How Interactions Shape the User Experience – a Mobile Virtual Reality User Study

Hur interaktioner påverkar användarupplevelsen – en användarstudie inom mobil-virtuell verklighet

Simon Bothén
Patrik Nilsson
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Simon Bothén and Patrik Nilsson

Game Development Program, Computer Science and Media Technology,
Malmö University, Sweden

Abstract. Virtual reality is becoming more popular and accessible to a broader audience, since practically every modern smartphone can be used. The problem with new components of a technology is the lack of guidelines for the developers. In this thesis, a set of mobile virtual reality games were analysed and broken down into its core interactions. These interactions were then isolated and implemented in a test application to be the base for a user study. A description of the implementation was presented focusing on these interactions. The purpose of the user study was to compare the different interactions and compare them to a traditional controller. From this, guidelines for mobile virtual reality interactions were developed by analysing the result comparing the interactions for both gamers and non-gamers performance in the user study. The results of this thesis showed that there are more preferred interactions in virtual reality and that both people that play video games, and those who do not, prefer virtual reality interactions over a traditional controller in many cases.

Keywords: mobile virtual reality, interactions, controller, gamer and non-gamer, comparison

1 Introduction

1.1 Background

In 2014, Google introduced what has become the beginning of cheap virtual reality (VR), by introducing the Google Cardboard for a few dollars (Google 2014). In December 2015, Google’s vice president of virtual reality announced that they sold over 5 million Google Cardboard headsets (Bavor 2016). Ever since then, Google has been the face of cheap mobile virtual reality and has made it available for everyone with a smartphone. It requires a smartphone to be used (Korolov 2016; Macqueen 2017). A much more expensive brand of VR headsets is the Oculus Rift, at a cost of $599, which have sold
more than 175,000 units since 2013 (Hayden 2015). It should be noted that Oculus Rift has a built-in display and does not require a smartphone to function (Oculus Rift 2017).

The market of mobile virtual reality has grown excessively since 2014, with over 25 million Google Cardboard applications downloaded from Google Play (Bavor 2016). The VR headset was awarded the Christmas present of the year 2016 by the Swedish Retail Institute (HUI Research 2016). One common issue with VR is cybersickness, and different factors cause different amount of nausea (LaViola Jr 2000).

The aim of this study is to investigate and analyse different interactions for smartphone-based VR against each other and in addition, compare the interactions to another input, a traditional controller.

1.1.1 Head Gaze
Head gaze is an input technique that uses motion sensors. The motion sensor device is mounted to a person’s head and will track your head movement. Zeleznik, Forsberg, and Schulze describes this technique by “[...] a common handbased rotation of an object is offloaded to gaze such that a viewer can essentially rotate an object in front of them by simply turning their head.” (2005). This creates what is called head gaze and it is common to use this to transfer the movement of your head to rotate a specific object.

1.1.2 Mobile Virtual Reality
Mobile virtual reality (MVR) is the term that will be used in this thesis to define the compound of hardware components needed to be called MVR. To clarify what we define as MVR, the following requirements must be fulfilled:
1. The headset does not contain a display of any sort.
2. A smartphone can be placed inside the headset to be used as a display.
3. The smartphone must have a gyroscope to be used with the head gaze technique.

1.2 Related Research
This section examines previous research related to MVR and traditional controller input.

1.2.1 Comparison of Inputs
Previous research has been made on the comparison between different inputs. A study made in California, United States used head gaze, a magnetic switch, and a Bluetooth controller with numerous of buttons as input. The goal was to compare and analyse these cheap VR inputs and how reliable they are. The results showed that using a Bluetooth controller was the most efficient for task performance, being nearly 50% faster than the magnetic switch controller. It also showed that the magnet switch is not 100% accurate and can provide an incorrect input. The results of head gaze movement showed that
making tight turns and unplanned manoeuvres should be avoided. In their test, they changed direction using head gaze while moving in a constant speed (Powell et al. 2016).

Similar research will be analysed and discussed in this thesis, which will be based on interactions instead of inputs, and comparison will be made within the same input type using different interactions.

1.2.2 Interaction Using Head Gaze

A recent study made in the Philippines researched VR combined with different types of input devices where three demonstrations were presented. The first one used a hand recognition input device and the second one added photorealism, living creatures, and reactive behaviours, controlled with head gaze. The last demonstration extended the core features of the second demonstration. Head gaze was used for navigation by using floating markers where the user could walk and climb the virtual world. The conclusions presented that the hand recognition device’s sensors had unquestionable low input reliability, and consequently they changed their primary input method to head gaze. Head gaze was used successfully to trigger specific activities and to move to predefined locations by gazing over the markers. The immersion was attained by adding animals and enabling the head gaze to interact with the virtual environment (Atienza et al. 2016).

In this thesis, head gaze will be analysed and discussed in relation to a traditional controller, and these two will be the primary inputs for this research.

1.2.3 Control Virtual Reality Using Smartphone

A study by Kovarova and Urbancok from 2014 had the goal to test a new way to control VR using a smartphone instead of mouse and keyboard. The study uses the definition of VR defined in 1997. The definition of virtual reality is to mimic the real world with a computer simulation (Tótsy de Zepetnek and Sywenky 1997). Today’s technology brings us closer to this goal, however it should be noted that the VR used today, differs from the VR used in 1997. VR used in 1997 was a 3D-world running on a computer, while the current VR is more focused on head mounted displays.

Kovarova and Urbancok compared different types of inputs that controls different objects. The time to complete a task was then logged and compared to the time it took to complete the same task using mouse and keyboard. The tasks consisted of three types of movements which were walking, flying a helicopter, and driving a car. The presented results showed that the keyboard and mouse were faster, however not in all the cases. The result of the analysis reported that if the testers were more used to smartphones the results would have been different. As a conclusion, the keyboard and mouse is a more natural way of controlling since it is something we use daily, on the contrary, we do not use the smartphones sensors to play games daily (Kovarova and Urbancok 2014).
1.3 Research Question

A problem with the majority of today's MVR applications is the lack of guidelines and research on which interactions creates a good user experience in a specified context. This was discovered during the background research, and to further prove this, an application review was carried out in this thesis.

Depending on which VR interactions that are used in a game, a user can feel different amount of nausea. LaViola Jr (2000) discussed cybersickness and its associated complications when working with a VR environment. He stated that there is no foolproof solution to the problem, however the authors to this thesis predict that finding a better developed interaction can therefore reduce the nausea, leading to an overall better user experience.

1.3.1 Questions

The thesis has three questions that will be answered:

1. How does the interactions differ between using MVR compared to a traditional controller?
2. What is the difference between gamers and non-gamers when it comes to preferred interactions for both MVR and traditional controller?
3. Which guidelines can be used for game designers to better understand MVR input and interactions to improve the end user experience?

1.3.2 Limitations

The thesis will be limited to MVR only. The result of the user study can be applied to other VR systems outside of the MVR realm, however the focus lies on cheap VR with limited inputs. While a smartphone has multiple ways of collecting user input such as a camera, GPS, and a pedometer, the thesis will be limited to motion sensors only. The study will be restricted to gamers and non-gamers, therefore e.g age and gender will not be included in this study.

1.4 Expected Results

We hypothesise that the non-gamer participants will be significantly faster with MVR than using a controller. However, the experienced gamers will prefer the controller for movement but enjoy the precision of head gaze which allows for a more natural input.

A hypothesis is that the free movements will be more difficult to learn and will take a bit longer than moving to predefined locations, though it will feel more natural and less restricted for the participants. The menus with fewer interaction steps will be the fastest option. However, there might be a chance of picking the wrong alternative especially when the time between looking at the menu option and when it triggers is low.
The conclusions from comparing controller and MVR might result in the same as the smartphone versus keyboard and mouse conclusions in Kovarova and Urbancok’s (2014) study.

2 Method

This section describes the method used to investigate the research questions in Section 1.3.1.

2.1 Method Description

To investigate the research question, we initially researched the current state of the art by doing a literature review, followed by an application review. The literature review gave us knowledge about the subject and how to carry out the study, while the application review presented the interactions in currently published games. A test environment application was then developed based on the previous knowledge established, which was later used in the user study to observe and collect data to use for analysis.

2.2 Literature Review

For this thesis, the snowballing-method was used as the primary method to find relevant literature. The snowballing-method involves using references from published articles in order to obtain a deeper understanding of the literature or to find related articles for the research (Wohlin 2014). The following literature databases were used for the literature search, as seen in Table 1.

<table>
<thead>
<tr>
<th>Database</th>
<th>Limitations</th>
<th>Search terms</th>
<th>Hits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portsmouth Research Portal</td>
<td>Virtual reality mobile interaction</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>ACM DL</td>
<td>acmdlTitle:(+Virtual +reality +phone)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>ACM DL</td>
<td>acmdlTitle:(+mobile +VR)</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>ACM DL</td>
<td>acmdlTitle:(+Virtual +reality +mobile +interaction)</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Database</td>
<td>Since</td>
<td>Search Term</td>
<td>Results</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
<td>----------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>IEEE Xplore</td>
<td>Since 2013</td>
<td>&quot;Abstract&quot;:Virtual reality phone</td>
<td>51</td>
</tr>
<tr>
<td>IEEE Xplore</td>
<td></td>
<td>&quot;Document Title&quot;:mobile VR</td>
<td>12</td>
</tr>
<tr>
<td>DIGRA</td>
<td></td>
<td>Keyword: virtual reality</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1. Search terms used during the literature review. Portsmouth Research Portal, Association for Computing Machinery Digital Library (ACM DL), Institute of Electrical and Electronics Engineers (IEEE) Xplore, Digital Games Research Association (DIGRA).

Literature that study non-MVR is not relevant for this thesis and was thereby excluded. This also includes studies that focus mainly on external devices as input, where external devices can be a range from Bluetooth controllers to a connected microphone.

2.3 Application Review
For the application review, a selection of games have been chosen and analysed. These games were selected from a list of top VR games in 2017 (Hindy Joe 2017). The snowballing-method was later used in order to find similar games on Google Play. The games were selected if they fulfilled the following requirements:
- The games should primarily be controlled with built in controls, such as motion sensors, however, a few interactions using external controller is acceptable.
- The game has more than 10,000 downloads, to make sure only popular games are picked.

2.4 Test Environment Application
The test environment application was developed to test the interactions from the results of the application review. Based on the application review results, the test environment application was narrowed down to feature a few categorised challenges that each test specific interactions in an isolated space. Everything that did not contribute to the interaction itself was removed due to the risk of potentially distracting the user from the end goal.

2.5 User Study
The thesis used summative usability study and the data of the study was obtained in two parts. Firstly, data was collected by observing the participant in order to show what
actually happened. Secondly, data was obtained by letting the participants answer a questionnaire. According to Tullis and Bill (2008, p. 45), questionnaires are designed to reflect what the participant actually experienced.

2.5.1 Experience Determining
In this thesis, a gamer is defined as a person who affirm that they are confident using a traditional hand controller and confident referring themselves as a gamer. The participants were divided into two groups, gamers and non-gamers, which made it possible to separate the results of each group and compare the difference between the groups.

2.5.2 Observations
Observational data was obtained by two different methods, the observer’s data and automatic data collection. The first method involved observing the user and additionally filling out a behavioural and physiological form. The second method was by collecting automated data from the test environment application, when the user completed a challenge or interacted with the application. This data was then sent to Google Analytics to give a good visual feedback and was done automatically by the application. These three sections are suggested to be observed by Tullis and Bill (2008, p. 167).

2.5.3 Questionnaire
A questionnaire was constructed to let the participant answer what they felt during the test and what they thought about the different interactions compared to each other. Quantitative data was collected by using Likert scale and polar questions as rating, while qualitative data was collected with the help of open-ended questions. The Likert scale questions and open-ended questions was implemented after the directions from Tullis and Bill (2008, p. 123).

2.6 Method Discussion
Games selected for the application review were selected from a top list and they also needed to fulfil the authors’ requirements, which resulted in a biased list. A better way would have been to filter out the top MVR games from Google Play, although this could not be done due to the lack of search methods on Google Play. We have chosen the most credible source we could find. The consequences with this is that it is possible to have chosen a poor set of applications representing the current state of the art MVR games. This could potentially result in testing out-dated MVR interactions. The reason we stopped gathering more games after the ten top games were selected was due to the high variance of interactions that was found. If more games were added, the user study would
have been larger because additional interactions would be needed to be tested, and would make the thesis exceed its time limit. A possible consequence of this could be that well refined interactions in lesser popular games would not be included in the user study, therefore the list of analysed games could be less diverse.

To develop the test environment application, Unity Daydream Preview 5.4.2f2-GVR13 (Unity Technologies 2017) game engine was used, which has already established tools for MVR. This allowed us to focus on the interactions by using an existing game engine.

3 Solution

This section describes the solution implemented in order to answer the research questions in Section 1.3.1. Firstly, the application review was researched and analysed, to then be used as an integral part of the test environment application. Afterwards, hardware and software were selected to implement the challenges in the most effective way possible. Lastly, three challenges were implemented, with each testing a specific interaction category gathered from the application review. After the challenges were implemented, a user study process was established which later will be described in Section 4.

3.1 Application Review

This section will investigate published MVR games and the interactions used within those games. Ten games were selected to represent the current state of the art MVR games, to be analysed and used in the implementation of the test environment application. The following games were chosen to be investigated, and are presented in Table 2. Table 3 presents the game interactions, categorised in aim-, movement-, and menu-interactions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Publisher</th>
<th>Package name</th>
<th>Downloads</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR X-Racer</td>
<td>DTA Mobile</td>
<td>com.dtamobile.vrxracer</td>
<td>1,000,000 - 5,000,000</td>
</tr>
<tr>
<td>Need for Jump</td>
<td>Jedium Game Studio</td>
<td>com.farlenkov.jmpr</td>
<td>50,000 - 100,000</td>
</tr>
<tr>
<td>BattleZ VR</td>
<td>Realiteer Corp</td>
<td>com.Realiteer.BattleZVR</td>
<td>10,000 - 50,000</td>
</tr>
<tr>
<td>Romans from mars 360</td>
<td>Sidekick VR</td>
<td>com.Sidekick.Romans360Cardb oard</td>
<td>10,000 - 50,000</td>
</tr>
<tr>
<td>Name</td>
<td>Aim Interactions</td>
<td>Movement Interactions</td>
<td>Object and Menu Interactions</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>VR X-Racer</td>
<td>Tilt head left and right</td>
<td>Constant speed forward.</td>
<td>N/A</td>
</tr>
<tr>
<td>Need for Jump</td>
<td>Look around using head gaze</td>
<td>Tilt head forward and backwards, jump to jump in-game.</td>
<td>Look at button, after 1.8 seconds it triggers.</td>
</tr>
<tr>
<td>BattleZ VR</td>
<td>Look around using head gaze. Shoot enemies when gazed at.</td>
<td>Shake head up and down to move forward, jump to jump in-game. Looking at specific</td>
<td>Look at button, after 0.6 seconds it triggers.</td>
</tr>
<tr>
<td>Romans from mars 360</td>
<td>Look around using head gaze. Shoot enemies when you</td>
<td>N/A</td>
<td>Requires a Google Cardboard</td>
</tr>
</tbody>
</table>

Table 2. Chosen applications and their metadata.
<table>
<thead>
<tr>
<th>Application</th>
<th>Interaction Description</th>
<th>Button Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamper VR: Firefly rescue</td>
<td>Look around using head gaze with a slight delay when moving head.</td>
<td>Constant speed forward. Requires a Google Cardboard button to click in menus.</td>
</tr>
<tr>
<td>BAMF VR</td>
<td>Look around using head gaze.</td>
<td>Requires a Google Cardboard button. Gaze anywhere on the ground and press the button to teleport. N/A</td>
</tr>
<tr>
<td>Little Vr Shooter</td>
<td>Look around using head gaze.</td>
<td>N/A</td>
</tr>
<tr>
<td>Space Rustlers</td>
<td>Look around using head gaze. Shoot enemies when gazed at after 0.3 seconds.</td>
<td>Constant speed forward with horizontal speed changed by a pitch rotation with the head. Look at button, after 1.2 seconds it triggers.</td>
</tr>
<tr>
<td>VR Crossy for Cardboard</td>
<td>Look around using head gaze.</td>
<td>Requires a Google Cardboard button to jump forward a distance.</td>
</tr>
<tr>
<td>Lost In The Kismet - VR Escape</td>
<td>Look around using head gaze.</td>
<td>Looking at interactable things will make you zoom in on it.</td>
</tr>
</tbody>
</table>

*Table 3. Application review showing summary of all interactions.*
3.1.1 Analysis

The result of the application review (see Table 3) demonstrated that there are multiple different interactions and that no clear guidelines have been used. It presented three main categories that were the most common in the analysed MVR games. The categories were divided in such a way that they had little to no interference with the other categories in order to fulfil the authors’ requirements of isolated interactions. Aim interactions describe how the user can aim or point at objects. The results showed clearly that this is achieved by using head gaze.

When analysing movement in MVR, there were a variety of different techniques available. Both Need for Jump and BattleZ VR were using a type of motion movement, however BattleZ VR additionally used floating markers that the user can gaze at to instantly teleport to. A similar method is used in Lost In The Kismet, where the user gaze at interactable objects to zoom onto them. The last movement interaction that was unique from the others was the one used in the game BAMF VR, where the user can gaze over an arbitrary spot on the ground and press an external button to instantly move to that location.

The result of the application review presented four different types of menus. The most commonly used menu interaction was the timed menu, requiring the user to gaze at a button for a set amount of time. Google Cardboard’s magnet button was the second most used interaction when it comes to menus. One can gaze at a button and interact with it at any time using the magnetic switch, although it requires an external input. Little Vr Shooter was alone when it comes to menu interactions. As soon as the user gaze over a menu-button, it gets selected, however one must confirm the option by looking at the “OK” button that is located slightly underneath the other options. This is a two-step menu that requires two actions by the user in order to trigger. Lost In The Kismet used a circular menu system, when gazing over interactable items, a menu featuring eight options pops up in a circular figure, where each option is mapped to an item in the inventory (see Figure 1). What should be noted is that a red cross can be found beside the top-right option that closes the menu.
3.2 Hardware and Software

This section describes the selected hardware and software chosen for the user study.

3.2.1 Game Engine

The test environment application was developed in the Unity Daydream Preview 5.4.2f2-GVR13 game engine (Unity Technologies 2017). The game engine has support for head tracking, head gaze and enables rapid development because of the convenient tools it features compared to writing an engine from scratch. Two builds of the application were compiled. One MVR build for Android phones, and one desktop build that was used exclusively for all the controller interactions.

3.2.2 MVR Hardware

For the user study, a SVR Glass by SnailVR was used for the MVR headset, and a Google Nexus 5X was used for the display and sensors. The headset was chosen due to its adjustable lenses and a high 96-degree field of view as promoted by SnailVR. This customization helped maximise the comfortability for the user. The smartphone was chosen because of availability and a high ~423 PPI pixel density (Google 2015).
3.2.3 Controller

A Microsoft Xbox One V2 controller was used for the desktop build. The look sensitivity could be changed on-the-go with the left and right bumpers and the user could also invert the X and Y look axes with a keyboard shortcut.

3.3 Challenges

The main study of the thesis are the interactions in MVR, which have been divided into three main categories: movement, aiming, and menu interactions, as described in Section 3.1. These categories were implemented as part of three different challenges, where each challenge explored one of the categories in the isolated environment to be able to investigate the interaction further. Each challenge has a version using the controller and was played on an identical test environment, however in a desktop application. The challenges have one or more variations of MVR interactions selected from the application review.

3.3.1 Target Range Challenge

Challenge number one is the target range (see Figure 2). The user is restricted to looking around and cannot move. Red targets will pop up one after another, as the user shoots at them. When the user’s crosshair has hovered over a target for 0.3 seconds, the same amount of time as Space Rustlers (see Section 3.1), the target is destroyed and a new one appears. Targets will appear in a pattern to minimise randomness and confusion. The first target will appear on the left shoulder, the second one in front, the third on the right shoulder, the fourth in front and then repeat. This challenge lasts 60 seconds, and starts when the first target is destroyed. According to the expertise of the authors, 60 seconds is enough time for the user to understand what to do. The goal of the challenge was to test the usability of aiming. The challenge will answer how many targets the participant can hit with each input type in the limited time span, and test if the fastest option is the most preferred one.
Head Gaze. Target range will only feature one MVR interaction type, head gaze, which uses this technique to look around and hover the targets. As seen in Section 3.1, this is the only aim interaction reviewed.

Controller. With the controller, only the right analog stick is available as input and is used to look around, giving the participant the ability to aim.

3.3.2 The Hallway Challenge

The second challenge is the turning hallway challenge, where the user will move through a curved hallway that has no branching paths (see Figure 3). A few turns will be included in the hallway and the user needs to walk through the hallway as fast as possible. The time will start when the player crosses the starting line and stops when reaching the finish line. This challenge has the goal to test usability of movements within MVR.
**Motion Movement.** One of the interactions in the hallway challenge is the use of head gaze only. The user can move in different directions by tilting their head. By looking down, the user will move forward and by looking up the player will move backwards. Tilting the head to either side will result in a sideways motion. This allows the user free movement in all horizontal directions in the 3D-space.

**Point and Look Movement.** In this type of interaction, the user needs to look where they want to go, and then hold their head still to move to that location. There are a few limitations that make this interaction possible. There is a max distance you can move towards, and if the player looks too far away, the reticle will turn red and nothing will happen. The user cannot pass through walls, they must gaze at the floor within the max range. The reticle will then turn green and start growing, and finally the user will move to the gazed location. If the user moves their head while the reticle is growing the timer and aim will reset in time and size respectively. This makes it possible to look at the floor without moving there. This interaction enables the user to move freely in 3D space.

**Floating Markers.** In this last MVR interaction for the hallway challenge, the user needs to look at predefined markers in order to move. The user looks at a marker in the world where they want to go, and after a small delay, the user moves towards the position of the marker. This method differs from all the other mentioned interactions in this challenge. One can say that this interaction is a fixed movement, which means that it is only possible to move to predefined positions in the virtual world. To clarify, there is no free movement in the 3D space, only predefined positions the user can jump between.
Controller. The controller movement is using a classic first-person movement. The left analog stick moves the user in the 3D world and the right one is used to look around and steer. This interaction is also a free movement type.

3.3.3 The Hammer Challenge

The third and final challenge will investigate the use of different menu interactions. The movement is locked and the user can only gaze around the room. Five hammers can be found on the floor that need to be picked up one at a time and be placed in separate boxes accordingly. When a hammer has been placed in a box, the lid will close and the box is marked as done. All the five boxes need to be marked as done after which the challenge will be completed. The goal of this challenge is mainly to investigate different MVR menus and compare them to each other.

Circular Menu. This menu shows a circle of buttons around the interacted object (see Figure 4). This means that there are buttons in all directions from the interacted object’s origin. The user can easily choose the desired button by moving their head in a direction where the button is located. There is a small delay on the button and it will be triggered almost instantly when hovered over.

![Figure 4. Circular menu in the hammer challenge.](image)

Select Menu. Select menu is an interaction used in Little Vr Shooter (see Section 3.1). When the user hovers over an interactable object, a menu will appear. This menu features a list of options the user can select from. When the user selects an option, a new “OK”
button appears and if the user hovers over the “OK” button, the selected option will be executed.

**Timed Menu.** Timed menu is the most commonly used interaction as seen in the application review (see Section 3.1). First, the user hovers over a button, after which a progress bar appears. After 1.2 seconds, the progress bar is filled and the button is triggered (see Figure 4). The average time to trigger a button when hovering over is 1.2 seconds, calculated from the application review (see Section 3.1).

![Figure 5. The hammer challenge using timed menu.](image)

**Motion Menu.** Motion menu is very similar to the controller interaction. For example, the user can interact with objects by performing a special gesture, a head tilt. This type of menu has no correct colour to select and the user is only required to do the head tilt to interact with the object.

**Controller.** The controller challenge part will not use any interactable menus, however it will show a help image when the controller can be used. Hovering over an object and pressing the correct colour button on the controller will interact with the object.
4 User Study

This section describes the execution process of the summative usability study.

4.1 Execution

The participants played every challenge twice. The first one was a practice run to make sure that the second run could be played without any obscurities. Each participant took approximately one hour to complete the test, and the following process was used:

1. The overall structure was explained, which challenges will be played and that each challenge was played twice.
2. A pre-session section of the form will be filled out by the participant, which contains general warm-up questions and expectations of the user study.
3. A practice run was played for all the target range challenges. This included playing the desktop build.
4. A short break was held to answer questions.
5. After the break, the challenges were played again, including the desktop build.
6. The target range section of the form was filled out by the participant.
7. The process was repeated from point number three for the other two challenges.
8. Lastly the post-session section of the form was filled out by the participant.

During the test, an office chair was available if the participant at any point felt uncomfortable by standing up.

4.2 Selection

Six non-gamers and six gamers were selected for the user study, and for a summative usability study, it is recommended to test on 50 to 100 participants in order to obtain a reliable result. Since one participant takes approximately one hour to complete the test, the number of participants in this user study had to be lowered. This is acceptable, but the variance in data can be high (Tullis and Bill 2008, p. 45). Participants were selected to get an equal amount of gamers and non-gamers, therefore e.g age and gender was excluded. An announcement was made on social medias to recruit both gamers and non-gamers.

4.3 Observations

A behavioural and physiological form was produced for the observers to fill out what feelings and verbal comments the user expressed during the user study. The form was separated into three sections; verbal behaviours, nonverbal behaviours, and task completion status. Verbal behaviour captures positive and negative comments that the participant says during the test. An example of an important comment could be that the
participant is feeling nauseous. For the nonverbal behaviours, notes were taken if the participant felt happy or frustrated by observing their facial expressions. The last section is the task completion status, where the overall progress was observed, for example if a challenge was cancelled by the participant. These three sections are suggested to be observed by Tullis and Bill (2008, p. 167).

4.4 Questionnaire
As suggested by Tullis and Bill (2008, p. 47), performance and satisfaction data was obtained from the participants. Performance data was automatically collected by the test environment application and sent to Google Analytics. The data sampled contained the time it took to complete a challenge. Satisfaction data was collected using self-reported metrics that the participant filled out during the user study. The metrics contained mostly semantic differential scales for each interaction but also a few open-ended questions.

5 Results
This section presents the results from the user study.

5.1 Likert Scale Questions
In the questionnaire, 19 Likert scale questions were answered where the participant could choose between “Strongly Disagree (1)” to “Strongly Agree (5)”. All participants finished the questionnaire except for one, who due to nausea had to quit the test.

The result from the Likert scale questions were divided into two groups, gamers and non-gamers. There were eleven interactions in total and all the interactions had one question asking how easy the interaction was to use (see Figure 6). An average value from each group was calculated and all the interactions were presented in Figure 6. Because the hallway challenge and the hammer challenge had multiple MVR interactions, the participants could rank the interactions, where the highest value was the most preferred interaction (see Figure 7 & 8). For each challenge, a question was asked how nauseous the participants felt — the result was calculated into an average value (see Figure 9). After each challenge, the participants had to fill out if they preferred MVR over the traditional controller (see Figure 10).
Figure 6. How easy each interaction is on average
Figure 7. Ranked order of the MVR interactions in the hallway challenge

Figure 8. Ranked order of the MVR interactions in the hammer challenge
Figure 9. How nauseous the participants felt on average for each challenge

Did you feel nauseous any time during the challenge? (Average)

Did you prefer VR over controller?

Figure 10. The amount the participants preferred MVR over traditional controller
5.2 Polar Questions

The participants had to guess which input they would perform best with before each challenge, and could choose between controller or MVR (see Figure 11, 12 & 13). When the participants completed all the challenges they had to decide if they preferred MVR or controller the most (see Figure 14).

**Figure 11.** Target range user expectation

**Figure 12.** The hallway user expectation
5.3 Open-ended Questions

The questionnaire featured eleven open-ended questions to collect qualitative data. Two of the questions were asked in all three challenge modules. The answers of all questions are summarised as following, categorised the same as the questionnaire modules:
Warmup
1. *How do you think the interactions with the controller compared to virtual reality (VR) will differ? Will one be more difficult to use than the other?*
   Six people answered that they believed that they would perform better with the controller, and three people answered VR. The rest were unsure, mostly due to the lack of VR experience.

Before Target Range
2. *Please explain why you think your choice will be easier to aim with.*
   The participants answered in two ways. They either replied that they were more used to a controller or they thought that VR would be easier because they only need to turn and tilt their head, which we do every day, however only gamers mentioned that they preferred the controller. One example of an answer from a participant was “Because head movement is faster than the stick on the controller”.

Before Hallway
3. *Please explain why you think your choice will be easier to move with.*
   Most of the gamers thought that it was going to be easier to move with the controller, mostly because of their experience with controller. On the contrary, one of the non-gamers thought it would be easier to use the controller because you did not need to move around in the real world.

Before Hammer
4. *Please explain why you think your choice will be easier to interact with menus/objects.*
   Four of the participants mentioned that they thought VR would be more precise when interacting with menus. Four other participants thought the controller would be easier to use because it has buttons, and because they are used to controllers.

Others
5. *If you felt nauseous, when did you feel it? (Answered after each challenge).*
   In target range, three participants felt nauseous in the beginning and one in the middle of the challenge. One felt nauseous because the person believed that the screen was blurry. In the hallway challenge, five participants, both non-gamers and gamers, became nauseous when moving with the floating markers. This was triggered when moving in one direction and looking in another. Four participants felt nauseous from the motion movement and in the hammer challenge, four participants expressed some nausea from the circular menu.

6. *Anything you want to add? (Answered after each challenge).*
   In the target range, the participants added that they had more fun with VR, but some got more tired and breathless. In the hallway challenge, most people added that VR was more fun, but the gamers still preferred the controller. In the hammer challenge, VR was answered to be the most fun and easier than most originally thought.
7. *How do you think the interactions with controller compared to virtual reality (VR) differed? Anyone was more difficult to use than the other?*

The gamers still preferred the controller and thought it was easier to use, however they all found some aspects of VR to be more interesting or faster than they originally thought. The non-gamers however did not like the controller because of its more complex and sensitive input method, and looking around is more natural with VR than with a controller.

## 5.3 Observations

This section presents the result of the observational data collected from the user study.

### 5.3.1 Observer Data

The majority of the people expressed some type of laughter or positive emotion during the MVR sections, while only three out of the twelve participants felt strong nausea.

In the target range, all participants were focused on shooting as many targets as possible. Half of the non-gamers said that the controller was difficult to aim with and that they felt more in control with VR. One person said that the room felt smaller in VR.

In the hallway challenge, a majority of the participants felt some confusion before the challenge, because they could not visualise how they would navigate in VR. Next to all participants laughed and expressed themselves positively with motion movement, even those who felt a bit nauseous. Most negative feelings were brought up during the point and look movement, where participants reported that it felt static and the instant teleportation was generally unpleasant. However, those who liked it felt that they could move faster with it. All the gamers and a few of the non-gamers said that they thought you walked slower when using the controller, even though you walk with the same speed as with the other interactions. Four participants mentioned that the floating markers movement is not free like the other movement interactions, you cannot walk anywhere you want, as mentioned in Section 3.3.2.

In the hammer challenge, all the non-gamers looked at the controller to identify the colours when using the controller. Several of the participants expressed either confusion or frustration when trying to tilt their head to pick up the hammer. This occurred when tilting the head which made the reticle moving away from the hammer resulting in a cancelled state. Timed menu was said to be very easy and smooth but boring because of the “long” time it took to trigger.

### 5.3.2 Automatic Data

Timestamps for each challenge was automatically collected by the test environment application. The result for both the gamers and the non-gamers time to complete each challenge can be found in Figure 15, 16 and 17.
Figure 15. Target hits in the target range

Figure 16. The hallway challenge completion time
6 Analysis
This section presents an in-depth analysis of the result from the user study.

6.1 Challenges
This section will analyse the three challenges, comparing the gamers and the non-gamers.

6.1.1 Target Range Challenge
Half of the gamers thought the controller would be the best performing input and the other half thought MVR (see Figure 11). They also explained that the input they use daily will be better (see Section 5.3). Figure 15 displays the number of target hits, and proves that the gamers performed better using MVR than with the controller. The majority of the non-gamers thought that MVR would be the most optimal performing input (see Figure 11), and Figure 15 showed that their expectations matched the results.

The high number of target hits indicates that using head gaze — that we humans use on our daily basis — as an input becomes natural, which strengthens the theory by Kovarova and Urbancok (2014). On the contrary, an input method, for example keyboard and mouse, feels natural for people who use this type of input every day, and the same applies for the gamers and their familiarity with using a controller.
When creating games or other interactive applications which involves aiming, VR should not be left out. Most non-gamer participants strongly preferred MVR over the controller (see Figure 10), as it creates a more immersive and fun user experience (see Section 5.3).

### 6.1.2 The Hallway Challenge

The gamers thought the controller was the easiest type of movement interaction, while the non-gamers thought the controller was very difficult to handle (see Figure 6). The time it took to complete the challenge using the controller shows that the non-gamers had some difficulties to reach the goal (see Section 5.3).

Both the gamers and the non-gamers ranked floating markers as the least preferred interaction (see Figure 7). Floating markers use fixed movement and does not allow the player to move freely, but it also allows the user to move in the virtual world while you can look in other directions. This combined causes a lot of cybersickness and could be a potential cause to being the least preferred interaction (see Figure 9 & Section 5.3).

Point and look movement allows for fast navigation in the world compared to the other interactions, as both the gamers and the non-gamers completed the challenge in a very short time span (see Figure 15). As seen in Section 5.3.1, the disadvantage is however that it uses teleportation to move forward which creates a static feel, as well as confusion when teleporting to a new location. To our observations and expertise, the confusions arose mostly because of the teleportation causing the view to instantly change, which led to the participants requiring time to re-adjust themselves to their new position and figuring out what direction they were looking in. Since there are no actual motion in this interaction, the participants did not feel as nauseous as the other MVR movement interactions.

Motion movement was the highest rated movement by both the gamers and the non-gamers. Additionally, the observations showed that the participants were very entertained by it, while it also felt like the fastest movement, even though the movement speed was the same for all the movements (see Section 5). A hypothesis for this could be due to the fact that when moving forward, the users needs to tilt their head down which forces them to see the ground that is close to their eyes. Since the user is moving in the virtual world, while looking down on something moving parallel to their velocity, it creates an illusion of moving faster than looking straight forward.

As seen in Figure 7, the gamers and the non-gamers ranked the different movement types in the same order, however with slightly different scores. Motion movement was the top choice for both most fun and most preferred interaction. What can be analysed from Figure 16, is that the time to complete the challenge is very similar for both the gamers and the non-gamers, giving motion movement an advantage over the other movements. Our hypothesis is that using head gaze, as previously mentioned, is something we do every day and because of this all participants performed similarly. On
the other hand, the controller increased the gap between the gamers and the non-gamers. From this, we can conclude that motion movement is the most preferred and can easily be learned quickly by almost anyone. This can be strengthened by Atienza’s et al. (2016) conclusion; a hand recognition input is more difficult to use compared to head gaze. Again, something we use on our daily basis feels more natural to use. We also do not recommend any automatic movement that imply in the velocity and the head gaze being separated as it caused great amount of nausea (see Section 5.3).

As mentioned by Powell et al. (2016), motion movement should not be implemented using constant speed and making tight turns and unplanned manoeuvres should be avoided. These guidelines work well with this thesis guidelines and does not contradict each other.

6.1.3 The Hammer Challenge

Motion menu was the least preferred MVR menu interaction, while the other MVR interactions shared the first place for the gamers. Both the gamers and the non-gamers got frustrated and confused over the motion menu and had difficulties understanding and interacting with it (see Section 5.3.1). For the non-gamers, timed menu was the most preferred menu interaction (see Figure 8), as they expressed that it was both easy to use and very smooth (see Section 5.3.1).

The gamers thought the controller was going to be the easiest menu interaction to use, and this can be strengthened by looking at the time it took to complete the challenge (see Figure 17). We would like to argue that the controller can be used as a fast and effective menu interaction, if you know how a controller works. Compared to the gamers, the non-gamers struggled with the controller and had to look down at the controller to press the correct button (see Section 5.3). If we exclude the controller interaction and analyse the MVR interactions alone, the timed menu and the circular menu was the easiest to use for gamers (see Figure 6). Circular menu was the fastest MVR interaction compared to the others for both the gamers and the non-gamers (see Figure 17). Select menu was the interaction that both the gamers and the non-gamers took the longest time to complete. We therefore suggest that select menu is the slowest menu due to the nature of requiring two actions from the user rendering it slower compared to its counterparts (see Figure 17).

There was no movement in the hammer challenge, however, a few participants reported that they felt nauseous during the circular menu. Both gamers and non-gamers had different opinions on what they would perform best with (see Figure 13). The participants mentioned before the challenge that they thought the controller would be easier to use since it has buttons. This proved to be correct, if you were a gamer and were familiar with using a controller. After the challenge, both the gamers and the non-gamers were more entertained with the MVR interactions than with the controller interactions (see Section 5.3).
The MVR menu interaction that worked best for both the gamers and the non-gamers was the timed menu, which was the most preferred by non-gamers. Gamers on the other hand thought the timed menu was too slow, however speeding up the timed menu slightly could result in a better user experience for all types of users. Controller works for both types of users as well, however, when making games that require a controller for non-gamers, the developer should keep in mind that they need to look down at the controller more often.

### 6.2 The User Study

From both the observations and the questionnaire, the participants were most receivable to feeling nauseous when moving in the virtual world, or making very fast head movements, for example in the target range.

As described in the introduction section, we hypothesised that the menu with the most steps would take more time to complete but a higher chance for the user to choose the correct menu option. As seen in Figure 8, this holds true to some degree, although the non-gamers did not enjoy it as much as the gamers did.

We also hypothesised that free movement would be more difficult to use, but more preferable. Figure 7 and 16 shows that both free movement interactions were ranked the highest, and were the fastest movement interactions overall. Several participants said that floating markers was annoying because they made you halt between the markers which stopped the flow of the movement. A correlation between these opinions and the high completion time for the floating markers, strengthens the point that free movement was faster.

### 7 Discussion

The weakness of this study is the number of participants in the user study. The recommended number of participants in a summative usability study is 50-100 users (Tullis and Bill 2008). In our case, the approximate amount for each test case was one hour. This would have resulted in 50 to 100 hours of user study, which would require far more time than we had for this research. The user study could have been faster by playing the challenges only one time instead of twice. The downside of this could be that the participants would not understand the interactions, and possibly causing the time to complete each interaction to increase.

The observations of the study showed that point and look movement in the hallway challenge felt very static and confusing for the user. Implementing a fading transition when teleporting could make the user experience better and minimise the amount of confusion. This however, would not fix the static feel of this type of movement.
As Figure 6 shows, the participants did not feel that the motion menu was easy to use, and therefore our design of the motion menu should not be used. One of the issues is that when users tilt their head, the amount of tilting is calculated as if the pivot point is the center of the MVR headset. When humans tilt their head, the pivot point is the neck. This results in some offset, and therefore the user has difficulties interacting using the motion menu. The implementation also has an issue calculating the amount of head tilting while looking at an object, resulting in the user tilting their head and no interaction is triggered. A correct implementation of motion menu could have given a different result.

Some participants reported that they felt nauseous when interacting with the circular menu. The circular menu does not differ very much from the timed menu, except that the options are in a circle and they trigger with a smaller delay. Because of this, the users should not have become more nauseous from the circular menu compared to the other interactions. A deeper analysis of the application was performed, which resulted in the following result and hypothesis. The original problem was that when displaying the spatial circular menu, it was prone to partially clipping through the ground, rendering it impossible to choose that option. To solve this problem, a shader was implemented by ignoring the depth and always drawing it on top of everything else (see Figure 4). The hypothesis is therefore that the shader breaks the perspective rules, resulting with it confusing the participants brain and possibly causing an optical illusion. We would argue that this was a mistake and when making VR games, the developers should never utilise any method that results in an optical illusion without studying the effects of it.

Because every challenge was played twice as stated, this could affect the result in several ways. One possible way could be that the gamers learn game related knowledge more quickly and determining how beginner friendly an interaction is therefore more vague.

### 7.1 Conclusions

This section presents the summarised concluded answers to the research questions stated in Section 1.3, and analysed in Section 6.

The first research question to be answered was the following. “How does the interactions differ between using MVR compared to a traditional controller?” The observations and the automatically collected data from the user study show that traditional controller is more sensitive to receive input but has a faster response time, while head gaze in MVR is used more successfully in bigger and more accurate motions.

The second research question is, “What is the difference between gamers and non-gamers when it comes to preferred interactions for both MVR and traditional controller?”. By concluding the results from the user study, non-gamers generally preferred MVR interactions, and had difficulties controlling a traditional controller. Notably, gamers preferred both controller and MVR, without discarding the other. There was only a small difference in the performance speed between gamers and non-gamers.
with MVR interactions, however, gamers performed faster than non-gamers when using a controller.

The last research question that this thesis questioned was, “Which guidelines can be used for game designers to better understand MVR input and interactions to improve the end user experience?”. The analysed data that was collected during the user study strengthens that MVR interactions can be used for both gamers and non-gamers, compared to the controller interactions that is more suitable for gamers. Designing movement interactions in MVR is shown to be more preferable using motion with the help of head gaze. Menus that uses buttons with a trigger delay was more preferable than using motion gestures or a two-step menu.

7.2 Suggestions for Further Research

Two of the non-gamers were men aged over 50, both became remarkably nauseous and one had to quit the test. The nausea appeared when they finished the hallway challenge, and they were not the only ones that became nauseous during this challenge. However, they felt more nauseated than the other participants. An aspect for future research in this field is how people in different ages and genders correspond to nausea in MVR and VR in general, which is important to understand in order to be able to maximise the target audience for a game.

In this thesis, an application review was produced, which resulted in three different types of movement interactions. However, each of these interactions had a lot of variety. An example of this is the motion movement in Need for Jump and BattleZ VR, where it varies on which type of motion the user needs to execute in order to move in desired direction. A more in-depth research on which types of interactions are the most optimal for movement, and what causes the least amount of nausea for the user should be a priority for future research.

While the isolated interactions in the test environment application for the user study helped obtain a better understanding of the core functions, in practice games are a compound of different mechanics and interactions. An aspect for future research in a related field could be to test the presented guidelines in an integration test, as well as to investigate how they would perform together.
References


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