible, but developers should test often and a lot in order to uncover the implications of the shortcuts in the mapping they chose to implement.

For bodily movements, like head movements or knee bends, the steps needed to make the mapping as realistic as possible is straightforward. Other actions should be experimented upon and new patterns will be found. For example, participants said that opening doors in Dreadhalls with only one button did not feel immersive. Maybe opening the door in-game by pushing four buttons on the gamepad would feel more immersive.
6.2 Encourage presence by realistic environment interaction

In *Dreadhalls* players are able to pick up items from the world. Items like a jar of lamp oil, pouch of lockpicks and coins for example. When the player picked up the item – looking towards it and pressing the action button – then the item flew towards the camera and disappeared. No further feedback to the player was given as of the status of the item. Several players reported that they experienced this feeling as “disconnecting”.

"There was little feedback, and the whole presence was just removed since it [the object] just went away. There was no sense of meaning with the objects, a lack of feedback on the items. They flew towards me, but then what? It made me feel disconnected. There was no meaning."

"It felt like I picked the objects up, but then they kind of disappeared. What where they for, how do I use them, where did they go?"

6.2.1 Recommendation

Similar to section 6.1, the recommendation is once again to look to reality in order to encourage the sensation of presence. Developers should ask themselves questions as

- How does it work in real life?
- What of these things can I convincingly implement?
- What kind of shortcuts can I take?
- What effects will these shortcuts have?

In *Dreadhalls* for example there are several things that come to mind. First, make sure that there is convincing audio feedback. Secondly, consider visual feedback integrated into the environment. Can lockpicks hang on the belt of the character? This requires an existing avatar in the game. If it is not feasible to implement then go one step further. How would someone pick up a lockpick in real life? They would put it in the bag of lockpicks. In some cases they would probably look at the bag while putting it in there. It is not recommended to take control of the camera (inducing vestibular mismatch mentioned in 4.1.6 and 4.2.1) but the bag can float up, “swallow” the lockpick, and float back.

Consider also what information is passed from these real world interactions that the player performs in VR. In the real world looking into the bag would show how many lockpicks there are inside. How can this be conveyed to the player in a natural way?

The possibilities are endless and will take time to explore. Based on these results the important thing is to start from the most realistic scenario and go from there.
6.3 Presence have implications on interaction

When the player is experiencing presence, he/she believes in that reality. They believe, intuitively, that their bodies exist in that space and expect that it should relate to the real world. For good and bad. It was discovered that this has implications that the game designers should be aware of when making decisions about the design.

6.3.1 No frame of reference implies a person

In the game *Kneebend* the player was supposed to simulate a ship, but this was not represented in the visual field. There was no cockpit or any other frame of reference that made the user believe they were sitting inside a ship. As a result, many people thought they were a running person inside the game. They thought that they had legs and that the legs would hit the obstacles that passed underneath them. As such they wanted to jump above the obstacles when they approached on the lower levels. This was never part of the design but without a frame of reference their intuitive thought was to act as they would have acted in the reality they perceived to be in. If they thought they were a running person then jumping above low objects felt natural.

In addition some people were had a premeditated notion of the distance their knee bends would take them in game. They thought a knee bend would only lower them down a meter, when they flew four meters they were very surprised.

6.3.2 Environment should work with presence

In Dreadhalls the setting was defined and the game designers had clear target for what kind of role they would want the player to have. However, some parts of the experience were not supportive of that presence. One player wanted to go to a place that was closed off by a small table. The table was so small that the player intuitively thought he should be able to step over/cross/pass it, it did not feel like an obstacle. This feeling of when the environment design did not fit the role the player was experiencing was reported to be very frustrating experience.

In addition, the player was sometimes able to walk too freely. Several participants accidentally walked into the wall. With the HMD and the in game camera standing a few centimeters from the wall it made for a very uncomfortable experience. In real life this is an action that a player would never want to perform. If the player ends up staring into the wall it is because of a navigational mistake, and not due to the fact that they actually want to stand there.
6.3.3 Recommendations
Design the environment around the role of the player. Define who the player will be in the game and raise the question if the world and environment supports this experience. Who is the player, what are the actions they perform, the size he/she has, the abilities possessed? What would the player want to do? Avoid uncomfortable experiences by making players unable to make mistakes they would never perform in real life. It is a daunting task to go through the entire environment so a recommended approach would be to start with this early and keep the questions in mind for design and asset creation.

6.4 Use new inputs pedagogically
It became clear that participants were not proficient in using the head to indicate what their choices were. It is understandable since in real life the center of the face is never used to indicate an exact direction, the eyes are used when millimeter precision is called for. The neck is used in broader gestures when the eyes cannot be turned comfortably.

6.4.1 Problem with accuracy
Sometimes players simply had issues with selecting a target or an item they had in mind. They did not hit the cards they wanted in Solitaire, were not able to get the crosshair to continuously aim at the enemies in Nighttime Terror.

"The movement was too sensitive, I missed the cards"

"It was hard to get very good precision with the head tracking"

"You looked at some place with your eyes. And when you wanted to aim there, actually move the crosshair over there, it was not easy"

"Would have liked it to be easier to aim at stuff. It was hard, very detailed, and often I did not hit what I wanted"

6.4.2 Uncertainty of direction
Sometimes they were not sure which card they were looking at in Solitaire, which enemies they were aiming at in Nighttime Terror or which objects they were targeting in Dreadhalls. This stems from a lack of feedback that the participants felt they needed due to their inability of using of the head input accurately.

"I aimed at the rabbit, I shot at the rabbit, but it did not hit the rabbit. I'm not sure if it was because the marker did not hit them or because the shots did not go to the marker"

"I tried aiming at the monsters, and it felt like I did, but the shots did not hit them. And I don’t know why"

"It was a little bit hard if two objects were next to each other. There was no feedback, I did not know which one I had selected"
6.4.3 Recommendation

More and more types of input will emerge. Designers should be aware of implications when demanding new types of input. Will the players have any previous experience of using it? Is it easy to use for all or do they need some help in the beginning? All novel input will take some time getting used to. Test the designs often and if needed, help the user along.

In the example of head tracking, it might be prudent to help the players with certain aspects so it doesn’t have to be as precise. The players could for example be helped with auto-aim.

Provide feedback to the players in order for them to learn how to use it more rapidly. Interestingly enough, none of the games offered a feedback loop to the players when they were unable to select or aim where they wanted.

All in all, help the player understand how to use the new input.

6.5 Avoid uncomfortable angles

The analysis shows that people found extreme angles downward discomforting. In Solitaire and Nighttime Terror the player was forced to look down sharply, see Image 17. In one game it was optional but some features were placed there. In no game was the player forced to look sharply upwards, but it is a safe assumption that an extreme angle upwards and to the sides are uncomfortable as well.

"Having a lot of stuff going on close to the chest was not nice, that was a very uncomfortable angle"

"There was too much action close to the body. It was really hard to do stuff here. The camera was fixed, and when my character got close I had to bend my neck"

"I had to tilt my head way down when looking at the map. That was horrible"

"In this game I had to look down a lot, and the neck movements was less comfortable the more extreme they were"

"I felt that I had to look down, very far down, in the screen. And that was uncomfortable"

Analysis of Solitaire and Dreadhalls show that the movements which users reported to be uncomfortable were as little as 35 degrees down from looking straightforward. It is therefore recommended to stay well within this angle. No data points on uncomfortable angles in other directions were found due to the design of the games in the tests.
6.6 Minimize head movement

Head tracking currently plays an important part in input for the current HMDs. Especially so on hardware like Samsung GearVR and Oculus Rift which has limited controls packaged in the retail package. But as was discovered in previous recommendations, section 6.4, using the neck for detailed movement is not a common action.

6.6.1 A game with too much activity

When playing Solitaire the players were frequently mentioning that they moved the head too much. Due to the current design of the game the players had to first pick up a card, move the head, and then put down the card where they wished it to go. This encouraged a lot of back and forth movement of the head.

The other games had a more suitable input design where the gameplay, while centered on the head input, did not encourage a lot of back and forth movement of the head. Instead they demanded precise movement area concentrated areas in the game environment.

6.6.2 Recommendation

If using the head as input take care to not require excessive head movement. Especially so early in the current wave of VR devices the general population is likely not used to this kind of demanding neck activity.

Use game design to eliminate the need to move the neck where possible. For example auto moving of cards in Solitaire instead of manual drag and drop.
7 Discussion

The goal of the study was to find new, or improve existing, control and interaction guidelines for games in VR. Even though some aspects of the data turned less poignant, several findings have nonetheless come to light that answers the research question.

7.1.1 Test often

One recurring theme in sections 6.1.4, 6.4.3 and 6.5.1 is the need to test often. Interaction and controls in VR are sure to produce unexpected reactions from players. The goal should be to strive to copy reality in as many ways as possible but even then unexpected results can occur, like finding out the head angles are uncomfortable (section 6.5). It is clear that there is much to learn and with the current knowledge it is hard to predict all implications. Test often to find them as early as possible.

7.1.2 Results validating existing recommendations

The recommendation of section 6.6, minimize head movement, clearly validates the earlier information found from studies by several authors and stated in section 4.1.6. The designer is encouraged to centralize gameplay in the VE and not require the player to swivel their head too much back and forth.

The guideline presented in section 6.1 states that designers should strive for controls that mirror real life. This also confirms previously known recommendations such as minimizing vestibular mismatch (section 4.1.6 and 4.2.1), inducing none or low amount of vection (4.1.6 and 4.2.2) as well as avoiding unnatural maneuvers (section 4.1.6). From the perspective of CS it seems that the best scenario would be if a player can perform a move in the real world, which is copied exactly into the game.

7.1.3 New interaction principles

The perspective of presence was also raised in the guideline of 6.1, to strive for controls that mirror real life, and here the recommendation found is of more novel value. Looking at the quote in section 6.1.2 we can see that a simple position mismatch upset a player. Section 6.1.3 describes how using a button to pick up a card felt OK but users would have preferred gestures for opening doors. Even when interacting with objects we have notions of how the interactions should be performed, for example: opening doors. If this can be mimicked the author believes a greater sense of presence is likely to be achieved.

In section 6.3 it was further found that presence has an impact on interaction. Without a frame of reference to indicate that the player was in a cockpit they wanted intuitively to jump above obstacles. The importance of the role the player assumes when presence is achieved is something that has not been found in any of the previous readings. It certainly has an impact on the type of interaction that is suitable for a game.

The guideline in section 6.4, using new types of input pedagogically, is based on the fact that players had troubles using the head as input. They often exclaimed a
lack of feedback or that controls were too inexact. The author believes this is due to the fact that it is completely new input for many and that some designers expect too much from this input too early. Imagine if one were to demand everyone to use the mouse with the left hand, the results would be catastrophic. Similarly we are unused to use the neck as input and designers should take this into account.

From an ergonomic standpoint the guideline 6.5 states that uncomfortable angles should be avoided. In one game an uncomfortable angle, 35 degrees down from straight forward, was required with some recurrence. Many players commented on how uncomfortable it was. This is a relatively low angle and it is questionable why no studies exist to support this fact if the user experience is consistent.

7.1.4 VR and the future
While it has only been a few years of the new era of VR, there are many interesting HMDs (3.2.6) and input devices (3.3.3) that soon will appear on the market. In the near future these will be replaced with even more advanced technology and with it the VR experience will evolve. It seems plausible to say that soon the hardware will be able to project a VE that looks and interacts as real life. So will CS not exist in the future?

While it certainly would decrease instances of CS we should not forget that we get motion sick in every day life. When riding a boat or a roller coaster the same symptoms that CS consists of can impact us. It seems prudent to suggest that CS is linked to the type of experience we want to have rather than the technology and so it will very likely still exist in VR both in the near and far future. For this reason research in the area of CS, particularly connected to game design, will be useful for a long time ahead.

7.1.5 Future work
It would be interesting to investigate if uncomfortable angles during gameplay are coupled with head activity. The fact that no earlier study mentioned as low as 35 degrees to be uncomfortable, as discovered in section 6.5, indicates that special circumstances might have been at play. One connecting variable that many participants commented on in the Solitaire game was excessive head activity. Investigating the correlation between these two would be highly interesting.

In addition it would be interesting to find what correlation the other directions have to each other in the aspect of uncomfortable angles. Some people mentioned they would rather look up than down, and the author is unaware of any ergonomic principles at play. For games that have a stationary camera this would greatly impact what kind of game designs that are suitable.

One major aspect of this study was the fact that the quantitative SSQ data was unusable for the study, because the gaming sessions being too short. Due to one of the recommendations of this study to test often it would also be of interest to know how long one needs to test in order to accurately be able to use the SSQ questionnaire.
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9 Appendixes

9.1 Test schedule

The test schedule is the document that was presented to each user as the test started. Using this as a template I walked through the outline of the test together with them in order to convey a sense of professionalism and to give them an idea of what to expect.

0 min
- Introduction
- Consent form
- Cookies
- Information about study
- Show how to use hardware
  - Gamepad
  - Headset
- Tell them about bugs in VR
- Fill out user info form

5 min
- Start tests, each test consists of
  - 3 min Gameplay
  - 2 min SSQ
  - 3 min Structured questions and ratings

40 min
- Debrief
- Thank them for participation
9.2 Control scheme instructions

Image 18 to Image 20 are the controller schemes that was used by me to explain the controls. Previous to starting each game I quickly went through the controls together with them so that they did not have to spend any time figuring them out.
Image 19 Solitaire control scheme

Image 20 Kneebend control scheme
9.3 User recruitment poster 1

The first recruitment poster that was posted in the surrounding user area, as well as on Facebook

Virtual Reality

Testers Wanted

23rd of April to 5th of May

Recruiting testers for a thesis investigating controls in Virtual Reality!

You will get to try out several Virtual Reality applications after which you’ll answer questions. The test takes about 30-45 minutes to complete at our office located in Saltsmåtargatan 19.

WHO
You who have not tried out VR in the past two years.
You who are not ill or have any disabilities (lenses are fine, glasses do not fit)

WHY
To get a fun experience with Samsung Gear VR, drinks and cookies!

WHEN
Friday 23/4 to Tuesday 5/5
Day time, evenings and weekends

CONTACT FOR SCHEDULING
Carl-Arvid at email: arvidew@kth.se
0707 345 234
9.4 User recruitment poster 2

The second recruitment poster that was posted in the surrounding user area, as well as on Facebook.

SEX DRUGS ROCK & ROLL
24th of April to 5th of May

Now that I have your attention: I’m recruiting testers for a thesis in Virtual Reality games!

You will get to try out several Virtual Reality games after which you’ll answer questions. The test takes about 30-45 minutes to complete at our office located in Saltsmåtargatan 19 (very close to SSE).

WHO
You who have not tried out VR in the past two years
You who are not ill or have any disabilities (lenses are fine, glasses do not fit)

WHY
To try out VR, drinks and cookies!

WHEN
Friday 24/4 to Tuesday 5/5
Day time, evenings or weekends

CONTACT FOR SCHEDULING
Carl-Arvid at email: arvidew@kth.se
9.5 User recruitment poster 3

The third recruitment poster that was posted on Facebook in university related groups

very funs
much controls
such VR
many games
doge is excite

26th of April to 5th of May

I’m recruiting testers for a thesis in Virtual Reality games!

You will get to try out several Virtual Reality games after which you’ll answer questions. The test takes about 30-45 minutes to complete at our office located in Saltnästargatan 19 (near Sveavägen).

WHO
You who have not tried out VR in the past two years
You who are not ill or have any disabilities (lenses are fine, glasses do not fit)

WHY
To try out VR, drinks and cookies!

WHEN
Monday 26/4 to Tuesday 5/5
Day time, evenings or weekends

CONTACT FOR MORE INFO
Carl-Arvid at email: arvidew@kth.se
### 9.6 Example of mapped data

One example of how the mapped data was truncated, where each row previously meant one user feedback session. In order to save space this connection was removed.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patterns of comfort</strong></td>
<td><strong>Head movement in abs angle from center</strong></td>
<td><strong>Queaziness from controls</strong></td>
<td><strong>Controls</strong></td>
</tr>
<tr>
<td><strong>Head movement in total distance/activity</strong></td>
<td>Device is heavy so I would rather look straight forward than down. In this game I had to look down a lot. I believe neck movements feel less comfortable the more extreme they are. Would rather look up than down.</td>
<td>It was very clean, relaxing, and not so impacting on the body.</td>
<td>It felt good using the button with cards.</td>
</tr>
<tr>
<td>I'm just too lazy for this amount of head movement.</td>
<td>It was hard to get an overview of the playing field. It was tricky to put it down when it was far down on the board.</td>
<td></td>
<td>It was easy to use, but the use of a button did not feel good.</td>
</tr>
<tr>
<td>Too much head movement was required in game.</td>
<td>Maybe it should be smaller, it required quite large movements of the head already.</td>
<td></td>
<td>The controls are very easy, but it would be nice with something else that controls except click. Maybe hands, or maybe staring at a card to pick it up.</td>
</tr>
<tr>
<td>The only thing that affected was that it's blurry below. So it required constant head movements. I would have liked to see all information clearly without moving my head.</td>
<td>I felt that I had to look down, very far down, on the screen. And that was uncomfortable.</td>
<td></td>
<td>It would have been nice blink or something to pick up and drop. The interaction with a button felt... not right. Maybe it would be better to move the hand or something.</td>
</tr>
<tr>
<td>In this VR thing you still need to take every card with a heavy thing on your head. Takes too much effort.</td>
<td>When you were picking up cards far down it was uncomfortable.</td>
<td></td>
<td>Sometimes it did not put down the cards where I wanted it, so it snapped back to the original place.</td>
</tr>
<tr>
<td>Maybe I had to move the head a little bit too much.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would have liked to be able to double click the cards to move. I would not be sad if it was faster to move the cards.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I had some fatigue from the horizontal head movements, I would prefer not being required to move at all. I had to basically move 150 degrees often, way too much.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
9.7 Consent form for interviews

Below is the consent form for the interviews. Users signed this after some short info had been given, and they are being kept until the data is deleted.

---

Consent for Participation in Virtual Reality
I volunteer to participate in a research project conducted by Carl-Arvid Ewerbring at Resolution Games. I understand that the project is designed to evaluate the impact of different controls in VR. I will be one of approximately 15 people being interviewed for this research.

1. My participation in this project is voluntary. I understand that I will not be paid for my participation. I may withdraw and discontinue participation at any time without penalty.

2. I understand that if I feel uncomfortable in any way during the testing session, I have the right to decline to answer any question or to end the interview.

3. Participation involves being interviewed by students from The Royal Institute of Technology. The test session will last approximately 30 minutes. Audio as well as a written transcript of my answers will be recorded. If I do not consent to this, I will not be able to participate in the study.

4. I understand that the researcher will not identify me by name in any reports using information obtained from this testing session, and that my confidentiality as a participant in this study will remain secure. Subsequent uses of records and data will be subject to standard data use policies that protect the anonymity of individuals and institutions.

5. I understand that the raw data will be saved until the end of 2015, after which it will be removed.

6. I understand that this study has been reviewed and approved by faculty members of the Computer Science institute at the Royal Institute of Technology. For research problems or questions regarding subjects, I should contact Björn Thuresson thure@csc.kth.se

7. I have read and understand the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.

____________________________ ________________________
My Signature Date

____________________________ ________________________
Interviewer Date
9.8 User Info Form

The users were asked to enter this form near the beginning of the test, before any games had been played.

User Info

* Required

Sex *
- Male
- Female

Age *

Previous Gaming Experience
Choose most suitable option
- None
- Moderate
- Extensive

Submit

Never submit passwords through Google Forms.
9.9 Simulation Sickness Questionnaire

After each game the participants were tasked with filling in a SSQ. After which, the interviewer conducted a short interview about each game.

Simulator Sickness Questionnaire

Fill in how much each symptom is affecting you right now

* Required

What game are you testing? *

Which user ID? *

* Fill in how much each symptom is affecting you right now.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>None</th>
<th>Slight</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>General discomfort</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headache</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye strain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty focusing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salivation increasing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nausea</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fullness of the head</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blurred vision</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dizziness with eyes open</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dizziness with eyes closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertigo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stomach Awareness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Definitions

*A feeling of tiredness or exhaustion or a need to rest because of lack of energy or strength
**A feeling of discomfort originating from looking at something for a long time.
***A feeling of pressure in the head, similar to hanging upside down.
****A feeling of dizziness and fear, and of losing your balance, that is caused in some people when they look down from a very high place.
*****The awareness that one possesses a stomach/upper abdomen/throat—an awareness that is not usually present in daily life unless something is amiss.

Continue »