Motion sickness in a virtual reality cycling simulation

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Abstract

Children with DCD have a backlog in the development of their motor skills and coordination and have trouble learning important, everyday skills, such as riding a bicycle, as a result. The Roessingh Center of Rehabilitation in Enschede (Netherlands) provides these children with extra help to acquire these skills. But the step from therapy in a safe practice environment to practicing in traffic was deemed too large by the therapists at the Roessingh. A virtual reality cycling simulation was developed to bridge this gap, providing a realistic yet safe practice environment. However, this simulation induces motion sickness, a phenomenon where the subject feels a number of symptoms, including nausea, disorientation, headaches and dizziness. This report describes the process of reducing this effect from this simulation. This process started with consulting scientific literature. A number of potential solutions (changeable aspects of this simulation that have shown to decrease the severity of VR induced motion sickness in different simulations) were deducted from this literature and implemented in the cycling simulation. They were then tested over the course of 2 experiments. First, a small pilot test (N = 7) to collect qualitative data on the potential solutions from participants who are experienced with virtual reality. Secondly, a larger experiment (N = 27) with the goal to collect both quantitative and qualitative data, which was used to determine which potential solution(s) actually prove effective in decreasing the severity of VR induced motion sickness. Over the course of this project, a total number of 13 solutions was narrowed down to 2 solutions for the second experiment. Of these solutions, only one proved consistently effective in reducing VR induced motion sickness, which was to point a fan at the user. However, as will become clear in the report, determining the effectiveness of a solution is a somewhat subjective matter and should be regarded as such. Therefore, the decision as to which solution(s) will remain permanently implemented into the simulation will be left to the therapists at the Roessingh.

Abbreviations

All abbreviations used will also be explained explicitly the first time they are mentioned in the text.

VR	Virtual Reality
AR	Augmented Reality
DCD	Developmental Coordination Disorder
RRD	Roessingh Research and Development
VE	Virtual Environment
VRE	Virtual Reality Environment
SSQ	Simulator Sickness Questionnaire
SS	Simulator Sickness
FOV	Field Of View
HMD	Head Mounted Display
EEG	Electroencephalography
HUD	Heads Up Display
MSQ	Motion Sickness Questionnaire
MSAQ	Motion Sickness Assessment Questionnaire
VRSQ	Virtual Reality Sickness Questionnaire
MSSQ	Motion Sickness Susceptibility Questionnaire

Table 1: The abbreviations used in this report and their meaning

Keywords

Virtual Reality, Virtual environments, Vection, Developmental Coordination Disorder, Cybersickness, Simulator sickness, Motion sickness, Simulation, Blurring, Vignetting, Waypoints, Fan

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Introduction

Introduction

Virtual Reality, or VR for short, has been an upcoming technology for some years now. VR makes use of a so called head mounted display (HMD), which is worn as goggles. These HMDs allow the user to be placed in a virtual environment where the user can look around. VR is often in combination with audio as well, for an even more immersive experience. To illustrate the massive growth of this technology; the global market size has doubled between 2016 ($1.8 billion) and 2018 ($3.6 billion) and is expected to more than three times this size in 2019 ($6.2 billion) [1]. This enormous increase can also be seen with AR (Augmented Reality, similar to VR, but maintains real world elements in the virtual environment) technology, but the focus of this report is on solely VR. This is because we are currently limited to a specific headset, which does not support AR. Originally VR systems were used for simulators, but it has also gained popularity within the education, health, military, space, and entertainment (especially gaming) and it is believed to have potential in many other fields. Affordable VR systems like the HTC Vive and the Oculus Rift have made VR technology available for private use.

However, many people experience motion sickness in VR. Motion sickness is a well-known phenomenon. It often occurs on long car rides, or in rollercoasters. Motion sickness can also be induced by virtual reality. In this case it is called 'Simulator Sickness', 'Cyber Sickness', 'virtual environment sickness' or 'VR induced motion sickness'. These terms are often used interchangeably but all refer to the same phenomenon (although some disagreement on this subject exists [2]). For convenience, we will stick to the term 'VR induced motion sickness' in this report and when talking about non-VR induced motion sickness it will be expressed explicitly.

The exact cause of (VR induced) motion sickness is still unknown; however, a lot of research has been done on this topic and some leading, generally accepted theories exist. This report will cover some important ones but will focus on the 2 leading theories; Sensory mismatch theory and Postural instability theory. Section "Ideation: The cause of VR induced motion sickness" will cover a more in-depth analysis of these and other current theories of (VR induced) motion sickness.

At Roessingh center of rehabilitation children with Developmental Coordination Disorder (DCD) can learn how to ride a bicycle. However, the step from just cycling to actually participating in traffic was deemed too large by the researchers of the Roessingh. Therefore, a VR cycling simulator was developed there with the purpose to familiarize the children with DCD with other traffic. However, this simulation can induce great amounts of motion sickness for the users, and my task will be to reduce this. For this I will need to answer the question 'How can we reduce the amount of motion sickness experienced in this cycling simulation?'. Which will be done in the "Ideation" section. But first, more information is needed about this phenomenon. Therefore, the objective of the first section of this report is to gain insight into the causes of motion sickness, as well as the prevention of- and remedies against motion sickness, focusing on motion sickness caused by VR experiences, with the eventual goal of reducing the amount of motion sickness caused by the VR cycling simulator at the Roessingh Research and Development Center (RRD). This research will be part of a project in association with University of Twente, TwinSense and Roessingh Research and Development.

In the first section of this report will be the ideation, in which all the background knowledge required to understand the rest of this report will be presented. Firstly, the exact definition of motion sickness will be defined, as well as particularly susceptible demographics and common symptoms.

After that theories about the possible causes of motion sickness are discussed. The next section will be devoted to the prevention of (VR induced) motion sickness. After that possible cures for motion sickness are discussed and lastly the challenge of measuring the severity of motion sickness is addressed.

The second section is the specification. This section shows the process of specifying and filtering the results of the “ideation” section. Note that some choices regarding specification of the solutions are discussed outside of this section also, since they were made at a different point in time. This section will primarily revolve around excluding solutions from the realization and/or testing phase.

The third section is about the realization of the solutions. This section explains how each solution is implemented in this project, which design choices are made and why and which problems were encountered. At the end of this section the simulation will be complete, with all the solutions implemented.

The fourth section is called “evaluation”. This section discusses the testing of- and feedback on the previously implanted solutions. This section will decide which of the still remaining solutions will remain in the simulation.

Plan of action

This section will describe the plan of action used during this project. This will be a basic description of which tasks were done in which order during the entire course of the project. The project started at 03-01-2019 and ended at 06-07-2019. This is roughly 26 weeks. However, the first half of this available time was also used for other projects, so I could not work on this project full time. The basic approach to this project consisted of 5 steps: 1) Consult scientific literature, 2) Deduct potential solutions, 3) Implementation, 4) Experimentation, and 5) Analysis, evaluation and filtering. These 5 steps are discussed more elaborately below. Note that these steps may not always follow in this perfect order, may overlap and may be repeated to some extent.

Consult scientific literature

The first thing that should be done for any project is gaining sufficient background knowledge. This process took about 2 months. The “Ideation” section of this report covers this step in the process. Many different types of literature were consulted (not all scientific) with the goal to gain sufficient, objective and broad knowledge about the many different aspects of (VR induced) motion sickness. This section would provide a number of things: 1) A proper definition for (VR induced) motion sickness, 2) Insight into different theories about the cause of (VR induced) motion sickness, 3) Potential solutions against VR induced motion sickness, and 3) An objective method of measuring VR induced motion sickness to verify these potential solutions.

Since both the definition and the method of measuring VR induced motion sickness were determined quite quick, and the cause of motion sickness is interesting but unknown, the main focus of this phase was to collect as many potential solutions as possible. For this I mainly looked for scientific experiments that measured the effect that changing a specific aspect of a simulation would have on the severity of the motion sickness induced by this simulation. I also looked at scientifically unproven solutions however, which may still be included if I believed they had potential. The “Ideation” section of this report gives a more in-depth analysis of the abovementioned subjects.

Deduct potential solutions

From the abovementioned scientific literature, I deducted potential solutions. These solutions have shown to decrease motion sickness in different simulations or are based on principles that are known to decrease motion sickness. Exceptions can be made for potential solutions that I personally believe have great potential. The “Specification: Deciding what to implement” section of this report discusses the process of deducting potential solutions and identifying the solutions with the highest potential more elaborately. The solutions will be sorted on a combination of 2 factors. Factor 1 is my estimation of their potential to reduce motion sickness and factor 2 is my estimation of how much time, money and effort each solution would need to be implemented. The highest ranking solutions will then be implemented and tested.

Implementation

The next step will be to implement these solutions. The general requirements of a solution are discussed in section “Specification: Defining requirements”, and the process of implementation is discussed in the “Realization” section.

Experimentation

Once implemented, the potential solutions will be tested. Depending on the amount of solutions, this may be during multiple, separate experiments. If there are a lot of solutions that need to be tested, a pilot test might be conducted first in order to filter the solutions a little. The goal is however, to do a large-scale experiment (goal: N = 30) that would allow for statistical analysis. This process is described in the “Evaluation” section.

Analysis, evaluation and filtering

Once an experiment has been conducted, the results are analyzed. These results may be qualitative or quantitative or a combination of the 2. A pilot test would focus more on qualitative data whilst the goal of a large-scale experiment would be the analysis of quantitative data.

These results will give an indication about which solutions were effective in preventing / reducing VR induced motion sickness. If a solution receives positive feedback it can remain implemented for further testing or usage by the Roessingh. If a solution receives (significant) negative feedback it will be filtered out. The “Evaluation” section discusses this entire process elaborately.

Ideation

Defining VR induced motion sickness and its symptoms

Clearly defining motion sickness within the context of this project proves difficult. VR induced motion sickness may differ from non-VR induced motion sickness in some aspects. Different names are used for the same condition; Cyber sickness, simulator sickness, virtual environment sickness or VR induced motion sickness. Generally, these terms are treated as synonyms even though they may differ in detail. For example, VR induced motion sickness must be induced in a virtual environment (VR or AR), but simulator sickness may occur in a different type of simulation [2], for example using projections. It is also unsure whether motion sickness and VR induced motion sickness originate from the same principles. Theories concerning the origin of (VR induced) motion sickness differ and will be discussed in the next section.

Unlike the cause of VR induced motion sickness, there is a general agreement about the definition of VR induced motion sickness. McCauley and Sharkey [3] define VR induced motion sickness as a collection of symptoms which is akin to classical motion sickness, without the presence of physical motion. This definition of VR induced motion sickness will also be used in this report. Rebenitsch and Owen [4] confirm this definition, describing VR induced motion sickness as an illness that is very similar to motion sickness, without the presence of physical motion (note that both of the definitions above were given for cybersickness, but this was translated to VR induced motion sickness for the sake of consistency in this report). Kaufmann et al. [5] also confirms this definition but bases it solely on sensory conflict theory, saying "Simulator sickness has been identified as a special form of motion sickness that does not rely on body movement but on vection, the effect that causes a person to feel self-motion when a large area of the visual field moves". The symptoms of VR induced motion sickness are comparable to the symptoms of motion sickness and include nausea, disorientation, headaches, and dizziness [4]. However, as will be stressed later in this section, the symptoms of (VR induced) motion sickness are highly personal, and many other different symptoms may occur. Nevertheless, the symptoms mentioned above are the most common.

VR induced motion sickness has a wide range of symptoms, some of which are quite uncommon. To illustrate the wide range of symptoms, the SSQ (Simulator Sickness Questionnaire) [6], as discussed in the International Journal of Aviation Psychology [7], lists the following symptoms: general discomfort, fatigue, headache, eyestrain, difficulty in focusing, salivation increase, sweating, nausea, difficulty in concentrating, fullness of head, blurred vision, dizziness (with eyes open and closed), vertigo, stomach awareness or burping [6] [7] [8]. Which symptoms occur and the severity and duration of these symptoms is highly personal and difficult to predict. The most important thing to note here is that the susceptibility to (VR induced) motion sickness is very personal, as are the symptoms experienced [3].

(VR induced) Motion sickness is not a disease and is not contagious [9]. In theory (VR induced) motion sickness could occur with anyone, but claims are that, at least for non-VR induced motion sickness, young children (age 2-12), pregnant/menstruating women, women on hormone therapy or people who get migraines (especially when they have one) are particularly susceptible [9]. However, R. Bulthuis from the RRD have said that in their personal experience it are the children who experience less motion sickness than the adults with this simulation. This may be due to the fact that non-VR induced- and VR induced motion sickness may not be the same phenomenon, or at least do not result in the exact same symptoms as each other, depending on which theory about the causes of motion sickness followed. Regardless, the target demographic for this project is fixed, and can not be changed anymore.

The cause of VR induced motion sickness

The exact cause of VR induced motion sickness is still unknown. The exact cause is hard to define due to high personal differences, learning effects, a large number of variables, parameters and devices and a large amount of possible causes. Nevertheless, this exact topic has been a popular topic for research for the past decade. Multiple theories currently exist, but two distinguish themselves in popularity; Sensory conflict theory and Postural sway theory. These two, amongst some other theories will be discussed in this section. This project does not attempt to find the exact cause of VR induced motion sickness however, this section is mainly meant to provide insight into different theories.

The first theory to be discussed is also the most supported one; Sensory conflict theory [10]. Sensory conflict theory states that VR induced motion sickness is caused by a phenomenon called vection. As stated by Tiiro [11] “Vection is an illusion of self-motion where the user is getting visual feedback that makes the user feel motion even when they are not physically moving” (p. 15). Sensory conflict theory states that motion sickness is caused by a mismatch between the visual- and inertial perception. Symptoms of VR induced motion sickness are expected if there is sufficient illusion of self-movement (vection) [8]. Take driving around in a car (as a passenger) for example: To your eyes the car seems to be standing still but your body feels the car accelerating and decelerating. Your brain receives mixed messages about whether or not you’re moving, and motion sickness occurs. In virtual reality this would be the exact other way around: Your eyes perceive motion via the VR goggles, but your body does not experience this motion. Whether the effect is the same however, is still unsure. The symptoms experienced with VR induced motion sickness and non-VR induced motion sickness are similar but may differ in some aspects regarding severity and the occurrence of more rare and specific symptoms (e.g. cold sweats).

A second widely supported theory is the postural sway or postural instability theory. The postural sway or instability theory of motion sickness [12] states that (VR induced) motion sickness is preceded by instability of the bodily orientation [13]. This theory states that humans suffer from motion sickness in an unfamiliar environment that forces them to find new ways of controlling their posture and stability, in a similar fashion as how animals get sick in environments where they cannot control their balance. As an example, people who have spent great amounts of time on boats don’t get seasick anymore, since they have learned to maintain their posture. People who are new on a boat haven’t acquired this skill yet and therefore get seasick. The postural instability theory claims that instability of the bodily orientation is both required and sufficient for the occurrence of motion sickness, and that this instability is caused by the unfamiliarity of a virtual environment. Being more familiar with an environment would thus reduce motion sickness. Postural instability theory cannot explain why the symptoms of (VR induced) motion sickness are the way they are and doesn’t attempt to do so [13]. This theory, however, has the advantage that it can predict motion sickness before symptoms occur [13].

A third theory is called rest frame theory. Rest frame theory states that motion sickness occurs when people lack a steady frame of reference [14]. This theory also intertwines with postural sway theory in the sense that both agree that motion sickness is caused by a difference between the orientation in a virtual environment and in the real world. In a virtual environment someone may think a certain direction is upwards based on the visual input, while it actually differs from what the real world upward direction is. Rest frame theory is applied differently in different experiments on VR induced motion sickness. It is claimed that having a steady horizon, some horizontal and vertical lines over the screen that do not move, or adding a virtual nose reduces the symptoms of motion sickness [4] [14].

Another theory is the Eye Movement Theory, which states that motion sickness is (partially) caused by rapid movements of the eye. Rebenitsch and Owen [4] claim that fatigue is one of the components of motion sickness. They claim that in a virtual environment the eyes are forced to make more rapid movements, thus tiring the muscles around the eyes. Overstimulation of the muscles around the eyes as a result of exposure to a virtual environment can cause fatigue of the eye muscles and headache, both symptoms of VR induced motion sickness [4] [7] [13]. Menshikova et al. [15] also showed that rapid eye movements and VR induced motion sickness often occur simultaneously.

Other factors that are often mentioned when discussing VR induced motion sickness are duration, lag, latency and resolution. These are too small and specific aspects to be the sole cause of VR induced motion sickness but could be contributing factors to its occurrence.

Duration in this case means exposure time; the time spend in a virtual environment without any pauses. It makes sense that longer exposure to a motion sickness inducing environment increases the amount of sickness experienced. Many stores or providers (E. G. vrwebwinkel [16]) already advice to limit the exposure time to a maximum of 10 minutes.

Lag mainly concerns the frame rate at which a simulation is running. Claims are that a low or inconsistent frame rate is (one of the) causes of VR induced motion sickness [17]. Rebenitsch and Owen [4] consider lag as an influencing factor on VR induced motion sickness.

Latency differs from lag in the sense that it does not concern frame rate but rather frame timing. With every motion the current orientation needs to be recorded, processed and the environment needs to be rendered again. This process takes up time and that causes a latency or delay within the goggles; the environment moves a little later than you do.

Resolution consists of two parts in this case. The first part claims that a low resolution, as a consequence of a poor or badly adjusted HMD, can cause motion sickness [18]. Although some argue that this correlation is due to other factors that have since changed, as most statistical evidence originates from comparing older and newer headsets [4]. A 2017 Kickstarter is already announced called the Pimax 8K with 3840x2160 resolution for both eyes [11]. This should provide insight into whether or not resolution is a influencing factor into the occurrence of VR induced motion sickness. The second element concerns style. Research has shown that highly realistic environments cause more motion sickness than less realistic, low-poly environments [4] [2]. This is also in accordance to the sensory conflict theory, as more visual input will cause a higher mismatch between the senses.

This leads to believe that improvements in technology, meaning higher and more consistent framerates, lower latency and higher resolution will decrease the symptoms of VR induced motion sickness. However, Duh et al. [19] opposes to this that, following the sensory conflict theory, this could potentially stimulate VR induced motion sickness. The logic behind this being that more visual input will result in a higher mismatch between the visual and internal perception. In their paper Rebenitsch and Owen [4] confirm this hypostasis, referring to an article by Stanney and Kennedy [2]. They do however mention that this may also be caused by the change in demographic from primarily military to the general public.

To conclude this section, it is important to remember that it is very likely that the exact cause of motion sickness is a combination of the factors mentioned above and can be different for everyone due to personal factors such as age, sex and experience, and other factors such as amount of sleep, the time of the day or which hardware is used.

Preventing VR induced motion sickness

Due to the uncertainty regarding the exact cause of VR induced motion sickness, preventing it is difficult. Preventing VR induced motion sickness is the goal most researchers of this subject hope to achieve. This goal is far from achieved, however. In their paper Duh et al. [19] refer to LaVoila Jr. [20], saying “Procedures to alleviate SS (Simulator Sickness) / VE (Virtual Environment) sickness have been of limited value”. Nevertheless, some solutions have been found that have shown to reduce the symptoms of VR induced motion sickness. These can be changes in the setup, hardware, code or preparations that can be done beforehand. The logic behind most of these solutions will be removing or reducing the possible causes of VR induced motion sickness mentioned in the previous section. In this project I’ will attempt to do the same thing, as well as implementing existing solutions that have shown to work. No conclusion about the cause of VR induced motion sickness will be drawn for this purpose, meaning that solutions based on more than one theory will be used.

The first solution to be discussed will be to add a frame of reference. Frame of reference, a very popular method employed to help with motion sickness, means to add a visual frame of reference (a rest frame) to the image. It helps to reduce the sensory conflict between visual and vestibular sensations [18]. In this case this may be adding a horizon, rest frame or virtual nose. Doing so has shown to reduce the intensity of the symptoms experienced [21] [18]. Whether a steady horizon, a grid of 2 horizontal and 2 vertical lines, or a virtual nose has the most effect is still unknown.

Besides the lack of a frame of reference, factors that are often blamed for causing VR induced motion sickness are lag, latency and resolution. Lag, in this case, refers to changes in framerate, often resulting in a low, or inconsistent framerate. It is advised to use a high and consistent framerate, with an absolute minimum of 60Hz and an advised minimum of 90Hz [22]. Lag is often caused by bad internet connection or overloaded servers. Our simulation does not make use of an internet connection, so lag cannot occur due to these reasons. One way lag could occur is if the computer that runs this simulation has to do more calculations that it is able to in a given amount of time. The best way to prevent this is, first off, closing all other programs, allowing the computer to focus solely on this simulation, but also to optimize the simulation to work effectively.

Latency differs from lag in the sense that, where lag is an inconsistent phenomenon, latency always occurs and can never be fully removed. Latency is a small delay between the input via the sensors of the HMD and the output via the screen. We are limited by the currently available technology, and setups (including the setup of this project) are often limited to a budget. The setup currently uses an HTC Vive set. The HTC Vive has a latency of 22ms, but it also depends on the computer on which a program is ran, and the program itself. The component most likely to be a bottleneck for this process is the graphics card. A better graphics card will result in a lower latency. The same thing holds for the amount of data processed. Less data means faster processing. Optimizing the simulation can decrease latency. This could also be a contributing factor as to why highly realistic and detailed scenes induce more motion sickness relative to less realistic scenes [2] [4] [11], since more detailed scenes require more processing time. Since optimizing games in Unity is a very broad subject no fixed solution exists and I cannot make any conclusions about the optimization of this game. Some of the adjustments that will be made on this simulation also focus on usability rather than optimizing the performance of the simulation.

Although the latency issue will never be resolved entirely, latency will be reduced with future improvements on the technology. There is no promise as to what technology will be available and used in the future. Some future improvements of both hardware and software by HTC and other VR and AR producing companies promise improvements concerning the decrease of both latency and lag. As for now, the entire environment is rendered every frame. Future software will only render the FOV (Field Of View) currently looked at by the user. This would theoretically save major amounts of processing time and thus reduce the overall latency of the headset.

Resolution is another unsolvable problem. The HTC Vive makes use of an OLED screen with a resolution of 1080 * 1200 per eye, which is quite high for the current standards, although the difference between devices is relatively small. Although I cannot change this resolution, the style factor however I can influence. As mentioned in the previous section a highly realistic style causes relatively more motion sickness than a less realistic style [11]. Remodeling the scene is out of the scope of my project, but others will work on that exact subject in the near future, so they could be given advice on the effect of the scene on motion sickness.

Another solution is to reduce VR induced motion sickness is decreasing the overall exposure time. Extended duration of exposure to a VE results in a greater severity of the symptoms [14] [23] [24]. Insufficient research has been done to determine the ideal exposure time, but as a rule of thumb it is advised to limit exposure time to a maximum of 10 minutes, as the chance of developing motion sickness increases exponentially with each 10 minutes [16]. It is possible, and not uncommon, to remain in a VRE (Virtual Reality Environment) for longer than 10 minutes, but this is unadvised for highly susceptible people. However, the simulation worked on in this project has an average completion time of 4-6 minutes, which falls within these standards already.

One very important aspect of VR motion sickness that is directly correlated to the resistance to the development of motion sickness is the learning effect. The learning effect is the phenomenon where people who've been repeatedly exposed to VRE's tend to have a lower susceptibility to VR induced motion sickness. Duh et al. [19] mentioned a research from Kennedy and Fowlkes [25] that showed that symptoms of VR induced motion sickness decreased with repeated exposures to the virtual environment. Heutink et al. [14] saw the same effect when measuring the differences between the severity of the symptoms of VR induced motion sickness during the first and second testing session of their advanced mobility scooter driving simulator. This effect does not limit itself to just repeated exposure to a VE. To illustrate, McCauley et al. [3] also mention that pilots tend to be less susceptible to motion sickness than the general population. This effect may also backfire, where people experience a greater severity of VR induced motion sickness due to association between previously experienced symptoms and virtual reality, therefore it is advised to remove the HMD as soon as symptoms of VR induced motion sickness arise [22].

Another thing that has shown to decrease the severity of VR induced motion sickness is limiting the field of view. Limiting the FOV has shown to decrease the symptoms of VR induced motion sickness [14]. Rebenitsch and Owen [4] found that a smaller FOV resulted in a reduced severity of the SSQ symptoms as opposed to a larger one. A different study by Norouzi et al. [26] yielded similar results using vignetting (the act of increasingly reducing an image's brightness toward the edges). Yet another study by Budhiraja et al. [27] also found similar results using the blurring of edges and the blurring of motion. Which of the abovementioned techniques has the best result cannot be concluded at this point, but the overall formula seems to be that reducing the peripheral vision will reduce the amount of VR induced motion sickness experienced, which fits nicely within the sensory conflict theory, since less visual input will result in a smaller mismatch between the body and eyes.

Lastly, Rebenitsch and Owen [4] also found that preserving an element from the real world in a VE reduces the VR induced motion sickness symptoms. This would also suggest that symptoms in an augmented reality environment will be less severe relative to a virtual reality environment [28]. However, the HMD used in this project, an HTC Vive, does not support augmented reality, so a switch to augmented reality is impossible. Nevertheless, this find fits nicely with sensory conflict theory, preserving an element from the real world will result in a smaller sensory mismatch, since the eyes recognize a small element in the same environment the body is currently sensing. Similar solutions exist that follow this pattern, either reducing the visual input or increasing the body's internal sense of motion. Examples of decreasing visual input are scenes with less detail/ realism [11], or working with a smaller FOV [4] [26] [27]. An example of increasing the feeling of motion on the body is to point a fan at a person in a VE, giving the illusion that this person is moving forwards in real life. Another application of this principle can be seen in a bicycle simulator that showed a decrease in motion sickness when making use of waypoints, which enable the body to predict motion [18].

For this project, I've created a list with adjustments that will potentially reduce or delay the amount of VR induced motion sickness experienced (see Table 2). Most of the potential solutions mentioned below have been tested and yielded positive results. However, they may follow different theories; some may be based on sensory conflict theory whilst others are based on postural sway theory. I will not try to follow one specific theory for this project, but instead stick to the solutions I deem promising. Some of these may not be scientifically proved yet, but seem promising nevertheless. Take pointing a fan at the user for example, this has not yet been scientifically proven to help decrease VR induced motion sickness, but does leave the user with a link to the real world, increase the sensory input to the body of the user to stimulate the illusion of movement, provide the user with fresh air, and is cheap and easy to test. More non scientifically proven tips and tricks are listed at the end of this section.

Each solution has a solution field, which states which principle this specific solution follows, a method field, which states the method with which this principle is put into practice, and a rationale field, which includes further explanation, predictions and advice for other researchers in this (or similar) project(s).

This list can be seen as a part of the result of the Ideation phase of this product. These solutions will be ranked and potentially implemented and tested.

Solution:	Reducing sensory conflict: Reducing the visual input
Methods:	Lowering realism of scene
Rationale:	This is actually not something I'll actively try to change, as it is not my expertise and there are currently plans to remodel the scene entirely. I'll advise the people doing this however, to stick to a less realistic, low-poly scene rather than a highly detailed realistic scene. The 2 reasons behind this is that less realistic scenes induce less motion sickness [11], and less realistic scenes require less processing power, which allows for a faster framerate.

Solution:	Reducing sensory conflict: Reducing the visual input
Methods:	Smaller FOV - Smaller FOV - Blurring the sides of the FOV - Vignetting the sides of the FOV
Rationale:	All of the techniques mentioned above essentially do the same thing using different methods; they reduce the visual input in the peripheral vision. Each of them has shown to reduce the symptoms of VR induced motion sickness [27] [26], but which one, or which combination will be used is still unsure.

Solution:	Reducing sensory conflict: Reducing the visual input
Methods:	Motion blur
Rationale:	Motion blur means blurring the view if (parts of) the scene moves relatively fast relative to the user. High speed translations through a scene can induce motion sickness and reducing the visual input may help reduce the symptoms [27].

Solution:	Reducing sensory conflict: Increasing bodily input
Methods:	Pointing a fan at the user
Rationale:	Pointing a fan at the user will not only provide this user with fresh air, it is also a link to the real world. Maintaining a link to the real world helps reducing VR induced motion sickness [4]. The feeling of air on the body will also induce a feeling of movement. This feeling reduces the mismatch between input from the body and visual input, as the body now also experiences (the illusion of) motion, to some extent.

Solution:	Reducing sensory conflict: Increasing bodily input
Methods:	Making the bike move
Rationale:	Researchers at the RRD found that, especially adults, lean in with the bike when going through a curve. If the bike remains stationary this induces a feeling of falling, and panic. Therefore, it would theoretically be beneficial if the bike could move a little bit. However, this might affect the motion sickness induced when cycling straight also. Testing is required to see the full range of effects this adjustment will have.

Solution:	Reducing sensory conflict: Increasing bodily input
Methods:	Making use of waypoints
Rationale:	Waypoints have shown to reduce VR induced motion sickness in another cycling simulation [18]. The current theory behind this is that the waypoints give the user the ability to predict their movements, and therefore the body is “less surprised” to feel motion, resulting in a smaller sensory mismatch.

Solution:	More realistic movement
Methods:	Continuous acceleration
Rationale:	As for now the speed of the bike is either 0 or a fixed amount set beforehand. However, the sensor used in the wheel to measure the input can measure the speed continuously, meaning we could directly use this speed in the simulation. This will not only be more realistic, but also put the user in a position of control, where the actions of the user result in a direct and intuitive effect in the simulation. This position of control has shown to delay the occurrence of non-VR induced motion sickness.

Solution:	More realistic movement
Methods:	Continuous deceleration
Rationale:	When the sensor measures a drop in the speed with which the physical wheel rotates, it sets the speed of the virtual bike to 0, meaning that the user can brake instantly. This is of course not realistic and should therefore be changed to a bike that has a certain braking distance depending on its original speed.

Solution:	Removing performance / hardware issues
Methods:	Optimization of game and scene
Rationale:	Although this game seems to be quite optimized on the first sight, if time allows it, I’ll do some performance tests and see if I can make the game run more efficient. This would reduce both lag (its occurrence, duration and severity) and latency.

Solution:	Removing performance / hardware issues
Methods:	Ensuring a high resolution
Rationale:	A higher resolution will not be achieved during this project. We will continue using the same HMD, which is an HTC Vive. The reasons for this are that this change is of low priority, since the resolution already is relatively high, but also that switching to a different HMD will cost a significant amount of money, which could be used for a better purpose.

Solution:	Rest frame theory: Adding a rest frame
Methods:	Adding a rest frame - Virtual nose - Grid of horizontal and vertical lines - Steady horizon
Rationale:	Adding a rest frame, or a steady, non-moving object, has shown to decrease the symptoms of VR induced motion sickness. Each of the proposed methods mentioned above is a potential way to add a rest frame. Which one, or which combination will be used is still unsure and requires further testing.

Solution:	Using the learning effect
Methods:	Have the user practice
Rationale:	More practice/ experience in VR is correlated with the resistance to VR induced motion sickness. If the user has had more experience with VR, specifically with this simulation, this user should become more resistant to VR induced motion sickness. However, this is a choice that the therapists at the RRD have to make. Nevertheless, I will advise them on this subject.

Solution:	Using the learning effect
Methods:	Stop the simulation when VR induced motion sickness occurs
Rationale:	It is important that the users do not associate their motion sickness with the VR headset. If motion sickness occurs the simulation should stop, and the user should be given time to recover. This is also important for a feeling of control for the user. Feeling in control about their current situation is not only ethically correct, it might also delay or reduce VR induced motion sickness.

Table 2: The list of solutions deducted from the paragraph above

Although not scientifically researched, a lot of tips and tricks to prevent or cure (VR induced) motion sickness can be found online. Some of these tips have potential or have worked for people personally but haven't been tested and will therefore be included in this section. Most of these tips originate from VR companies (HTC and Oculus), sellers (Coolblue, VRwebwinkel and Mediamarkt), blogposts, health forums and articles in newspapers and magazines. The sources from which each tip originate are listed below. According to these sources time (1), relaxation (1, 5, 7), fresh air and deep breaths (1, 5, 7), distraction such as music (2), closing your eyes (1, 2), drinking water whilst avoiding caffeine and alcohol (1, 2, 5, 7), laying down (5, 7), eating in small amounts (1, 5, 7), placing yourself in a position of control (2, 3, 5), pointing a fan at yourself (4), looking in the distance/ at a stable object (1, 3, 5), using a HMD with correct specifications (6, 7), eating ginger beforehand (4), wrist pressure bands (4, 5), or even the use of marijuana (4) will help prevent or cure motion sickness. Whether these tricks will work has (in some cases) not been proven and will most likely highly depend on the person in question. Also note that some of the above-mentioned tricks are based on non-VR induced motion sickness, which is, depending on which theory you follow, not the same as VR induced motion sickness. Although not scientifically proven, some of these solutions may be used in the cycling simulation project for the RRD.

1. https://www.webmd.com/cold-and-flu/ear-infection/motion-sickness#2
2. https://www.webmd.com/first-aid/how-to-beat-motion-sickness#1
3. https://medlineplus.gov/motionsickness.html
4. https://uploadvr.com/7-ways-overcome-vr-motion-sickness/
5. https://familydoctor.org/condition/motion-sickness/?adfree=true
6. https://www.coolblue.nl/advies/motion-sickness-vr.html
7. https://vrwebwinkel.nl/wat-kan-ik-doen-tegen-motion-sickness-in-vr/

Measuring VR induced motion sickness

A quantitative analysis of the symptoms of VR induced motion sickness is difficult due to a number of factors. “The measurement of motion sickness is challenging because (1) there are a variety of symptoms, (2) symptomatology is internal, non-observable and subjective, (3) there are large individual differences in both symptom profiles and general susceptibility, and (4) the constellation of symptoms develops over time periods ranging from a few minutes to several hours” [3] (p. 311). Motion sickness also often goes unrecognized, and fatigue or boredom are blamed for the symptoms instead [24]. Add to this that different experiments use different measuring techniques, ranging from questionnaires to EEGs (Electroencephalography). Different experiments also use different VR experiences, for example one experiment may use a VR game, whilst another uses a VR rollercoaster simulator. As stated by Stoffregen et al. [13] (p. 322); “commercial (console) video games tend to have greater realism, faster update rates, and more content-related decisions and interactions; these and other factors may influence the incidence and severity of motion sickness.” Lastly, many experiments use different, although comparable, HMDs and software, which may not have a big influence on the experiment itself but makes it more difficult to compare different experiments with one another.

That being said, tools to accurately measure the severity of a number of symptoms of VR induced motion sickness do exist. The most commonly used is the SSQ [6] [29]. This questionnaire lets users rate 16 distinct symptoms of simulator sickness on a 4-point scale (None, Slight, Moderate or Severe). Although questionnaires are the most common method of measuring VR induced motion sickness [30], there are some who criticize this method. Ramsey [31] (p. 6) claims that “this method prompts subjects to introspect on their internal state in situations in which they would normally not, that they may not adequately understand the meaning of the responses in questionnaires, and that some subjects may wish to avoid reporting feeling any symptoms”. Nevertheless, this specific questionnaire has become a standard in the measuring of VR induced motion sickness. Some researches use different methods, such as EEG. Although these measurements provide great insight, due to time- and budget restrictions, or other factors such as the number of participants, most researchers use questionnaires.

The SSQ is derived from a different questionnaire named the motion sickness questionnaire (MSQ). The MSQ originally had 28 symptoms, but 12 were removed because they occurred to infrequently (e.g. vomiting) or because they might give misleading indications (e.g. boredom) [7]. The SSQ divides the remaining 16 symptoms in 3 distinct categories: Nausea, Oculomotor and Disorientation [7] [29] [32]. Each category has 7 symptoms related to it and a certain symptom may relate to multiple categories. A weighted score can be calculated for each category, and a total score can be calculated from these 3 scored [7] [5] [29]. The higher the score, the more (VR induced) motion sickness experienced.

Different questionnaires to assess the (subjective) severity of motion sickness, cyber sickness and simulator sickness. Examples are the Motion Sickness Assessment Questionnaire (MSAQ) [33], the Virtual Reality Sickness Questionnaire (VRSQ) [34] and the Motion Sickness Susceptibility Questionnaire (MSSQ) [35]. However, since the vast majority of modern scientists in this area use and advice the SSQ, that will be the questionnaire that will be used during this project.

Specification

The “Ideation: Preventing VR induced motion sickness” section describes 13 distinct solutions that would theoretically reduce the amount of motion sickness induced by this simulation. These solutions can be considered the result / conclusion of the “Ideation” phase. The following section describes the process of implementing these solutions into the cycling simulation. This section will discuss all the choices that were made about, for example, which solutions were fit for testing and which ones are not.

Deciding what to implement

To recapture, 13 potential solutions that would decrease the severity of VR induced motion sickness were presented in section 2.3. Naturally, I don’t have the time to implement and test all of these. Therefore, a list was made at the start of module 12. The first thing that was done was to decide which of the solutions were at all possible for me to implement in the available time. This already excluded 4 of the solutions.

Lowering the realism of the scene was excluded because of multiple reasons. First of all, this would take a lot of work, especially since it is not exactly my expertise. Secondly, the RRD is planning to hire professional game designers to redesign the level in the near future. Although I would like to advise these designers to maintain a low level of detail/realism in the levels (more in “Tips for continuation of this project”), I will not do it myself in this module.

Ensuring a high resolution is the second solution that won’t be implemented (by me). This project is restricted to a limited budget, and enhancing the resolution of the HMD would require a new VR set, which costs a lot of money. Add to that the fact that the priority of implementing this solution is rather low, since there are other options with less costs and more estimated potential.

Having the user practice and stop when VR induced motion sickness occurs are the last 2 solutions that won’t be implemented. This is because, first of all, they can be regarded as being more “damage control” than a real solution. But secondly, how often and how long they want to practice is for the therapists to decide, not for me. I would, however, advise the therapists to follow these solutions to some extend (more in “Tips for continuation of this project”).

May be changed

1. Smaller FOV
2. Motion blur
3. Pointing a fan at user
4. Make the bike move
5. Using waypoints
6. Continuous acceleration
7. Continuous deceleration
8. Optimization of game and scene
9. Adding a rest frame

Won’t be changed

1. Lower realism scene
2. Ensuring high resolution
3. Have user practice
4. Stop when sickness occurs

Planned order

1. Continuous acceleration & deceleration
2. Smaller FOV
    a. Smaller
    b. Blurring peripheral vision
    c. Vignetting peripheral vision
3. Adding a rest frame
    a. Virtual nose
    b. Grid
    c. Steady horizon (if it isn’t already present)
4. Pointing a fan at the user
5. Using waypoints
    a. Coins
    b. Waypoints (in any sense of the word, maybe deciding what fits the style best)
6. Making the physical bike move
7. Motion blur
8. Optimization of game and scene

I then made a second list, ranking the remaining solutions based on how likely they are to be implemented into this simulation. This likeliness was a subjective estimation of a combination of expected effect on VR induced motion sickness and effort required to implement this solution. A solution that will require a lot of work to implement must therefore also be very promising whilst a solution that would be easier to implement is allowed to have less impact on the severity of VR induced motion sickness. Note that the continuous acceleration and deceleration are now placed together as they are 2 parts of the same problem.

This list was presented to Roos Bulthuis during a meeting at the RRD. The goal of this meeting was to narrow this list further down. The main reason that this was necessary was time restriction. There is not enough time to implement all 8 remaining solutions and test them sufficiently. Together we decided to implement and test solutions 2 – 5 (Smaller FOV, Adding a rest frame, Pointing a fan at the user, Using waypoints). This meant that solution 1 will also be implemented, but wouldn't require testing. Instead, it'd be regarded as the new 'Null' test.

This also meant that different variants of a certain solution would still all be implemented. However, not all of these were applicable to this simulation. We excluded the addition of a "steady horizon" as a solution since it was already present in the simulation. We also specified waypoints more explicitly, distinguishing them from other game objects such as collectable coins. This specification is discussed more elaborately in the "Realization: Implementation of the waypoints" section. Later on, I decided to exclude the smaller FOV solution as well (the variant where the FOV would simply be smaller). That decision is explained in the section "Realization: Implementing the vignetting and blurring". This decision was made at a later point in time and therefore the variant of this solution is still present on the final list of solutions (below).

1. Continuous acceleration & deceleration
2. Smaller FOV
    a. Smaller FOV
    b. Blurring peripheral vision
    c. Vignetting
3. Adding a rest frame
    a. Virtual nose
    b. Grid
4. Pointing a fan at the user
5. Using waypoints

Defining requirements

Because of the variety between the different solutions that are to be implemented, the requirements for each solution will be quite subjective. Not every scientific article (clearly) specified the parameters of the solution they tested. Not every solution is easy to replicate. Even if a solution would be easy to replicate, this variation of that solution may not be the best fit within this simulation (e.g. different types of waypoints). Some solutions (the fan) are not done before, and therefore I can't copy the parameters from scientific literature.

For the most part I created a solution in such a way that they "felt nice" for me. This is of course a subjective assessment, but it is the fastest / most efficient way to work. It would be an interesting topic of research to experiment with different variants of a specific solution (e.g. different widths for a virtual nose). More on this in the section "Conclusion: Continuation of this project".

Of course, I still have requirements for all of the solutions. These requirements are more a "work standard", and I believe that every proper programmer would implement the solutions according to these requirements. Nevertheless, these requirements should be listed and can be found in Table 3.

Requirement	A solution should not cause bugs
Rationale	Naturally, you don't want any bugs in your game. Bugs are annoying and can cause crashes or increase motion sickness. Therefore, none of the solutions should cause any bugs.

Requirement	A solution should not require too much processing
Rationale	If a solution requires a lot of processing, it will make the simulation run slowly, resulting in a low / inconsistent framerate. If a solution requires significant processing time it is also an indication that it does not work as efficient as it should.

Requirement	A solution should not cause lag
Rationale	Similar to the previous requirement, a solution should not cause lag. With this I mean that for example the virtual nose should move with the view as the user moves. This nose should not lag behind.

Requirement	Solutions need to be able to be turned on / off
Rationale	Especially important for testing purposes, the solutions should be able to be quickly and easily switched on or off. This is also useful to keep solutions implemented, even if they are not used. So that they may remain available for future testing. For this I will build a solution manager script with checkboxes for each solution.

Requirement	The parameters of a solution should be easily adjustable
Rationale	The parameters of a solution will for the biggest part be determined by me. Therefore, they should be easy to change later on, since it's not unlikely that somebody else prefers a solution with different parameters. In order to do so, every parameter will be either a public variable or a variable with a [SerializeField] attribute.

Requirement	Solutions should be able to work together
Rationale	Multiple solutions should be able to be active at the same time. Maybe, at some point in the future, I want to test the grid and the vignette together. The simulation should be able to do this.

Requirement	A solution should work on any computer
Rationale	This is a little more difficult to test, but I want the solutions to work on different computers as well, given that the version of Unity is the same. In order to do this, I won't make the solutions dependent on any external program. If the game is eventually built, the solutions should work on any computer.

Requirement	A solution should reduce motion sickness
Rationale	Although very obvious, it should be mentioned that a solution should reduce motion sickness. However, this can't be determined until they're tested, but if I personally, or other people who are related to this project experience an increase in motion sickness, the solution will be excluded.

Table 3: The requirements of every solution and the rationale behind them

The process of implementing these solutions is described in section "Realization". After implementing these solutions, I had another meeting with Roos Bulthuis (RRD) and Robby van Delden (Supervisor). Together we tested the solutions and decided which ones were pleasant and ready for a pilot test. During this process another solution was excluded (Blurring the peripheral vision). Despite the high potential of this solution (its ability to decrease visual input whilst, theoretically, not influencing gaze behavior), both Roos and Robby found it to be unpleasant, resulting in its exclusion.

The following section of this report will cover the process of implementing these solutions. It describes what methods were used to implement a certain solution, what problems were encountered and how they were solved. It also explains some important terms in the game development industry and explains these with existing examples of popular games.

Realization

Continuous acceleration and deceleration

The first solution that had to be implemented is to change the acceleration and deceleration of the virtual bike to continuous. This had to be implemented regardless of VR induced motion sickness in order to make the simulation more realistic, but since we (Me, Robby van Delden and Roos Bulthuis) suspected it to increase the severity of VR induced motion sickness as well it was the first thing to be done.

Up until now it worked such that the virtual bike moves at a certain, constant speed if a certain speed threshold on the physical bicycle is surpassed, otherwise the bike is standing still. This caused the virtual bike to continue to cycle for a while after the user brakes, and then instantly stop. This was changed, enabling the user to cycle at different speeds and the bicycle to roll off slowly when the user brakes. Instead of setting the velocity to 0 and making the rigidbody of the virtual bicycle kinematic, the velocity is multiplied by a constant smaller than 1 and a time variable (to ensure smooth roll off during inconsistent framerates).

The condition on which the virtual bicycle stops was also changed. The measuring of the speed works by counting how much magnets (which are attached to the spokes in the rear wheel) pass a certain point. However, when the user brakes, no more magnets are detected, making it more difficult to measure. Previously the Unity code that handles the input from the Arduino timed out after a certain period with no input. This was changed such that the Arduino code will time out, and then send a 0 to Unity. Not only can the Arduino time out faster and more accurate, it also saves processing power for Unity, since a bigger part of the calculations is now made in the Arduino rather than in Unity. To conclude, the implementation of continuous acceleration and deceleration resulted in a more realistic and smooth simulation.

The UI problem

Before the implementation of the solutions is covered, let’s have a look at a big problem that I faced when trying to implement these solutions. The problem I’ve encountered when trying to implement my solutions was that not all variants of UI (User Interface) are supported in VR. The most common type of UI is a non-diegetic UI, which is just an overlay over the screen. This type of UI displays things like a player’s health, score, mini map, stamina, items currently equipped, the crosshairs in first person shooters and so on (Figure 1). This type of UI is often called a HUD (Heads Up Display). The term non-diegetic is also used in film in order to describe things that are present, and work within the context of the film, but generally don’t make sense. In film, music would be a good example of this. Realistically, it doesn’t make sense to see health bars or score in games, but it makes sense within the context and is useful information for the player. Menus, pause screens, character/class creators and in game shops can also be regarded as UI.

Figure 1: A screenshot from team fortress 2 (2007) shows different UI elements. Bottom left shows the class and health and the in-game text chat, bottom middle shows the captured checkpoints, bottom right shows the ammunition, top right shows who has recently killed who and top center shows the remaining time. All of these are UI elements.

With normal, non-VR games, creating a non-diegetic UI is accomplished by overlaying the UI elements over the normal screen. This makes sense since the UI elements should never disappear behind objects in the scene (e.g. your health bar disappearing behind a tree). However, non-diegetic UI is not supported in VR. The reason being that “our eyes are unable to focus on something so close, and Screen Space-Overlay is not supported in Unity VR” [36]. Although I understand and agree with this decision of Unity, it does make my work more difficult, since I cannot simply overlay for example a virtual nose sprite.

The typical approach to UI’s in VR is to use a spatial UI. A spatial UI means that the UI elements are placed at a certain position in the 3D scene (Figure 2). If done correctly, this can work very well without causing eye-strain or VR induced motion sickness. However, for this project it is not ideal. I’ve tried to implement a transparent canvas in front of the camera through which the player sees the environment. On this canvas I could put a 3x3 grid, a virtual nose, or a vignette. However, due to the order in which Unity makes its calculations, when the player would move around, the canvas would only follow a few frames later. Given that the motivation behind some of the solutions was to have a steady point of reference, that would not move relative to the player, this was a problem.

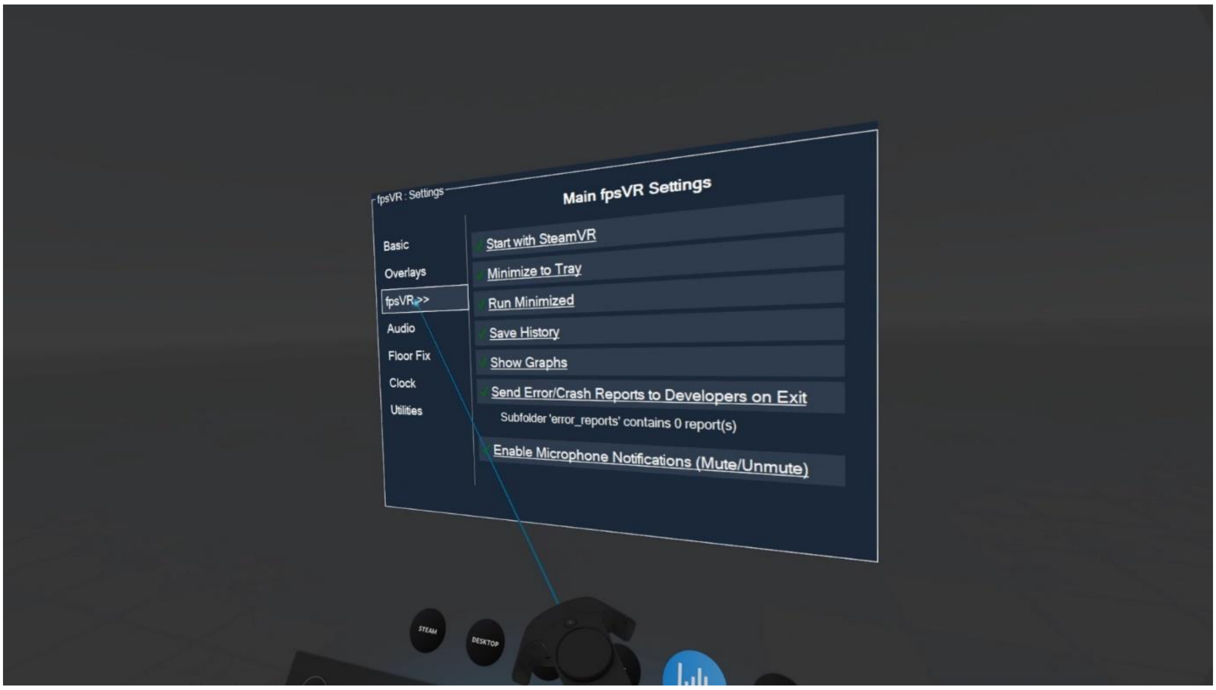

Figure 2: The build in UI of Steam VR is a simple plane, that does not move with the player. The player controls this UI via a "laser pointer" on the controller.

Ideally, I want everything to be calculated and rendered, ready to be send to the VR goggles, and then add my solution. Luckily, there is a way to do this; Shaders. Shaders are small scripts that contain the mathematical calculations and algorithms for calculating the Color of each pixel rendered, based on the lighting input and the Material configuration [37]. Unity uses shaders for postprocessing, which ensures that they won't move relative to the camera.

Shader coding is something I hadn't done until this project, but luckily a lot of online reference and premade shaders exist. A different problem that I also encountered was that although shaders will work just fine on regular games, they may behave differently on VR games. This is due to the fact that VR games make use of 2 cameras instead of one (one camera for each eye), and part of what these cameras see will overlap (Figure 3).

Figure 3: Example of the 2 screens in an HMD and how their view overlaps.

Implementing the vignetting and blurring

Vignetting is the process of making an image increasingly darker towards the edges. It is a popular method of preventing VR induced motion sickness and some non-VR games also use vignetting. Using a red vignette is also a popular method of indicating that the player has recently taken damage or is low on health (Figure 4).

Figure 4: Call of Duty 2 (2005) (and a lot of sequels since then) use a red vignette to indicate that the player has recently taken damage or is low on health.

In our simulation we will use a black vignette rather than a red one. An advantage of the use of vignetting is that it decreases the FOV without showing an obvious, hard cutoff. The screen just slowly fades away until it is completely black.

I had the luck of finding a premade Unity package specifically designed for vignetting in VR. This package has the advantage over other options not specifically designed for VR that it centers the vignette around the center of your eyes, and not the center of the screen (Figure 5). This required some calibration but will help reduce eye strain according to the creator of this package. This package is also used to make the FOV smaller without vignetting. This is done simply by making the vignette go from 100% transparency to 0% instantly, rather than gradually.

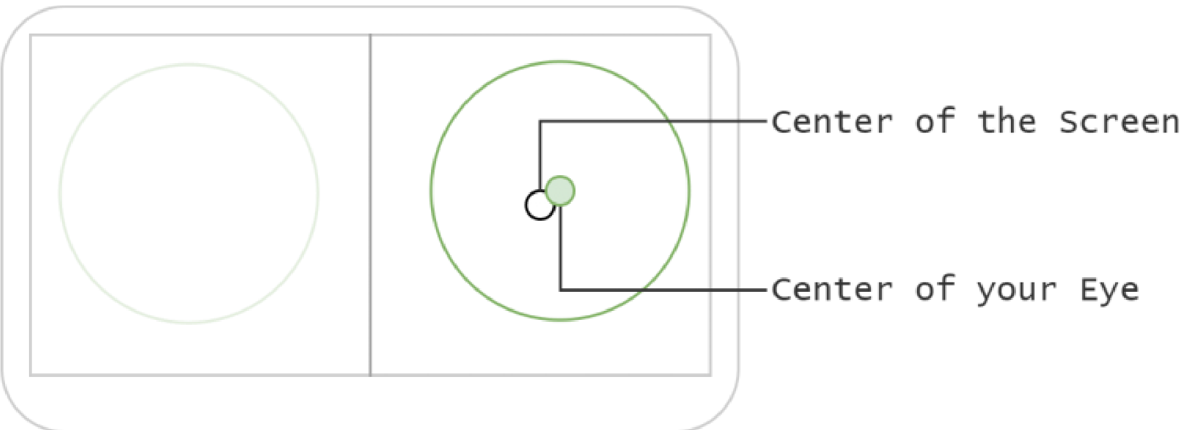

Figure 5: The difference between the center of the screen and the center of your eye

A drawback of vignetting in this simulator specifically is that it decreases the number of things the user can see. This is exactly the point of a vignette, and this problem is therefore unsolvable. Since this is a cycling simulation that is supposed to help children learn how to cycle in traffic, together with other road users, therapists are interested in the gaze behavior of these children. They want to know what the children are looking at and improve this behavior. Therefore, this simulation should closely resemble reality to ensure that the users behave the same way in traffic as they would in the simulation. Limiting the FOV may change gaze behavior.

One of the favored alternatives was to blur the peripheral vision of the user instead of vignetting. This would still allow them to see things, but blurry. Due to the blur, the visual input is still reduced and should therefore theoretically still reduce the amount of VR induced motion sickness. Your eyes work in a similar fashion, where the center is clear, but the peripheral vision is blurry. Blurring the peripheral vision is one of the solutions that will also be tested, and its implementation is discussed below. Figure 6 shows a comparison of the different methods of decreasing the size of the FOV in this simulation. However, at this point in time it is unsure which solution will have the most impact on VR induced motion sickness.

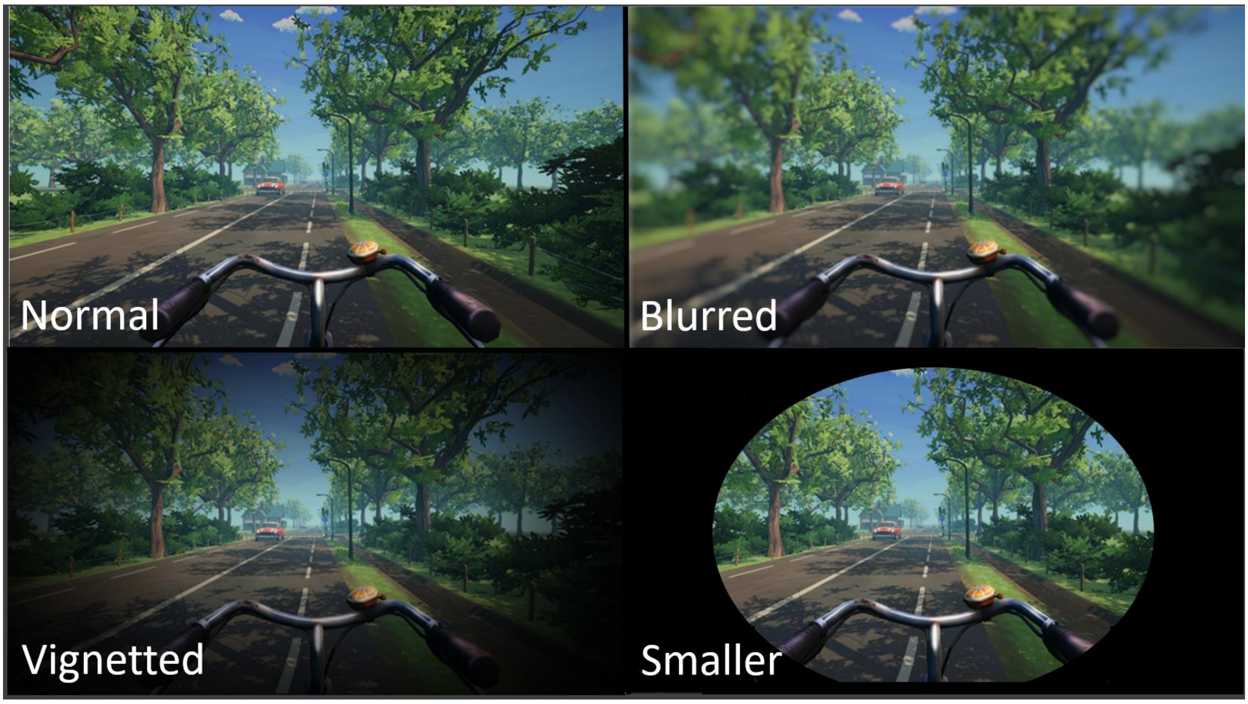

Figure 6: The different methods of decreasing the size of the FOV compared. Note that not everything is on scale and different parameters will be used for the actual testing.

A shader called radial blur will be used for blurring. This shader chooses a circle at the center of the screen, in which there is no blurring effect. After that the blurring effect starts and will increase more towards the edges of the screen. A radial blur means that each pixel is blurred outwards from the center of the screen. This gives the illusion of forward motion and is the same thing that Google Earth uses when you zoom in.

The solutions mentioned above are all different methods of making the FOV smaller. Another implementation of this principle is to simply make the FOV smaller. However, I decided not to implement this method because it is essentially the same as vignetting, but it feels more noticeably present and less smooth. It gives the feeling of looking through a tube.

Implementation of the rest frame

In the literature discussed in section 2.3, 3 different methods of adding a rest frame were presented. A rest frame being something that does not move relative to the user's eyes, giving the user a point of reference. 3 different methods of implementing a rest frame were found: 1) adding a virtual nose, 2) adding a grid and 3) adding a steady horizon [21] [14]. Because a steady horizon is already present in this simulation, only the first 2 methods had to be implemented.

Both the grid and the virtual nose were implemented using shaders. The reason for this is that shaders are added after everything else has been calculated, and therefore don't lag behind as much as canvasses in world space. The shader for the grid is quite simple. All it does is place a black vertical and horizonal black line at certain intervals. The shader is calibrated such that one line is exactly in the center between the eyes. This line can be seen with both eyes and any deviation from the exact center would cause one eye to see it more clearly than the other. This problem doesn't exist with the horizontal lines of the grid, as these are on the same position for both eyes, giving the impression that it is one smooth line extending over two screens.

The virtual nose was done a little differently. First, the position of the eye relative to the screen is calculated in a similar fashion as with the vignetting and blurring. From here, the rest of the screen can be viewed as an X,Y graph. Calculating both the X and Y values, we know the exact distance a certain pixel has to the center of the eye of the user. Using these values, we create a formula for a line. Everything under this line will be colored black whilst everything above this line will be transparent. The formula is then translated to an if-statement and looks as shown in Figure 7. This results in a shape resembling the graph in Figure 8. The shape of a nose, as seen with the left eye can roughly be extracted from this graph. Everything under and to the right of this line would be colored black. I chose the color black because the rest of the inside of the HMD is also colored black, and also so that I don't have to adjust to a specific skin tone for each participant. The graph would be mirrored for the other eye. Both graphs combined would create a shape resemblant of a nose.

```
float noseWidthScaling = 3.75; //width of the nose scaling factor

    if(unity_StereoEyeIndex == 0 && i.uv.x > -0.2 && i.uv.y < pow((noseWidthScaling * i.uv.x),3)){ //left eye
        return fixed4(0,0,0,1); //black
    } else if(unity_StereoEyeIndex == 1 && i.uv.x < 0.2 && i.uv.y < pow(-(noseWidthScaling * i.uv.x),3)){ //right eye
        return fixed4(0,0,0,1); //black
    }
   else {
   return fixed4(0,0,0,0); //return Transparent
   }
```

Figure 7: The code snippet that calculates the shape of the virtual nose for each eye.

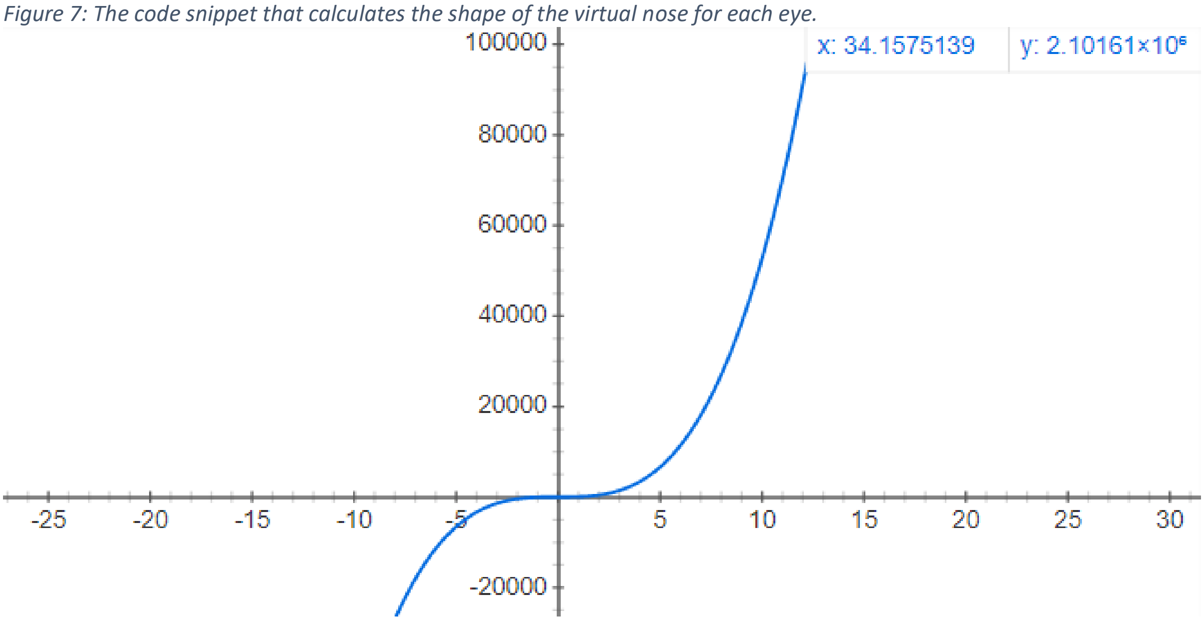

Figure 8: The graph describing the shape of the virtual nose as seen from the left eye.

The implementation of the fan

One of the solutions that will be tested is the fan. This idea does not originate from a scientific article and has not been scientifically proven. However, it fits in very well with different theories and is easy to implement. Hypothetically, the fan will reduce the amount of VR induced motion sickness experienced in 3 different ways. First of all, it will provide the user with fresh air, which is known to decrease the symptoms of motion sickness. Secondly, it gives the user a link to the physical world and allows the user to sense some input that is not virtual. Thirdly, it gives the user's body a feeling of motion, which will decrease the mismatch between the user's eyes (which perceive motion) and the user's body (which does not perceive motion). The blowing of air may also give the user the feeling that he or she is outside, making for a more immersive and realistic cycling experience.

We will be using a simple table fan from the Action. This fan has 4 different settings; 0 (off), 1, 2 and 3. The goal is to make the speed of the fan relative to the cycling speed of the user. When the user cycles fast, a lot of air is blown in his or her direction, and vice-versa. We used a relay module to switch between the different settings of the fan based on the RPM (rounds per minute) measured by the Arduino. The parameters are listed in Table 4 below.

RPM	Fan setting
0-15	0
16-55	1
56-95	2
95>	3

Table 4: The RPM ratios and their corresponding fan setting.

The code works as follows. The function takes the RPM as an integer as input. It then powers all the pins that a relay is attached to, this turns off the fan. Normally this is done the other way around, where no power is required to turn everything off, but this way of doing it would cause the fan to be briefly powered when restarting the program. After every relay has been closed, it looks at the current RPM and decides which setting is fit for the fan. This relay is opened, and the fan will be on this setting. The setting of the fan is updated each time the RPM is measured. Figure 9 shows the code snippet that updates the fan speed.

```
void Sensing_Speed::UpdateFanSetting(int rpm){
  digitalWrite(FanRelay1, HIGH); //turn everything off, then only turn on the correct value, or nothing if the player isn't moving fast enough
  digitalWrite(FanRelay2, HIGH); //HIGH instead of LOW is used because otherwise it would trigger for a second when starting the arduino
  digitalWrite(FanRelay3, HIGH);
  if(rpm > 15 && rpm <= 50){ //turn fan on, lowest setting
    //Serial.println("Fan 1");
    digitalWrite(FanRelay1, LOW);
  } else if(rpm > 55 && rpm <= 95){ //turn fan higher
    //Serial.println("Fan 2");
    digitalWrite(FanRelay2, LOW);
  } else if(rpm > 95){
    //Serial.println("Fan 3");
    digitalWrite(FanRelay3, LOW); //highest capable intensity of fan
  }
}
```

Figure 9: Code snippet of the function that updates the fan speed.

The way this system works is that it has 2 cables as an input, the 230 volts of Dutch outlets, and a ground. The ground cable is connected directly to the electromotor. The 230 volt cable is connected to either none (fan setting 0) or one of 3 cables going to the electromotor. Translating these 230 volts into a certain speed for the fan happens in the motor and is not something I had to worry about. I only need to decide which cable the power can flow through.

Implementation of the waypoints

The word waypoint can mean a lot of things. A waypoint is a specific point on the route that the player has to reach. Waypoints in games are present in order to ensure that the player stays on track, knows where to go to and doesn't cheat. Anything can function as a waypoint and they can even be invisible to the player and just exist in order to ensure that the player has completed a certain route. The purpose of waypoints in this simulation would be to give the player an indication of where he or she should go to next. This indication should theoretically allow the player to predict his motion, causing it to be less of a shock when the player moves in this direction.

Often, waypoints disappear when the player reaches them. New waypoints may appear when a certain waypoint has been reached. The distinct difference between waypoints and collectibles is that waypoints do not give the player any bonus. However, sometimes waypoints can give the player additional time to complete a certain route. Even more confusing, collectibles can also be used as waypoints. This phenomenon can be seen in the old Sonic games (Figure 10).

Figure 10: Left: Collectibles (gold rings) used as waypoints in Sonic the Hedgehog (1991). Right: Waypoint that rewards the player with bonus time to complete the track in Need for Speed Payback (2017).

The waypoints that were implemented into this simulation exist of a yellow cube, which is rotated 45 degrees on all 3 axes (Figure 11). When the collider of the cube, which is a little bigger than the cube itself, notices a collision with another collider, which would be the collider of the player, the cube deletes itself. Since these waypoints are yellow, quite big and close together, we are inclined to focus on these blocks and not the rest of the scene. This is of course not the goal of this simulation. Therefore, the waypoints will be adjusted to be more subtle and less eye-catching before their effect can be tested. We did decide that we want to test the effect of waypoints. This is because they are different that other solutions, and we are curious what effect they will have on the severity of VR induced motion sickness after they are adjusted. We do not yet know what kind of effect this would be, as our own experience goes counter to the literature. The testing phase will tell.

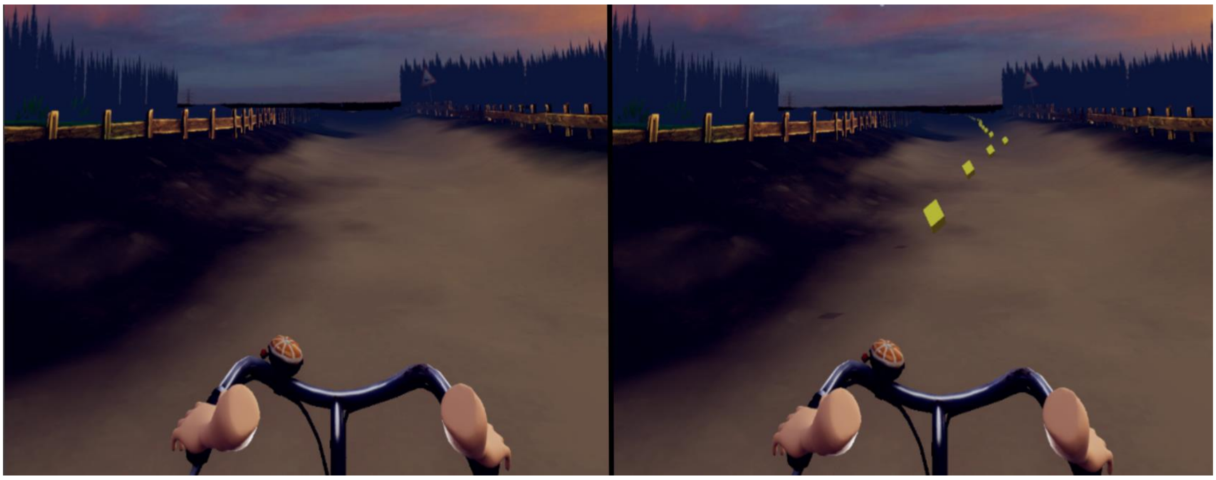

Figure 11: The simulation with (right) and without (left) waypoints

Evaluation

Pilot test: Introduction

There are still too much solutions for a large testing session. There isn't sufficient time left to test all of them elaborately. Therefore, in order to reduce this number of solutions, a pilot test will be held. For this test, 7 specifically selected participants will be invited. They all have significant experience with VR/AR and some of them are also closely related to this specific project. The goal behind this pilot test is to receive feedback on each of the tested solutions and, using this, exclude one or more of these solutions from the next testing period.

Pilot test: Method

Each tester will first read the information brochure and the informed consent form in their preferred language (English or Dutch). These forms can be found in appendix 3. They are also given the opportunity to look at the list of symptoms (appendix 2A-B) and the list of solutions that will be tested (appendix 1A-B). After signing the informed consent form, they will be asked if they have any remaining questions and these will be answered accordingly. The experiment can now begin.

The tester will begin the experiment by filling out an online questionnaire. This questionnaire serves 2 purposes. Firstly, the demographic data (age, gender, estimation of amount of experience with VR) is collected here. Secondly, it will measure how the is feeling, regarding the 16 symptoms of VR induced motion sickness that will be measured in the upcoming trials. This measurement allows us to conclude that any increase in severity of a specific symptom can be attributed to the cycling simulation. Upon completion of the first questionnaire the tester is presented with a screen that reads "Thank you for your participation in this experiment. The experiment can now begin. You can go sit on the bicycle.". The experimenter will give the tester the HMD and ask if this tester is comfortable and ready to start.

Whilst wearing the HMD, the user is asked to put the steering wheel straight, and the position of the HTC Vive controller is calibrated. This step is essential, because otherwise the angle of the steering wheel on the virtual bicycle may differ from the angle of the steering wheel on the physical bicycle. After this step the tester is ready to begin, and the experimenter can start the simulation. The tester will cycle through the virtual environment until a certain point. The experimenter will tell the tester to stop and take the testers HMD.

The tester will now be presented another questionnaire. This questionnaire lets the user rate the severity of 16 symptoms related to VR induced motion sickness in the same fashion as the first questionnaire. The difference between the 2 questionnaires is that the first one also asks for the demographic data. The second questionnaire also asks for the trial number and the trial condition, but these fields are filled in by the experimenter. Upon completion of this questionnaire the tester has an option to take a short break or to continue with the next trial. The option for a break is present to ensure the wellbeing of the testers. The process above is repeated 5 times for each tester (unless the tester decides to discontinue the experiment). Each trial will be held with a different condition. There are 5 different conditions in total:

1	Null test, no solutions implemented
2	Using the fan
3	Using the virtual nose
4	Using waypoints
5	Using vignetting

Table 5: The different possible conditions of a trial during the pilot test on Wednesday 29-5-19

The conditions are held in a different order for each trial in order to filter out the learning effect. This is the principle that experience in a specific virtual environment decreases a person's susceptibility to VR induced motion sickness. However, it is also true that longer exposure time is related to an increase in the severity of the symptoms (add reference). Although these 2 phenomena have an opposing effect, it is unsure whether they cancel each other out. This means it is to be expected that the trial number is of influence on the severity of the symptoms, but it is unsure whether this influence is positive or negative.

The order of the different conditions is assigned via the Latin Square method. However, there are more testers than conditions (6 users, 5 conditions). Therefore, 2 testers will test using the same order of conditions. For each other testers the condition for each trial will move one up (E.G. if the first user tests using conditions 1,2,3,4,5 for trials 1,2,3,4,5 respectively, the next tester will test using conditions 2,3,4,5,1 for trials 1,2,3,4,5 respectively). The order of conditions remains the same, so every tester will test condition 2 after condition 1 (unless condition 1 is the last trial).

After each condition has been tested, and the tester has filled out the last questionnaire, the tester is thanked for his or her participation in this experiment. The tester will be presented with an opportunity to ask any newly arisen questions. The tester is also reminded of his or her right to ask exclusion of his or her data from this experiment. Contact information for this request or for questions will be given to the tester. Lastly, the user is given a chocolate as thanks for participating.

Pilot test: Results

Although the testers assessment of the severity of each of the 16 symptoms from the SSQ has been measured after each trial, the most important result from this experiment is the open feedback from the testers. To clarify, after each trial the tester had the opportunity to write anything that they thought was helpful in the questionnaire. These things may be bugs in the simulation that they've encountered, specific elements that they liked or disliked, tips on how they think VR induced motion sickness may be reduced, tips for experiments in the future, suggestions for future research, or anything else that might help the reduction of VR induced motion sickness in this project.

Since the participants of this experiment were selected specifically for characteristics like their experience with VR/AR, knowledge about video games/technology in general, or a close relationship with this project, their feedback holds a lot of value. Their feedback will be discussed below. Please note that a lot of the testers are native Dutch speakers and their feedback was done in Dutch as well. The feedback will be translated to English and discussed, however the unedited feedback from the testers, as well as the ratings of the symptoms of VR induced motion sickness and some basic analysis of these ratings can be found in appendix 4A and 4C.

Tester 1 mentioned that the braking feels weird, as you can't slow down smoothly, but stop instantly instead. After the first trial I edited the roll off value and this problem was fixed. This tester also mentioned that he missed some resistance on the physical wheel, so this was added after the first trial as well (the TRAX that is used to hold the rear wheel in place has a build-in resistance unit). The tester called the steering "funky". The steering feels quite odd, especially in the curves, and this will be seen in other feedback as well.

Regarding the solutions specifically this tester mentioned that at first the virtual nose felt annoying, but after a while he stopped noticing it. He also mentioned that the air from the fan felt pleasant and that the vignette felt natural.

Tester 2 also mentions the problems with the curve. He calls it very unnatural and says that you suddenly accelerate and go straight even though you steer to the side. This is a bug that currently exists in the game and needs to be solved. The problem is that the angle of the steering wheel is calculated with respect to its parent, which is the rest of the bike. The rest of the bike however, also rotates when you go around a corner. It automatically adjusts to the angle of the steering wheel (with a 5 degree error margin). Somewhere in this calculation something goes wrong, and the steering is not properly translated to motion in the virtual environment. This tester also mentioned that he does not go from left to right as much when using the waypoints as opposed to the other trials. Regarding the game experience, this tester said that he was heavily inclined to run over the ducks and suggested to replace these ducks with cars for a more realistic experience.

Tester 3 gave a lot of feedback. To begin with the feedback regarding the curve; this tester said that the curve was really difficult, since you can't lean into the curve, and also since the virtual bicycle does not steer in the same way that a real, physical bicycle would. From the third trial onwards, this tester stopped the test before the curve, claiming the curve is undoable.

This tester also mentioned that, in the trial with the waypoints, it seemed like the tester was supposed to go from left to right. The tester mentioned that this might be caused by the fact that the waypoints were pretty closed together. This tester also said that it seemed like you can't look very far in the simulation. The trees in the background always appear to be the same distance. The odd thing here is that this tester only experienced this feeling in trial 3 (Null test), whilst nothing regarding the distance to the trees has been changed relative to the other trials. A similar thing occurred with this tester in trial 4, where this tester said that the screen quality appeared to be worse than in different trials, whilst nothing was changed regarding the screen quality in this trial (it was the trial with the fan). Since I don't know the cause of this experienced change in screen quality or distance to the background, and this tester is the only one that has experienced this phenomenon, I cannot use this feedback.

Regarding the solutions, this tester mentioned that the fan was "chill". It cooled down your head, delaying the occurrence of nausea. The virtual nose required some getting used to. The bottom of your nose is always more visible than the top, which is something that could maybe be adjusted to better simulate the real situation. In practice, this is already the case. The nose takes the shape of a 3th power formula, coming up from the bottom, going flat for a bit and going further up again. However, this shape can still be tweaked/ adjusted in every way.

Tester 4 only pointed out a specific bug, the fixing of which is beyond the scope of this project for me. The tester pointed out that you can, at times, look through the asphalt. This user also mentioned that the vertical poles of the fences "flicker". This phenomenon is called Z-level glitching and occurs when 2 planes are at the same position in a scene. When the game level gets redesigned this problem should be fixed.

Tester 5 also pointed out the steering bug in the curve, saying the steering is "way off". This tester also said that the speed of the virtual bike should be more accurately adjusted to the speed of the physical bike. This would be an easy fix, since we can simply adjust some multipliers.

Tester 6 game feedback similar to that of tester 5, saying that both the acceleration and deceleration speed need to be adjusted. Regarding the solutions this tester said that the virtual nose might even induce motion sickness and hypothesized that the cause of this is that its positioning is delayed, and thus, the nose can move a little bit, especially with quick head movements. About the waypoints this tester said that, since not every waypoint is directly (in one line) behind the previous, they encourage the tester to make more curves, possibly inducing more motion sickness. This tester also mentioned that the waypoints distract the tester from the rest of the scene, defying the original goal of this project, which is analyzing and improving gaze behavior. This tester called the vignetting the best solution of all, even though it has a small delay (similar to the virtual nose).

Lastly, since this tester is very close to this project and I highly value this tester's feedback, we tested an additional solution; the blurring of the peripheral vision. Although previously decided that this solution would be excluded from this project, since this tester gave very positive feedback about the vignetting, which is based on the same principles as blurring, and the therapists were very enthusiastic about the blurring I thought that some extra feedback on this solution was welcome. The blurring does essentially the same thing as vignetting, which is making the FOV smaller, but without as much impact on the gaze behavior. The tester said that the blurring takes some getting used to, but when cycling it's actually very comfortable.

Tester 7 experienced more vertigo and dizziness than that this tester initially expected. This tester experienced these symptoms especially in the curves and from trial number 3 onwards the tester stopped before the curve. This tester said that the fan did help a little bit.

The previous section described their open feedback. For a more in depth analysis of the symptom ratings also please consult appendix 4C.

Pilot test: Conclusion

The first thing that should be really clear is that the curves are a big problem. The main cause for this is the bug with the steering wheel, where the steering of the virtual bicycle is not the same as the steering of the physical bicycle. This generally causes the user to make a very big curve, even though they'd make a smaller one if the steering of the physical bicycle was used. This really needs to be fixed and although this was not originally part of this project, I personally feel that this is one of the biggest causes of motion sickness in this simulation. Another reason that VR induced motion sickness occurs in the curves is that people tend to 'lean in' into the curves. Allowing the physical bicycle to move and allow this leaning in was one of the original 13 solutions, but would require a lot of effort to build and might make the VR induced motion sickness even worse, and was therefore excluded from further testing. Following sensory conflict theory, it would also make sense for the turns to induce the most motion sickness since the tester expects to feel some centrifugal force but does not. To illustrate, S. A. Balk [29] said "it is suggested that simulations minimize turns, curves, stops, et cetera, if possible, in order to minimize participant simulation sickness symptoms.".

A second thing that is clearly noticeable amongst most testers is that they like the fan. This shared opinion is somewhat surprising, since this is the only solution that does not originate from a scientific article. Nevertheless, given the unanimous approval of this solution it will not be excluded at this point and will be further tested with a larger group, allowing more accurate statistical analysis of its effects.

The vignetting received positive feedback from the testers. However, a small increase in the severity of the rated symptoms can be observed with the vignette relative to the previous trial. Nonetheless, this solution will be kept for further testing. This is because the increase in symptoms is small, and the result of a small group of testers, making it not statistically viable. As previously mentioned, the open feedback is more highly valued than the rating of the symptoms, and although the rating shows a small increase, the open feedback is positive.

Both the virtual nose and the waypoints received negative feedback. Where opinions about the nose were mixed, the feedback about the waypoints was either negative or non-existent. However, much of the feedback was on how the waypoints were implemented rather than the concept op waypoints. Meaning that people reacted on how they looked, how close together they were positioned, which path they followed in the curves, etc. All of these are factors that can be changed whilst maintaining the functionality and it'd still be waypoints. However, given the negative feedback they received, the waypoints will be excluded from further testing.

The virtual nose received mixed feedback. Some testers said that it was annoying, the shape was off, or it was distracting, whilst others didn't notice its presence. Not noticing its presence is taken as a good thing here, because that's how you see your real nose as well. But even then, the analysis of the severity of the symptoms also does not show any decrease relative to the previous trials when the nose is tested, and sometimes even an increase for some symptoms. Therefore, the virtual nose also be excluded from further testing.

Final test: Method

The final experiment of this project was conducted over the span of 3 days. The testing began on Monday the 17th of June on 11:30 and ended on Wednesday the 19th of June on 15:00. The testing method was very similar to that of the pilot test. Before the experiment would start the tester would read an information brochure in either English or Dutch (whichever the tester preferred). These information brochures can be found in appendix 3. This time the information brochures also listed the solutions that were to be tested. They also presented the participant with the opportunity to have a look at the list of symptoms (appendix 2A-B). After having read this brochure and asked any remaining questions, the tester is asked to sign an informed consent form (appendix 3E-F).

The user then fills in a questionnaire. The questionnaires used in this experiment are the same as the ones used for the pilot test. The first questionnaire is used to collect demographic data and measure the severity of the 16 symptoms before the start of the experiment. The second part of this questionnaire is repeated after every trial. The user also has the ability to give any open feedback after every trial. However, whereas the focus of the pilot test was on this open feedback, this test focusses more on the questionnaires. The goal is to conduct a statistical analysis of the ratings of the symptoms. The ratings of the symptoms can be translated to a single variable, which is an indication of the amount of VR induced motion sickness experienced. This score is the dependent variable in this experiment, the trial condition is the independent variable.

After completing the first questionnaire the tester will mount the physical bicycle. The tester gets some time to adjust the settings of the bicycle (gear, saddle height) and the HMD (tightness of the headband, distance between the eyes, optional: glasses on/off). After the tester confirms that he or she is comfortable the first trial can begin.

The trial will be the same as that of the pilot test. The tester has to cycle straight ahead over a dirt road. After a short distance, a small family of ducks will cross the road which the tester has to dodge. The tester continues his route and the road will turn to asphalt. A second family of ducks crosses the road. Lastly, the road takes a turn left. After this turn the trial is completed. If a tester hits the ducks, this tester is reset to the previous checkpoint. This checkpoint is the start for the first pack of ducks and the point where the road just turned to asphalt for the second pack of ducks. Upon completion of a trial the user is asked to fill in a questionnaire and has the chance to give open feedback.

The process above is repeated 3 times for each tester (unless the tester decides to discontinue the experiment). Each trial will be held with a different condition. There are 3 different conditions in total:

1	Null test, no solutions implemented
2	Using vignetting
3	Using the fan

Table 6: The different possible conditions of a trial during the final test on Monday 17-6-19 to Wednesday 19-6-19

As was also the case with the pilot test, the condition for a certain trial may vary. This means that one tester may have condition 1 in trial 1, whilst another tester has condition 2 in trial 1. This is done to counter both the learning effect as well as the fact that longer exposure time means increased symptoms. The order of the conditions is determined via the Latin Square method and is described in Table 7.

N % 3	Trial number and respective condition number	
1	Trial 1 Trial 2 Trial 3	Condition 1 Condition 2 Condition 3
2	Trial 1 Trial 2 Trial 3	Condition 3 Condition 1 Condition 2
0	Trial 1 Trial 2 Trial 3	Condition 2 Condition 3 Condition 1

Table 7: The condition of each trial based on the participant number (N)

After each condition has been tested, and the tester has filled out the last questionnaire, the tester is thanked for his or her participation in this experiment. The tester will be presented with an opportunity to ask any newly arisen questions. The tester is also reminded of his or her right to ask exclusion of his or her data from this experiment. Contact information for this request or for questions will be given to the tester. Lastly, the tester is given chocolate as a thanks for participating.

Final test: Results – Open feedback

This section will be added later. The focus will be on the statistical analysis of the results. Open feedback may be included but not as elaborate as with the results of the pilot test. The unedited open feedback as well as all of the symptom ratings will be included in appendix 4B and 4D as well.

The goal of this experiment was to provide statistical evidence that a certain solution decreases the severity of the experienced VR induced motion sickness, or not. This statistical analysis will be provided in this section. However, as was also the case with the pilot test, the testers had the opportunity to give open feedback. Due to both the increased number of testers relative to the pilot test and the difference in focus of these 2 experiments this open feedback will not be discussed elaborately. This feedback is naturally subject to some amount of interpretation due to translation or categorization. Therefore, the unedited open feedback is also provided in appendix 4B.

In order to analyze the open feedback, I read it and made a list of the comments that every user made. These comments were combined if they were very similar. For example, the comments "With the ventilator I was a lot less dizzy." (Tester 3) and "the fan made the experience considerably more pleasant." (Tester 19) were combined into "The simulation is more comfortable with the fan". This comment than claims to be supported by both tester 3 and 19. It is important to once again stress that this method requires a lot of interpretation and selection, and that any conclusions drawn from the open feedback should originate from the feedback itself (appendix 4B) and not from the interpretation of it in this section. Table 8 shows the comments made by the testers and which tester supports which comment. Also note that a tester may still support a certain comment whilst not being listed as such, simply because this tester didn't make this comment explicitly.

Comment	Testers supporting this comment
More comfortable with fan	1, 3, 4, 5, 7, 12, 19, 24, 25, 27
Motion sickness occurs especially when steering/ in the turn	3, 4, 5, 17, 20, 23
The simulation had a low framerate	13 (test 2), 14, 21, 24 (in turns)
The acceleration and/or deceleration was unrealistic	14, 20, 25
The first trial induced more motion sickness than the last one	1, 9, 10 (decreased dizziness) ,16, 19, 21
The speed limit is unrealistic / annoying	13, 26
I didn't notice the vignetting effect (until being told about it)	1, 7
Experienced more imbalance with the vignette	1
The null trial had the nicest visuals	3
Increased symptom ratings of later trials may be attributed to previous trials	4
The steering wheel was sometimes wrongly calibrated	5
The testing room was hot	6
Experienced greater balance with the vignette	6
After testing my eyes hurt in a similar fashion as they do after gaming for 3-4 hours	8
You seem taller on the virtual bike	14
Physical and virtual speed do not match	15
Cycling in the simulation is scarier than cycling in real life	19
More immersive than I expected	19
It feels like I'm floating	21
When I hit a bump in the road, I expect to feel this on my steering wheel	23
If I brake before the turn, I don't feel the need to lean in	23

Table 8: The comments made in the open feedback of the final test and which tester made this comment. Sorted by popularity

The first thing you'll probably notice is that no less than 10 testers explicitly mentioned that the simulation is better with the fan. The statistical analysis will tell whether the fan also worked against VR induced motion sickness, but this is already a clear indication.

Secondly, a lot of testers mentioned that they primarily experienced motion sickness during the left turn or when steering. Since the trial consisted of a road straight ahead and a left turn, I expect that the steering in this case also refers to the left turn. However, it might also refer to the steering a user might do to avoid the ducks. Following sensory conflict theory, it makes sense that the steering induces the most motion sickness. This theory states that (VR induced) motion sickness is caused by a mismatch between the signals from the eyes and body, where one of them things that they are moving whilst the other doesn't. If this mismatch is reduced or not present than no motion sickness will occur. When a tester cycles at a continuous speed, the body does not sense motion, but when a tester accelerates or decelerates the body expects to feel slowness (traagheid). When steering your body does not only expect to notice the slowness but also the centrifugal force, but it does not. Centrifugal force in this case is the same as slowness but at an angle, and it's the reason why cyclist lean into a turn. One tester (23) also commented that if he brakes before the turn, he does not feel the need to lean in anymore. This makes sense since less velocity means less centrifugal force and thus would require less leaning in. To conclude, the greatest sensory mismatch occurs when steering and therefor most VR induced motion sickness occurs when steering, which is illustrated by the fact that a significant number of testers mentioned it explicitly.

Some testers mentioned that the simulation had a low framerate. Some of them experienced this specifically during a certain trial, but this can't be caused by any of the solutions, since none of them require great amounts of processing power. It is more likely that this is simply caused by other programs running on my computer during the test or normal fluctuations in refresh rate. Nevertheless, a low framerate is a problem and should be improved. However, this will happen automatically when the simulation is put into use at the Roessingh. For the test I used an unbuild version of the simulation that I ran in Unity's game test mode. The game will run faster when it's built into a standalone application. This is because, when running in test mode, Unity also runs debugging and profiling tools simultaneously. These tools require a significant portion of processing power.

Another reason why the simulation will have a higher framerate when it's put into practice at the Roessingh is that it won't be ran on my computer. I did the testing on my Lenovo P51 ThinkPad from 2018. Although this computer is quite fast, it is still a laptop, whereas the computer at the Roessingh is a more powerful desktop. My laptop also has a NVIDIA Quadro M1200 graphics card, which may have been a bottleneck for the amount of processing power that my computer can put into running this simulation. HTC provides a program that can check your computer and rate its compatibility for the HTC Vive. This program also concluded that my graphics card may cause the simulation to run more slowly (Figure 12).

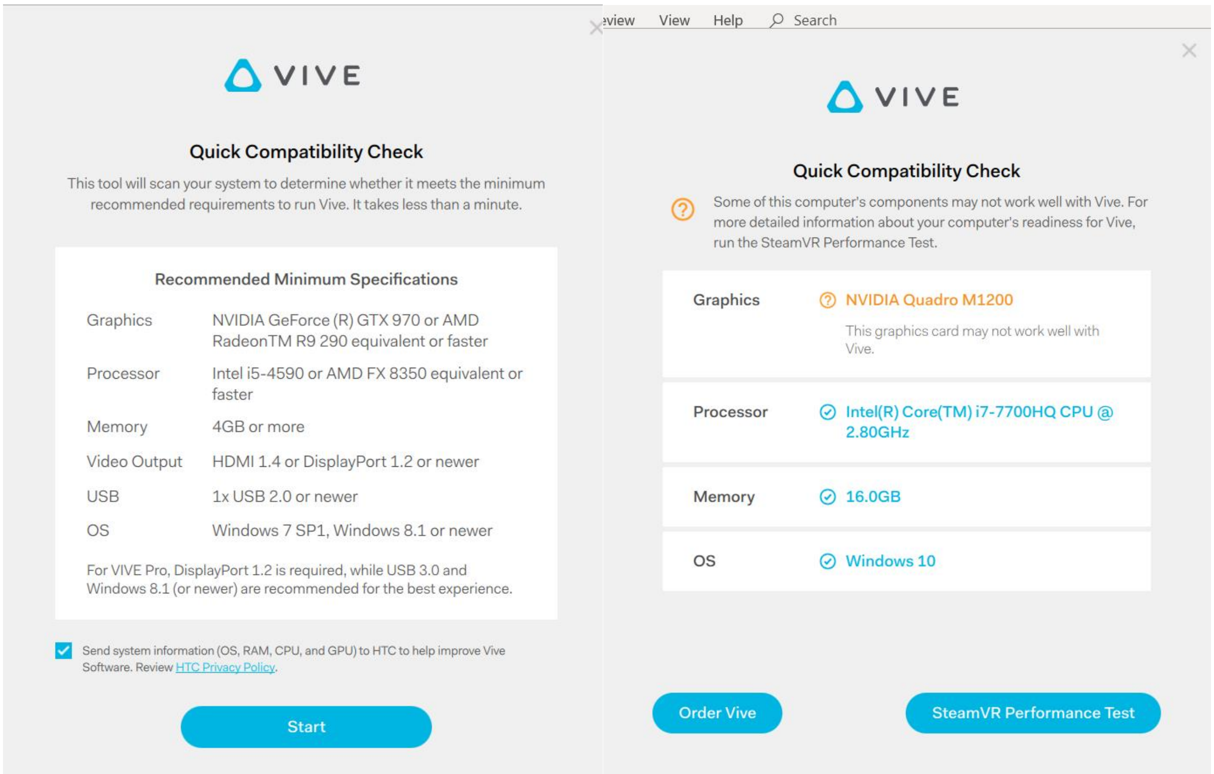

Figure 12: The HTC Vive compatibility check and its result when ran on my laptop (right).

Some testers commented that the acceleration and deceleration was unrealistic. This is a difficult problem to fix, given the provided hardware. Since the speed of the bike is measured using magnets, it takes some time to accurately determine this speed. When the user accelerates, a certain number of magnets has to have passed the reed switch in order to calculate the speed. This takes time, but a physical bicycle would've sped up right away. When the bike decelerates, or rather brakes, the reed switch does note sense any more magnets. However, in order to determine whether the wheel is actually not moving, or the sensor just missed a magnet, this also requires some time. After not sensing a magnet in a set amount of time, the Arduino sends a brake message. Upon receiving this message, the virtual bicycle starts to multiply its speed with a decreasing factor and a time factor. This braking speed can be adjusted, but the delay on both acceleration and deceleration will remain. However, different types of sensors which can measure the speed of a wheel exist. A more accurate sensor that is able to respond more quickly to any changes in the speed could replace the reed switch in the future. More on this in the section "Conclusion: Continuation of this project".

A handful of testers were annoyed by the speed limit. After reaching a certain speed, the virtual bike cannot accelerate further. Although this is a logical game design choice because it allows the game more control over the virtual bike, I personally agree with the testers on this point. I do think that if a user cycles faster that the virtual bike should also move faster. If the bike then moves too fast, the user can simply cycle a little slower. A good compromise would be to add a decreasing factor after a certain threshold, where the speed limit can be surpassed, but the speed does not count for 100%. As an example. If the speed limit would be 100 and the user cycles at 100, the speed would result in 100. But if the user cycles at 120 the speed would be 115 for example. And if the user cycles 150 the speed would be 125. This game mechanic would allow the user to pass this limit but also allows the game itself to maintain control over the virtual bicycle. However, since this mechanic might also influence motion sickness, it would require some testing.

Some users didn't notice the difference between the null trial and the trial with the vignette. I personally think that this is a good thing since the vignette is supposed to be a very subtle effect.

Since the vignette didn't receive a lot of open feedback, its effect will have to be analyzed using the ratings of the symptoms. What is interesting to note is that 1 tester specifically mentioned to be more imbalanced during the trial with the vignette, whilst a second tester specifically mentioned to have increased balance when using a vignetting effect.

Final test: Results – Statistical analysis

The SSQ provides formulas to calculate 4 distinct values. The score for the each of the 3 different categories of symptoms, which are nausea, oculomotor and disorientation, and a total score. The scores of a certain category are determined by the rating of the symptoms in said category. Each category has 7 symptoms and some symptoms apply to more than 1 category. Which symptom applies to which category can be found in appendix 2A-B. The total score is a combination of the scores of each category. The formulas to calculate a certain score are as follows:

$$N = [1] * 9.54$$
$$O = [2] * 7.58$$
$$D = [3] * 13.92$$

Equation 1: The formulas to calculate the score of the categories Nausea (N), Oculomotor (O) and Disorientation (D), where [1], [2] and [3] is the sum of the rating of each symptom in the given category

$$TS = ([1] + [2] + [3]) * 3.74$$

Equation 2: The formula to calculate the total score of the SSQ. Where [1] is the sum of the ratings of each symptom in the Nausea category, [2] is that of the Oculomotor category and [3] that of the Disorientation category

Using these formulas, the amount of motion sickness induced can be accurately determined for each trial for each user. The possible range of outcomes is described in Table 9. For simplicity sake, only the total score will be used to compare the solutions. The goal is not to reduce the symptoms in a specific category but all of the symptoms. Therefore, it is possible that a certain solution may increase 1 category of symptoms and yet still decrease the symptoms overall, although this is unlikely. The scores of each category can be found in appendix 4D.

	Nausea	Oculomotor	Disorientation	Total score
None	0	0	0	0
Slight	66.8	53.1	97.4	78.5
Moderate	113.6	106.1	194.9	157.1
Severe	200.3	159.2	292.3	235.6

Table 9: The possible range of outcomes for each category of the SSQ.

However, we can't just compare the numbers of each trial. A tester's susceptibility to VR induced motion sickness may change depending on experience (learning effect) and exposure time. These 2 phenomena have opposite effects, where one (learning effect) predicts that latter trials will induce less motion sickness (due to experience), whilst the other predicts that latter trials will induce more motion sickness (due to the fact that the motion sickness from previous trials is still present). It is unsure what this effect will be. To complicate this even further, this may also change depending on the person. For this reason, the results of a certain trial will have to be compared with the results of the previous trials.

Before the start of the experiment, the tester is asked to rate his or her symptoms. This is so that we can indicate whether the occurrence of a symptom can be attributed to the simulation or was already present. This will be done simply by subtracting the total score of the SSQ before trial 1 of the total score of the SSQ after trial 1. The number resulting from this calculation is the increase (or decrease) in VR induced motion sickness from trial 1.

Because we expect the simulation to induce motion sickness, we expect this number to be positive. A negative number would mean that the tester experienced more motion sickness before than after the trial. This is not impossible and may occur more often when we compare trials 2 and 3 as well. But because we expect this simulation to induce motion sickness, we expect this to be a positive value. Therefore, a solution may show an increase in motion sickness and yet still be helpful, because the increase is lower than the expected increase. Or vice versa, where a simulation can show a decrease in symptoms, but less than the expected decrease, meaning it is not helpful against VR induced motion sickness. This expected difference for the assessment of trial 1 is simply the average increase of the group who did the null trial.

To recall, the participants can be divided into 3 groups. One who start with the null trial, one who start with the vignette and one who start with the fan. Together, all 3 groups will have tested every condition on every trial number. Table 7 shows which group of testers had which condition during which trial.

If the difference in total score after trial 1 is significantly lower than the expected difference, it can be concluded that that solution has helped reduce VR induced motion sickness in trial 1. Table 10 shows the increases after trial 1 as compared to before the trial as sorted by trial condition.

Trial 1: null	Trial 1: fan	Trial 1: Vignette
11,22	-14,96	37,4
108,46	14,96	11,22
-11,22	-18,7	-18,7
18,7	3,74	-18,7
14,96	26,18	-26,18
0	29,92	-7,48
29,92	11,22	11,22
-18,7	-14,96	7,48
11,22	3,74	7,48
18,28444444	4,571111111	0,415555556

Table 10: The total score after trial 1 minus the total score before trial 1 sorted by trial condition. The average difference is also listed below

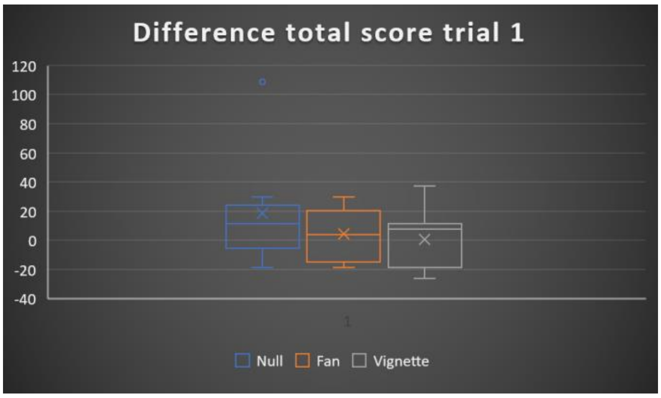

Figure 13: The boxplot of the difference in total score of trial 1

These 3 different scores give us an indication of how well a solution reduced the amount of motion sickness for a certain group during trial 1. Both the fan and the vignette show lower total scores of the symptom ratings, which means that they helped reduce the amount of motion sickness induced. However, as can be illustrated by Figure 13, the total scores that were used to calculate the expected difference contain an outlier. Tester 4 showed an increase in total score of 108,46. If the expected difference is calculated without including this outlier, it becomes 7,0125.

But the effects of the solutions in trial 2 and 3 can also be analyzed. However, this increase can not simply be compared to that during trial 1, because the different groups had different conditions during the first trial. Instead, we will regard the total score after trial 1 as the new starting score for trial 2. We assumed that the symptoms experienced at the end of trial 1 are the same as those when starting trial 2. This way we can compare trial 1 and 2, regardless of what condition was used in trial 1. This means that each tester group (3 groups based on trial condition order) has its own expected difference for each trial. Note that we use the total score of trial 1 and not the difference between before the trial and after trial 1. This will be subtracted of the total score of trial 2 and this results in a difference between before and after trial 2. These values can then be compared to see whether the solutions show a decrease / lower increase. Also note that these differences will probably be lower since comparing a normal state to having been in the simulation once shows a bigger difference than comparing having been in the simulation once versus having been in the simulation twice.

Trial 2: null	Trial 2: fan	Trial 2: vignette
18,7	-41,14	33,66
3,74	-3,74	-52,36
11,22	0	0
0	0	-3,74
-3,74	-3,74	11,22
-14,96	0	0
-14,96	29,92	-11,22
0	-7,48	7,48
0	-7,48	-11,22
0	-3,74	-2,908888889

Table 11: The total score after trial 2 minus the total score after trial 1 sorted by trial condition. The average difference is also listed below

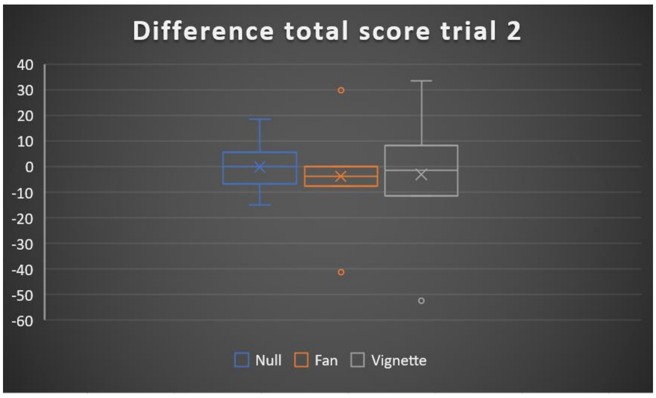

Figure 14: The boxplot of the difference in total score of trial 2

As can once again be seen in Figure 14, the values in the table are partially based on outlying scores. If these outliers were to be excluded the average difference of the fan in trial 2 would be -3,205714286 and the average difference of the vignette in trial 2 would be 3,2725. Just as the outlier of trial 1, the outlier of the vignette can be attributed to tester 4. This tester had a very high total score after trial 1, and this results in an outlier when comparing the before trial score with the trial 1 score and also when comparing the trial 1 score with the trial 2 score.

What can be seen is that the fan actually has a negative value. This is due to the fact that the testers of the group that had the fan during trial 2 experienced (slightly) less motion sickness in trial 2 relative to trial 1. Oddly enough, the null trial does not show an increase or decrease when compared to the previous trial. The tester group that had the null condition on trial 2 had the fan during trial 1.

Different than after trial 1, the vignette now actually shows an increase in total score, meaning that these testers experienced slightly more motion sickness after trial 2 than after trial 1. This may be unexpected since the vignette had the lowest increase in total score after trial 1 of all 3 conditions. Let's compare trial 2 and 3 and see how well each solution does.

Trial 3: null	Trial 3: fan	Trial 3: vignette
-18,7	-44,88	0
-7,48	-37,4	14,96
7,48	-3,74	0
7,48	-14,96	0
33,66	0	3,74
3,74	0	0
-44,88	-3,74	0
0	-11,22	0
22,44	-7,48	0
0,415555556	-13,71333333	2,077777778

Table 12: The total score after trial 3 minus the total score after trial 2 sorted by trial condition. The average difference is also listed below

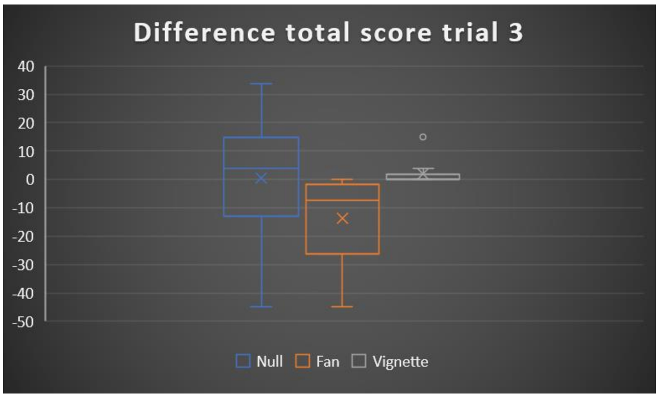

Figure 15: The boxplot of the difference in total score of trial 3

This time there is only a single outlier, with the vignette. This outlier is the value of 14,96. I chose to include this value when calculating the average this time, because this outlier is caused by the fact that most of the rest had a total score difference of 0.

This means that, when compared to trial 2, the null condition shows a (slight) increase in total score. The vignette also shows a less slight but still small increase when compared to trial 2. The fan, however, shows a significant decrease in total score. Testers actually felt better after trial 3 than before.

Let's analyze. Table 13 shows the average difference a trial has on the average total score of a group of testers, sorted by trial condition. We can see that the simulation still induces motion sickness by the fact that there is an increase in score after the first trial. However, both the vignette and the fan show a smaller increase than the null test.

After that, the null test remains quite consistent. It does not induce more motion sickness than the previous trial, but it does not show a decrease either. The vignette does show an increase in trial 2 and 3. This is odd, because the vignette shows the lowest increase during trial 1. The fan does show a decrease. When compared to a tester's "natural state", which would be the total score of the SSQ that was filled out before trial 1, it does show an increase after trial 1. But this increase is smaller than the simulation would have had without the fan. Trial 2 and 3 both indicate that testers actually felt better after the trial than before. As illustrated in Figure 16, the fan consistently receives lower scores than the null test, meaning that this simulation induces less motion sickness when using the fan.

	Null	Fan	Vignette
Trial 1	7,0125	4,5711	0,4155
Trial 2	0	-3,2057	3,2725
Trial 3	0,4155	-13,7133	2,0777

Table 13: The average difference in total score between each trial and the previous trial

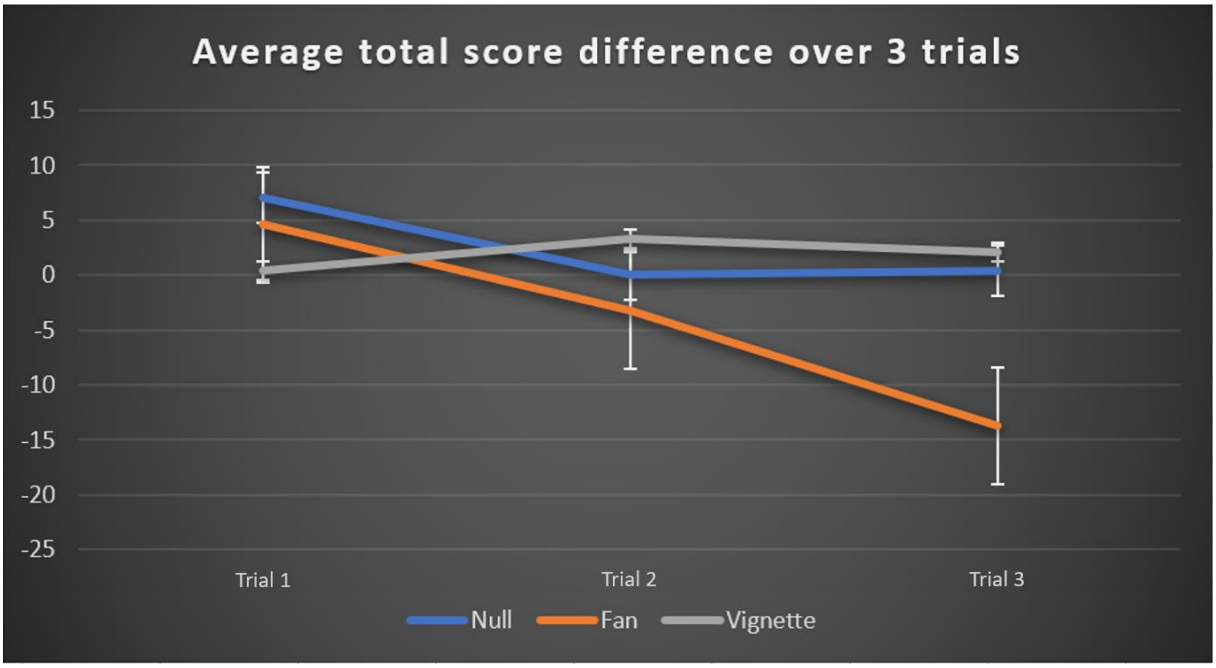

Figure 16: The average differences in total scores over 3 trials

Now there's only one thing left to do, and that is to prove that the values are actually statistically different. For this I will be conducting a 2-tailed t-test on the difference between the expected difference in total score and both of the solutions. I will use $\alpha = 0.1$ (a smaller Alpha value would be superfluous since the group size is rather small). I will not include any outliers when comparing samples. Before I continue, I think that it's important to note that I personally believe that whether or not the solutions should be implemented is more of a subjective subject, and that it (should) depend on more factors than just the statistical difference.

Trial 1	*Null*	*Fan*
Mean	7,0125	4,571111111
Variance	225,3314938	320,9377111
Observations	9	9
Pearson Correla	0,454311484	
Hypothesized M	0	
df	8	
t Stat	0,42151195	
P(T<=t) one-tail	0,342239435	
t Critical one-tai	1,859548038	
P(T<=t) two-tail	0,684478869	
t Critical two-tai	2,306004135	

Table 14: The results of the t-test comparing the null and the fan scores of trial 1

Since μ (Fan) is smaller than μ (Null) we look at the P(T<=t) one-tail value. This value is 0.34, which is larger than α (0.1) and therefore we cannot conclude that at 95% significance the μ (Fan) is smaller than the μ (Null).

Trial 1	*Null*	*Vignette*
Mean	7,0125	0,415555556
Variance	225,3314938	400,2007778
Observations	9	9
Pearson Correla	0,091703068	
Hypothesized M	0	
df	8	
t Stat	0,828615339	
P(T<=t) one-tail	0,215673717	
t Critical one-tai	1,859548038	
P(T<=t) two-tail	0,431347435	
t Critical two-tai	2,306004135	

Table 15: The results of the t-test comparing the null and the vignette scores of trial 1

Since μ (Vignette) is smaller than μ (Null) we look at the P(T<=t) one-tail value. This value is 0.22, which is larger than α (0.1) and therefore we cannot conclude that at 95% significance the μ (Vignette) is smaller than the μ (Null).

Trial 2	*Null*	*Fan*
Mean	-7,89492E-16	-3,205714286
Variance	118,8946	8,492471429
Observations	9	9
Pearson Correla	-0,047163749	
Hypothesized M	0	
df	8	
t Stat	0,842234888	
P(T<=t) one-tail	0,212059056	
t Critical one-tai	1,859548038	
P(T<=t) two-tail	0,424118113	
t Critical two-tai	2,306004135	

Table 16: The results of the t-test comparing the null and the fan scores of trial 2

Since μ (Fan) is smaller than μ (Null) we look at the P(T<=t) one-tail value. This value is 0.21, which is larger than α (0.1) and therefore we cannot conclude that at 95% significance the μ (Fan) is smaller than the μ (Null).

Trial 2	*Null*	*Vignette*
Mean	-7,89492E-16	3,2725
Variance	118,8946	186,8655938
Observations	9	9
Pearson Correla	0,643697783	
Hypothesized M	0	
df	8	
t Stat	-0,920026704	
P(T<=t) one-tail	0,19223069	
t Critical one-tai	1,39681531	
P(T<=t) two-tail	0,38446138	
t Critical two-tai	1,859548038	

Table 17: The results of the t-test comparing the null and the vignette scores of trial 2

Since μ (Vignette) is larger than μ (Null) we look at the P(T<=t) one-tail value. This value is 0.19, which is larger than α (0.1) and therefore we cannot conclude that at 95% significance the μ (Vignette) is larger than the μ (Null).

Trial 3

Trial 3	Null	Fan
Mean	0,415555556	-13,7133333
Variance	522,5922778	269,2613
Observations	9	9
Pearson Correlat	0,343364801	
Hypothesized M	0	
df	8	
t Stat	1,833823626	
P(T<=t) one-tail	0,052012876	
t Critical one-tail	1,39681531	
P(T<=t) two-tail	0,104025753	
t Critical two-tai	1,859548038	

Table 18: The results of the t-test comparing the null and the fan scores of trial 3

Since µ (Fan) is smaller than µ (Null) we look at the P(T<=t) one-tail value. This value is 0.052, which is smaller than α (0.1) and therefore we can reject H_0 and conclude that at 95% significance the µ (Fan) is smaller than the µ (Null).

Trial 3	Null	Vignette
Mean	0,415555556	2,077777778
Variance	522,5922778	24,86684444
Observations	9	9
Pearson Correla	0,006816774	
Hypothesized M	0	
df	8	
t Stat	-0,213428211	
P(T<=t) one-tail	0,418165859	
t Critical one-tai	1,39681531	
P(T<=t) two-tail	0,836331717	
t Critical two-tai	1,859548038	

Table 19: The results of the t-test comparing the null and the vignette scores of trial 3

Since µ (Vignette) is larger than µ (Null) we look at the P(T<=t) one-tail value. This value is 0.41, which is larger than α (0.1) and therefore we cannot conclude that at 95% significance the µ (Vignette) is larger than the µ (Null).

Allow me to summarize the above tables to save you some reading. Except for the fan in trial 3, none of the solutions were significantly different than the expected difference in total score from the null trial at α = 0.1. The fan showed significant decrease during trial 3, however. Because of the small group sizes, it is difficult to prove significant statistical difference. Therefore, as mentioned before, I'd personally advice the decision as to whether or not a certain solution should be implemented to be based on different factors than the statistical difference. I'd advice the therapists to try the simulation with and without a solution and determine what they prefer. The open feedback from both testing sessions (Appendix 4A – 4B) could prove helpful in making this decision.

Final test: Conclusion

Very little can statistically be concluded from the final test. It is for this reason that my conclusion will be a little more subjective. Although it can only be statistically proven in trial 3, I do believe that the fan is of great aid when it comes to reducing the severity of VR induced motion sickness in this simulation. This can be illustrated by the fact that with every group, in every trial, it has a lower difference than the null trial (Figure 16). Table 8 also illustrates that a lot of testers prefer the simulation with the fan, as opposed to without. I personally share this opinion and I'd advice the RRD to keep this solution implemented.

Although the vignette showed the best result during trial 1, after trial 1 it only scored worse than the simulation without the vignette. Although this difference is small, and in one case caused by removing an outlier, it does indicate that the vignette actually increases VR induced motion sickness. I personally prefer the simulation with the vignette, but apparently the testers do not. The opinions regarding this solution are divided, which can be illustrated by these 2 quotes from the open feedback of the final test: "*I experienced more imbalance with the vignette*" and "*I experienced greater balance with the vignette*". I'd advice to keep this solution implemented but with the ability to turn it off, so that users who prefer the simulation with vignette can use it, but others don't have to.

Conclusion

Discussion

This section will discuss anything that happened during this project, focusing on the testing sessions, that may have caused deviations in the results. It is important to note, however, that the focus of the pilot test wasn't to acquire accurate measures that allow for statistical analysis. Instead, the hope was to receive a lot of open, personal, subjective feedback on the suggested solutions. Therefore, any differences of the simulator sickness questionnaire results from this test would be of little impact. Nevertheless, there are always factors that might have influenced a tester's experience in the simulation.

Let's start with the fact that (VR induced) motion sickness is highly personal. Great individual differences exist between not only the resistance against VR induced motion sickness, but also the symptoms experienced. Given that the people selected to participate in the pilot test were all experienced with VR, it is possible that they have an above average resistance to VR induced motion sickness and this may have influenced their opinions regarding the solutions. This effect would be amplified by the fact that it was a very small tester group, so any difference will have a relatively large impact. Personal differences would be of less effect during the final test. This is because of 2 reasons. First of all, the number of participants was way higher during this testing session, making any deviation from the average less impactful on the overall results. Secondly, the participants of this experiment weren't specifically selected to have a lot of knowledge and experience with VR. This means that the deviations in susceptibility to VR induced motion sickness will be both above and below average, theoretically cancelling each other out.

Another important factor is the trial completion time. Longer exposure to a VE means increased severity of the symptoms [14] [23] [24]. Some testers were faster than others. Sometimes a trial had to be restarted. Some testers decided to stop the trial before the left turn (during the pilot test only). These differences in trial completion times and thus exposure times may have resulted in different symptom ratings.

The learning effect is the phenomenon where a person becomes more resistant to VR induced motion sickness due to experience. It is also known that increased exposure time is correlated with increased motion sickness. These phenomena counter each other, but it is unsure to what extent. Will trial 5 generally induce more motion sickness than trial 1 or the other way around? It is unknown. To counter this effect, every condition was held at different trials, as described in the section "Pilot test: Method" and "Final test: Method". The results from the final test indicate that the simulation does induce some level of motion sickness, but it will remain quite steady after trial 1. This would indicate that the learning effect and the increased exposure time balance each other out.

It might be interesting to assume that the learning effect and the increased symptoms due to a longer exposure time perfectly cancel each other out. A similar trend can be seen when analyzing the 'Null' condition over several trials. Making this assumption would allow us to compare the conditions of several trials at once, which means that we can perform a statistical analysis with N=27. This might have different results than the 3 different t-tests of each solution provided in this report.

Every tester had the opportunity to adjust both the bike and the HMD. They could adjust the height of the saddle, the gear or the amount of resistance. They could redo their hair, tighten or loosen the headband or adjust the distance between their eyes. If they have glasses, they could decide whether they'd test with glasses on or off. However, this does force testers to adjust these things in a limited amount of time. It is possible that the simulation was more comfortable for one tester than for the other. This could've resulted in different symptom ratings (such as for general discomfort).

The fact that some of the testers stopped the trial before the left turn of course influences the severity of their experienced symptoms. This happened only during the pilot test and only with some of the testers. Most of the testers said that they experience the most motion sickness in and after the turn. Skipping this turn will therefore logically decrease the amount of motion sickness experienced. However, the people who decided to skip the turn did so because they were already experiencing motion sickness to some degree. Also, I interpreted skipping the turn as a sign that the turn was a cause of motion sickness.

It should also be mentioned that experiments with more participants yield more accurate results. This one applies primarily to the final test, since I didn't perform a statistical analysis on the pilot test. Although I'm very satisfied with the 27 participants I managed to get, more participants is always better. This can especially be noticed by the fact that they were divided into 3 groups. This resulted in each solution having 3 results instead of one, but each result is based on a smaller number. In some cases, like with the vignette, these results may oppose each other. One result was positive, but 2 others were negative.

Although the SSQ is praised by most scientists in this field, it is not the optimal choice for every experiment. This can best be illustrated by a quote from Kaufmann et al. [5]: "the SSQ inventors argue that the scale is not intended to differentiate between simulators with low scores, but rather should be used to distinguish between problematic simulators (high score) and unproblematic simulators (low score)". Since the final test yielded mostly low-moderate scores this is of course of influence on the ability to compare the different conditions. The open feedback (appendix 4B) can be of help to determine whether the scores accurately represent the tester's opinion and condition (regarding VR induced motion sickness) or not. Repeating this experiment using different questionnaires (options provided in section "Ideation: Measuring VR induced motion sickness") is another method these results could be confirmed or not.

Another thing that may have been of influence during the final test is that it was performed under the assumption that the previous trial condition had no impact on the next trial. This is not exactly true since the total scores of the participants were adjusted by those of their previous trial. However, some participants started trial 1 with the fan (the fan reduces the amount of motion sickness induced), and others had the null condition during trial 1 (which induced the most motion sickness). These scores were subtracted for the next trial, but the pattern with which VR induced motion sickness builds / arises is still different and this may be of influence over the course of multiple trials, although this is unknown. But since the effect of a certain solution is rated relatively to the solution tested before, both solutions are of importance whilst only one of them is actually considered. In a future experiment, the order of the solutions should be more randomized, so that each trial condition is preceded by every other trial condition in equal amounts.

Conclusion

This section will discuss the overall conclusion of the entire project. What do I think of the results of this project? What conclusions can be drawn from them? What do I think had the most impact?

Let me start off with saying that, although I am satisfied with the results of the implemented solutions, I think that those were not the biggest improvement on this simulation I made. Even if none of the solutions were to be implemented, I still finished with a better product than I started with. This is because I fixed a lot of existing bugs in the code, I improved the efficiency of the code and I added comments to the code. Let me be clear, I am not trying to insult the previous people who worked on the project, but it really did require some fixing. There were no comments in the code whatsoever, so I had to figure out how everything worked myself. I added a lot of comments so that the next person working on this project doesn't have to do this. This doesn't influence motion sickness, but it does improve the program for the future people who work on it.

I also optimized the code. This was mainly done when fixing bugs or figuring out what a piece of code actually did. The simulation performed quite smooth already (in terms of framerate / required processing power), but I did make some improvements. This mainly includes things like referencing to another script or gameobject (an action that requires relatively high processing) once in the setup instead of every frame, Replacing hardcoded functions with native / dynamic functions, and removing pieces of code that don't do anything.

I also fixed a lot of bugs. This is, in my opinion, the greatest improvement of the simulation I made. Fixing bugs wasn't part of my project and didn't require research. We can all agree that the ability to turn the steering wheel should be present in a cycling simulation without consulting scientific literature. Some bug fixes are also discussed in section "Realization" The most important bugs that I fixed are:

- The virtual steering wheel is now at the same angle relative to the virtual bike as the physical steering wheel is to the physical bike.
  Previously the angle of the virtual steering wheel depended on the angle of the physical steering wheel relative to the virtual bike, meaning that after a 90° turn, the virtual steering wheel would have an offset of 90°.
- The virtual bike now adjusts with a maximum allowed difference of 1° or -1°.
  Previously, the user had to turn the wheel more than 5° or -5° before the virtual steering wheel adjusted.
- The acceleration and deceleration are now continuous. This is described in section "Realization: continuous acceleration and deceleration".
  Previously, the user could only cycle at 1 preset speed and could only brake instantly. The speed is now dependent on the speed of the rear wheel of the physical bike and the braking is a roll off function that is called upon when the speed of the physical bike hits 0.
- The orientation of the steering wheel can now be measured in any setup.
  Previously, the steering wheel would only work if the physical bicycle would face a specific direction. This is a bug you'd typically not encounter, since you don't move the setup very often. I encountered it when testing and the problem was that the orientation of an HTC Vive controller is not based on the orientation of the virtual scene. This means that you can start with an orientation of 355 degrees and after turning 5 degrees it'd go to 0 again. Different values that are calculated by using e.g. "X = Controller.GetAngle() – 180;" will then crash.
- The simulation can now recognize which controller is used.
  The steering wheel requires an index of the HTC Vive devices, which ranges from 1 to 15. I don't know how a certain device determines its index, and they have the tendency to change indexes after being turned off, making it even more unpredictable. Instead of hardcoding one index, the simulation now echoes the index of the device that is the most to the front, which would be the controller on the steering wheel.

I fixed more bugs than just these, but these are the ones that have the most impact on a user's ability to use the simulation the way it is intended to use.

Although I said that I personally believe the bug fixes were the biggest improvement on the simulation, the implementation of the solutions is also something I'm quite proud of. I expect that only the fan will be permanently implemented. The other solutions still exist within the simulation and can be turned on again if they were to be subject of experiment in the future. Oddly enough, the only solution that does not originate from a scientific source is the one that would prove the most efficient in reducing VR induced motion sickness. Since this solution was king of my baby during this project, I'm proud that this solution made it this far. The decision about which solutions should remain implemented will be left to the therapists at the Roessingh, but I do hope that they will follow my advice.

To conclude, the simulation underwent great improvements during this project, but I still think that this simulation is not yet ready to be used as a tool to practice participation in traffic. In spite of the improvements regarding the reduction of VR induced motion sickness, this simulation still induces some amount of motion sickness. Most of the testers did not experience significant amounts of motion sickness, but since high personal differences regarding one's susceptibility to VR induced motion sickness exist, it is not unlikely that some will still experience this. Especially since the simulation is meant to be used by children, who may not be able to accurately assess the risks, I think further improvements are needed. I'd like to illustrate this with a quote from one of the testers (tester 19) of the final test, which was when the simulation was already greatly improved:

"*I really did not expect the experience to be like this; the fear of falling and bumping into obstacles was prominently present. I must admit that cycling in VR is significantly more scary than cycling in real life, which is a daily activity for me. I did not expect the immersion to be this intense. For the first time ever, I have experienced motion sickness in VR. In some cases, it felt like I lost control over steering the bicycle*."

There is also another reason behind my opinion. Real traffic is hectic and unpredictable, but the simulation is not. The only obstacles in the simulation are road barriers and ducks. The road barriers can be seen from a great distance and always provide a practical alternative route, meaning that they might as well be excluded. The ducks only appear at specific points and move at a constant speed over the road. They are small and easily avoided.

If you want to accurately replicate a traffic situation, the simulation would have to include other cyclist, cars, traffic lights, trains, trucks, different weather situations, pedestrians, emergency vehicles, and all of the other stuff one might encounter in traffic. Each of these should have their own behavior. For example, most of the time a car would stop for a red light, but sometimes it might not, forcing the user of the simulation to react. I think that the therapists at the RRD would agree with me on this point and this will be one of the tips I further explain in the section "Conclusion: Continuation of this project".

To end this section, I do think this simulation has potential to be an effective tool to practice participation in traffic in the future, but further improvements are needed before it's used as such.

Continuation of this project

This section will be devoted to listing any advice I have for people who will work on this project in the future. By definition, this advice is subjective and based on my experience with this project. The goal of this section is to form a good starting point for the people who continue with this project. This section will list all sorts of things: interesting topics of research, upgrades to the simulation that would be nice, bugs that haven't been fixed and tips for the therapists who will eventually work with this simulation. Because not every tip is aimed at everybody, I have divided my advice in 4 distinct categories: hardware, unity-related, interesting topics for future research and advice for the therapists.

Hardware

Let's start with the hardware. Although the simulation works fine with the current hardware, some adjustments could improve several aspects of this simulation. The first thing I'd change is the steering. At the moment the simulation uses an HTC Vive controller to measure the angle of the steering wheel. Even though these controllers provide fast and accurate measures, this method of measuring the angle has been the cause of numerous bugs in the simulation. Sometimes the controller loses tracking for a while and this causes a difference between the angle of the physical and the virtual steering wheel. It would be better if the controller was to be replaced by a sensor attached to the Arduino. This would not only fix a lot of bugs and greatly simplify the Unity code, It'd also enable the simulation to work with different HMDs. Right now, the simulation requires an HTC Vive set because it requires the controller. If this requirement is removed, the simulation could work with any headset. One last advantage would be that you won't have to charge the controller anymore.

Replacing the Vive controller with a different sensor has been attempted by others in the past. They wanted to replace it with a potentiometer, which is not a bad idea in my opinion. But they put this small and fragile sensor underneath the front wheel and created some big wooden rotating construction that would hold the wheel. This is not the best approach if you'd ask me.

Instead, I'd advice to attach a potentiometer (or a different, comparable type of sensor) to a different part of the bike. At the moment, the bike has an attachment at the point where the frame is attached to the steering wheel. This attachment is a small box. Around the steering wheel is a gear, connected to a smaller gear. This smaller gear would rotate when the steering wheel rotates and this would be an ideal place to implement a potentiometer.

While we're at it, let's replace the reed switch. The reed switch measures the speed of the rear wheel by sensing how many magnets (attached to the spokes of the wheel) pass it in a certain time period. Although this sounds nice, it requires multiple magnets to have passed before it can accurately calculate the speed, and even then, it requires a lot of smoothing. It also cannot measure anything when the wheel is standing still, so the user has to rely on a time out function to brake the bike.

Replacing this sensor with a more responsive and accurate one would improve the simulation. Not only would it make the simulation more realistic, it may also help reduce motion sickness. It is known that a feeling of being in control helps reduce motion sickness. Your actions need to be translated into direct, logical and linear reactions. The biggest problem that the reed switch now causes is the small delay before accelerating and braking. This is not the biggest problem, but even so, better sensors exist for a reasonable price and there is no reason not to use these instead.

Unity-related

As mentioned several times in this report, the RRD is planning to hire professional game designers to create different levels. I want to advice these game designers to create the levels in a less realistic, low-poly style. The current style of the simulation is already quite cartoonish / low-poly, so I don't think any further decrease in realism would improve the simulation, but I would advice against increasing the realism / detail of the scene.

Low-poly scenes do not only induce less motion sickness relative to more detailed ones, they also require less processing. The detail of the scene is of great influence on the speed with which the scene can render. Low-poly scenes would thus allow for a higher framerate, which is an aspect that both the literature as well as the testers claim would reduce motion sickness. Since low-poly scenes require less processing, you'd also be able to build bigger scenes if you use this style, but this would require more processing again.

Remodeling the scenes would also allow us to remove some of the existing bugs. The Z-level glitching that tester 4 mentioned during the pilot test (Appendix 4A) could be removed for example.

Lastly, it is my personal opinion that the level should be more dynamic. This means improving more factors than just the scene; it'd also mean programming some behavior for different elements in the scene (e.g. traffic users, weather, traffic lights, etc.). Improving this would be the best next step for this project, according to me. One last note would be to also make the scene look more like a typical Dutch landscape. I expect that this simulation would only be used by Dutch children when it's put into use at the Roessingh. It would be a more realistic practice for these children if the scene would then resemble a Dutch landscape.

Although I fixed a lot of bugs, some still exist. Bugs come and go when programming and it's not unlikely that there exist some bugs that I don't even know of, or new bugs will arise. The only bug that still exist that I know of is that sometimes, after braking, the bike can't accelerate anymore. I haven't been able to fix this bug because I was unable to get this phenomenon to occur myself, but some testers did experience it. It's rare and not all that annoying, but it should be fixed nonetheless.

The next 2 are more features than bugs, but I think that they should be removed. The first one is that after braking, the minimum velocity reached is still faster than 0. If you brake in real life you end up standing still and so should it be in virtual reality. This mechanic was made on purpose by the student who worked on this project before I did, and I'm not sure why he did it this way. I expect new bugs to arise when removing this mechanic, but it should be changed nonetheless.

The second mechanic I'd remove is the maximum speed. Although I understand why it was made this way, it is my personal believe that cycling in the simulation should resemble cycling in real life. This also means that if you cycle faster, you actually go faster. A compromise could be made here and is suggested in section "Final test: Results – Open feedback".

Interesting topics for future research

The "Ideation: Preventing VR induced motion sickness" section of this report has shown a lot of adjustments that can be made to a VR simulation that have shown to delay/decrease the symptoms of VR induced motion sickness. Excluding the tips and tricks that have not been scientifically proven, each of these solutions decreases the symptoms of VR induced motion sickness. These experiments were conducted in a different context however; some researchers tested their potential solution using a VR game, whilst others tested theirs using a VR rollercoaster simulation. It is still unsure whether these same solutions will work within a different context. Different variants of a solution should be tested, to see which parameters yield the best result. Also, all of these solutions have been tested separately, and not combined. The next step in research about the prevention of VR induced motion sickness would be to test different combinations of these solutions. Some of these may potentially amplify each other, creating an even greater decrease of the symptoms, whilst others may cancel each other out. It would be of great interest, not only for the RRD cycling simulator project at the RRD, but for the field of research regarding (VR induced) motion sickness, to see which combinations have the greatest effect. Learning about different combinations might also provide new insights into the exact cause of VR induced motion sickness.

The scientifically unproven tips and tricks to prevent or recover from VR induced motion sickness presented in section “Ideation: Preventing VR induced motion sickness” would be an interesting topic of further research. These tips and tricks are not scientifically proven and are presented as such in the report, so logically it follows that this is a point of discussion still, and no definitive conclusion should be drawn from these tips and tricks. Nevertheless, the scientifically unproven solution that was tested during this project (the fan) proved to be the most effective in reducing motion sickness. Research into these would be interesting since extending the list of possible solutions to VR induced motion sickness will also enhance research options regarding research into the combinations of potential solutions as mention above. Extending the list of possible solutions might also provide more insight into the exact cause of VR induced motion sickness. I personally believe that this is an obvious direction that research into solutions to VR induced motion sickness would take.

Curing the symptoms of VR induced motion sickness specifically, has not been researched extensively. This is of course due to the fact that there are bigger questions to be answered at the moment, the cause of VR induced motion sickness for example. As of now, it is generally assumed that learning the cause of VR induced motion sickness will provide a method of preventing it. However, this is not certain, and neither is if and when we will learn the exact cause of VR induced motion sickness. And even if the exact cause of VR induced motion sickness is determined, it is unsure whether people will even be able to prevent it. Therefore, research into methods for the curing- or reducing the severity of the symptoms of VR induced motion sickness is needed.

The last interesting topic for future research could be to just repeat my experiment. As mentioned in the discussion, more testers would yield more accurate results. Although this would be useful, I personally think that, especially since there are so many things regarding VR induced motion sickness that haven’t been researched yet, this is not the subject that is the most in need of more research at the moment.

Advice for the therapists

I also have advice for the therapist who’d work with this simulation if it is eventually put into practice. First of all, you can use the learning effect to reduce one’s susceptibility to VR induced motion sickness. I experienced this firsthand during this project. The first time I was in this simulation I felt quite sick, but after being in it hundreds of times I have developed quite the resistance. Maaike (A student working on analyzing gaze behavior in the same simulation) said she also experienced this phenomenon.

The second piece of advice I’d give these therapists is to stop the simulation when signs of VR induced motion sickness occur. The learning effect may work counter effective if the users start to associate the simulation with a feeling of motion sickness. Of course, there is also an ethical aspect to this, since it would be unethical to knowingly and purposefully induce VR induced motion sickness to a little child.

To give a short overview, here are the tips I have for people who will work with this project in the future.

Hardware

- Replace the Vive controller with a potentiometer
    - Saves processing power
    - Simulation can be used with different HMDs
    - No charging controller
- Replace reed switch with more accurate sensor
    - More accurate speed measurements
    - Faster response times when accelerating and braking

Unity-related

- Remodel the scene with lower realism
    - Saves processing power
    - Shown to decrease symptoms of VR induced motion sickness
    - Able to build bigger scenes
    - Rebuilding the scene allows us to remove some existing bugs (e.g. z-level glitching)
    - More detailed scene, more participants, own behavior, realistic situations
    - More realistically typical Dutch landscape
- Remove bugs
    - No acceleration after braking
    - Z-level glitching
    - Moving when standing still
    - Remove speed cap

Interesting topics for future research

- Research scientifically unproven tips and tricks
    - May provide more insight into (VR induced) motion sickness
    - May provide more helpful solutions
    - The fan originated here and proved helpful
    - An obvious direction for future research
- Research different combinations of existing solutions
    - Different combinations
    - Different contexts
    - Different parameters on 1 solution
    - May provide insight into the exact cause of motion sickness
- Experiment again with more people

Advice for the therapists

- Have users practice regularly
    - Use the learning effect to increase resistance to VR induced motion sickness
- Stop when signs of motion sickness occur
    - Prevents association between the simulation and motion sickness
    - Ethical reasons

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Appendix

Appendix 1A: List of solutions pilot test (English)

The adjustments that will be tested in this experiment.
Please note that not all of these adjustments will be tested on one person due to time, ethical and logistical reasons. Also note that each of the testers will complete one test without any adjustments.

Adjustments:

- Making the field of view smaller
  - Vignetting (the act of making the peripheral vision increasingly darker)
  - Blurring the peripheral vision
- Using a point of reference
  - Using a grid overlay
  - Adding a virtual nose to the view of the user
- Using waypoints
- Using a fan that blows relative to the speed of the user

Note: The blurring and grid overlay were excluded from testing on request of the supervisor and client. For further explanation please consult section “Specification”, “Realization: Implementing the vignetting and blurring” and “Realization: Implementation of the rest frame” of this report.

Appendix 1B: List of solutions pilot test (Dutch)

De aanpassingen die getest zullen worden in dit experiment.

Houd er rekening mee dat, vanwege tijd, etische en logistieke redenen, niet al deze aanpassingen op een persoon getest zullen worden. Houd er ook rekening mee dat elke tester een complete test zonder aanpassingen zal doen.

Aanpassingen:

- Het gezichtsveld kleiner maken
    - Vignetting (Het donkerder maken van het perifere zicht)
    - Het wazig maken van het perifere zicht
- Een referentiepunt gebruiken
    - Een raster over het gezichtsveld van de tester leggen
    - Een virtuele neus toevoegen aan het gezichtsveld van de tester
- Gebruik maken van waypoints (punten op de route die aangeven waar de tester heen moet)
- Een ventilator gebruiken. De hoeveelheid wind die deze ventilator op de tester blaast is relatief aan te snelheid waarmee de tester fietst.

Note: The blurring and grid overlay were excluded from testing on request of the supervisor and client. For further explanation please consult section “Specification”, “Realization: Implementing the vignetting and blurring” and “Realization: Implementation of the rest frame” of this report.

Appendix 2A: The list of symptoms of VR induced motion sickness (English)

The following is a complete list of all the symptoms of VR induced motion sickness that will be measured during this experiment. Please note that not all symptoms will have to occur. The severity of the experienced symptoms is subject to high personal differences.

Symptoms	Nausea	Oculomotor	Disorientation	Explanation
General discomfort	X	X		A general, subjective assessment of how comfortable the user feels
Fatigue		X		How tired the user feels
Headache		X		How much headache the user feels
Eye strain		X		Pain in or around the eyes, tiredness of the eye muscles
Difficulty focusing		X	X	Blurred vision, occasional double vision
Increased salivation	X			The (increased) amount of saliva produced in the mouth of the user
Sweating	X			How much the user is sweating
Nausea	X		X	The amount of nausea experienced/ the urge the user feels to vomit. Bloated feeling
Difficulty concentrating	X	X		The difficulty with which the user is able to concentrate on a specific subject
Fullness of head			X	The user's head feels heavy. It feels very full and pressurized from the inside. In cases the user's heartbeat can be felt on the head.
Blurred vision		X	X	The blurriness of the user's vision. Different from difficulty focusing in the sense that the user does not attempt to focus.
Dizzy (eyes open)			X	The amount of dizziness experienced with the eyes open
Dizzy (eyes closed)			X	The amount of dizziness experienced with the eyes closed
Vertigo			X	Objects around the user seem to be moving whilst they're not. Comparable to the feeling you get after you've been spinning around or been in a rollercoaster.
Stomach awareness	X			The stomach feels uncomfortable. Comparable to nausea but in the stomach specifically.
Burping	X			The amount of burps from the user

Appendix 2B: The list of symptoms of VR induced motion sickness (English)

Het volgende is een complete lijst van alle symptomen van VR geinduceerde bewegingsziekte die tijdens dit experiment gemeten zullen worden. Houd er rekening mee dat niet alle symptomen voor hoeven te komen. De ervaren symptomen zijn erg verschillend per persoon.

Symptomen	Misselijkheid	Oculomotor	Disorientatie	Uitleg
Algemene onconfertableheid	X	X		Een algemene, subjectieve beoordeling van hoe onconfortabel een tester is
Vermoeidheid		X		Hoe moe een tester is
Hoofdpijn		X		Hoeveel hoofdpijn een tester heeft
Oogpijn		X		Pijn in of om de ogen, vermoeidheid van de spieren rond het oog
Moeite met focussen		X	X	Wazig zicht, ziet soms dubbel
Toename speekselafscheiding	X			De (toegenomen) hoeveelheid speeksel geproduceerd in de mond van de tester
Zweeten	X			Hoe erg de tester zweet
Misselijkheid	X		X	De hoeveelheid misselijkheid van de gebruiker/ het gevoel dat de gebruiker moet overgeven. Opgeblazen gevoel
Moeite met concentreren	X	X		De moeite waarmee een tester zich kan concentreren op een specifiek onderwerp
Volheid van het hoofd			X	Het hoofd van de gebruiker voelt vol en zwaar, alsof er druk op zit van binnen uit. De hartslag kan soms gevoelt worden op het hoofd.
Wazig zicht		X	X	De wazigheid van het zicht van de tester. Dit verschilt van moeite met focussen in de zin dat de tester niet probeert te focussen in dit geval.
Duizelig (ogen open)			X	De duiziligheid van de tester met de ogen open
Duizelig (ogen dicht)			X	De duiziligheid van de tester met de ogen dicht
Duizeligheid / Vertigo			X	Stilstaande objecten lijken te bewegen. Vergelijkbaar met het gevoel nadat je lang rond gedraaid hebt of in een achtbaan bent geweest.
Naar gevoel in de maag	X			De maag voelt onconfortabel. Vergelijkbaar met misselijkheid maar specifiek in de maag.
Boeren	X			De hoeveelheid boeren van een tester

Appendix 3A: Information brochure pilot test (English)

Research into VR induced motion sickness in a cycling simulator.

Children with DCD have trouble learning how to ride a bike and receive extra help with acquiring this skill at the Roessingh center of rehabilitation. In order to practice interaction with other traffic participants without exposing the children to the risks of actual traffic, a VR cycling simulation was developed. This is the simulation that will be tested today.

This simulation has a downside, which is that it has the tendency to induce motion sickness. VR induced motion sickness is a phenomenon that can occur in any VR/AR simulation. VR induced motion sickness comes with a variety of symptoms which will afterwards be rated on a 4 point scale (if preferred, this list can be seen before signing this document). The most common symptoms are nausea, disorientation, headaches and dizziness. Anybody can get VR induced motion sickness, it is not contagious, and it will go away over time.

For this experiment, you will cycle through a virtual environment on a physical bicycle. The steering and pedaling will be used to control your virtual bicycle. Finishing the route takes 5-7 minutes.

The goal of this experiment is to repeat this route multiple times[1], changing some aspect that is correlated with VR induced motion sickness. These aspects may be things like pointing a fan at the user, making the field of view smaller or making use of waypoints/ collectables during the simulation (if preferred, the complete list can be seen before signing this document).

In between the testing sessions there is a short break in which the test user fills in a questionnaire and can give some additional verbal feedback. These breaks are about 5 minutes but can be extended if requested. The total duration of the experiment should not be longer than 1 hour.

As a test user, it is important to beware of the risks regarding participation in this experiment. You are at risk of developing (temporary) VR induced motion sickness.

Criteria for test users:

- The test user is 18 years or older.
- The test user has been in a virtual environment at least once[2].
- The test user is not particularly susceptible to VR induced motion sickness[3].

Important things to note as a test user:

- You have the right to stop the experiment at any time. If I, as experimenter, see signs of motion sickness I will discontinue the experiment. The data might still be used unless requested otherwise.
- You can request for your data not to be used until 24 hours after the experiment. If this request is made after this time period, I will try to exclude the data, but this may not be possible in every case. In order to request the exclusion of your data in this experiment, see the contact information on the next page.
- You can remain completely anonymous. I will need to know your age, gender, experience with virtual reality and an estimation of your own susceptibility to motion sickness. No names or addresses will be used.

If you have any questions regarding (VR induced) motion sickness, the setup of the experiment, your rights as a test user, or anything else, you can ask the experimenter (Joep Eijkemans) now. If any questions arise later in time, you can contact the experimenter via the contact information below.

Contact information for questions, problems, information about your rights as a participant, requesting exclusion from this experiment or suggestions for other participants.

Telephone and WhatsApp: (+31)6 1977 9165

E-mail: j.w.eijkemans@student.utwente.nl

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary pro tem of the Ethics Committee of the department of EEMCS, mrs J Rebel-de Boer.

E-mail: ethics-comm-ewi@utwente.nl

1) Ask the experimenter for the exact number of trials.

2) Experienced a virtual environment via a head mounted display for at least 5 minutes. Augmented reality can also suffice for this criterion, if a sufficient percentage of the environment was virtual, discuss this with the experimenter.

3) If you know yourself to be susceptible to motion sickness in virtual reality you cannot participate in this experiment. If unsure, discuss with the experimenter.

Appendix 3B: Information brochure pilot test (Dutch)

Onderzoek naar VR geinduceerde bewegingsziekte in een fiets simulatie

Kinderen met DCD hebben moeite met leren fietsen en krijgen hiervoor bij het Roessingh centrum voor rehabilitatie extra hulp. Om interactie met andere verkeersgebruikers te trainen, zonder de kinderen bloot te stellen aan de risico's van het verkeer is een VR fiets simulatie ontwikkeld. Dit is de simulatie waarmee we vandaag zullen testen.

Deze simulatie heeft een probleem, namelijk dat hij erg geneigt is bewegingsziekte te induceren. VR geinduceerde bewegingsziekte is een fenomeen dat in elke VR/AR simulatie kan ontstaan. VR geinduceerde bewegingsziekte heeft een hoop symptomen, die achteraf gemeten worden op een 4 punt schaal (Op verzoek kan de gehele lijst ingezien worden voor het tekenen van dit document). De meest voorkomende symptomen zijn misselijkheid, disorientatie, hoofdpijn en duizeligheid. Iedereen kan VR geinduceerde bewegingsziekte krijgen, het is niet besmettelijk, en het gaat na een tijdje vanzelf weer weg.

Voor dit experiment zal je door een virtuele omgeving fietsen op een echte, fysieke fiets. Het stuur en de trappers zullen gebruikt worden om de virtuele fiets te besturen. De route duurt ongeveer 5-7 minuten om te fietsen.

Het doel is om de route meerdere malen te fietsen[1], en telkens een aspect dat gerelateerd is aan VR geinduceerde bewegingsziekte aan te passen. Dit zullen dingen zijn zoals een ventilator op de fietser richten, het gezichtsveld kleiner maken, of gebruik maken van 'waypoints' (Op verzoek kan de gehele lijst ingezien worden voor het tekenen van dit document).

Tussen de testsessies zal een korte pauze zijn waarin de tester een enquête invult en verbale feedback kan geven. Deze pauzes zijn ongeveer 5 minuten lang, maar kunnen verlengt worden op verzoek van de tester. De totale duratie van het experiment zou niet langer dan 1 uur moeten zijn.

Als tester is het belangrijk bewust te zijn van de risicos met betrekking tot deelname aan dit experiment. Je loopt het risico (tijdelijke) bewegingsziekte op te lopen.

Criteria voor de testers:

- De tester is tenminste 18 jaar oud.
- De tester is tenminste één keer in een virtuele omgeving geweest[2].
- De tester is niet uitzonderlijk gevoelig voor VR geinduceerde bewegingsziekte[3].

Belangrijke dingen waar testers zich bewust van moeten zijn:

- Je hebt het recht om op elk moment te stoppen met het experiment. Als ik, als onderzoeker, tekenen van bewegingsziekte zie zal ik het experiment stoppen. De gegevens kunnen misschien nog gebruikt worden, tenzij anders verzocht wordt.
- Je kunt tot 24 uur na het experiment verzoeken dat de verzamelde data niet gebruikt wordt. Als dit verzoek na deze periode wordt gemaakt zal geprobeerd worden de data niet te gebruiken, maar dit is niet in elk geval mogelijk. Zie de contact informatie op de volgende pagina om exclusie van de data aan te vragen.
- Je kunt volledig anoniem blijven. Ik moet je leeftijd, geslacht, ervaring met virtual reality en een schatting van jouw gevoeligheid voor bewegingsziekte weten. Geen namen of adressen worden gebruikt.

Als je vragen hebt over VR geinduceerde bewegingsziekte, de setup van het onderzoeker, jouw rechten als tester, of wat dan ook, kun je ze nu stellen aan de onderzoeker (Joep Eijkemans). Als er later nog vragen ontstaan kun je de experimenter bereiken via de contact informatie hieronder.

Contact informatie voor vragen, problemen, informatie over jouw rechten als tester, exclusie van de data verzoeken of suggesties voor nieuwe testers.

Telefoon en WhatsApp: (+31)6 1977 9165

E-mail: j.w.eijkemans@student.utwente.nl

Als je vragen hebt over jouw rechten als deelnemer aan een onderzoek, informatie wilt verkrijgen, vragen wilt stellen, of bedenkingen over dit onderzoek wilt bespreken met iemand anders dan de onderzoeker, neem dan contact op met de secretaris pro tem van de Ethics committee of the department of EEMCS, mrs J Rebel-de Boer.

E-mail: ethics-comm-ewi@utwente.nl

1) Vraag de onderzoeker naar het precieze aantal experimenten.

2) Een virtuele omgeving ervaren via een op het hoofd gemonteerde display voor tenminste 5 minuten. Augmented reality kan hiervoor ook volstaan, gegeven dat een voldoende percentage van de omgeving virtueel was, overleg dit met de onderzoeker.

3) Als je jezelf kent als zijnde gevoelig voor bewegingsziekte in virtual reality kun je niet meedoen aan dit experiment. Overleg bij twijfel met de onderzoeker.

Appendix 3C: Information brochure final test (English)

Research into VR induced motion sickness in a cycling simulator.

Children with DCD have trouble learning how to ride a bike and receive extra help with acquiring this skill at the Roessingh center of rehabilitation. In order to practice interaction with other traffic participants without exposing the children to the risks of actual traffic, a VR cycling simulation was developed. This is the simulation that will be tested today.

This simulation has a downside, which is that it has the tendency to induce motion sickness. VR induced motion sickness is a phenomenon that can occur in any VR/AR simulation. VR induced motion sickness comes with a variety of symptoms which will afterwards be rated on a 4 point scale (if preferred, this list can be seen before signing this document). The most common symptoms are nausea, disorientation, headaches and dizziness. Anybody can get VR induced motion sickness, it is not contagious, and it will go away over time.

For this experiment, you will cycle through a virtual environment on a physical bicycle. The steering and pedaling will be used to control your virtual bicycle. Finishing the route takes 5 minutes.

The goal of this experiment is to repeat this route 3 times, changing some aspect that is correlated with VR induced motion sickness. These aspects are 1) pointing a fan at the user, 2) making the field of view smaller, 3) null test, nothing changes.

In between the testing sessions there is a short break in which the test user fills in a questionnaire and can give some additional verbal feedback. These breaks are about 5 minutes but can be extended if requested. The total duration of the experiment should not be longer than half an hour.

As a test user, it is important to beware of the risks regarding participation in this experiment. You are at risk of developing (temporary) VR induced motion sickness.

Criteria for test users:

- The test user is 18 years or older.
- The test user has been in a virtual environment at least once[2].
- The test user is not particularly susceptible to VR induced motion sickness[3].

Important things to note as a test user:

- You have the right to stop the experiment at any time. If I, as experimenter, see signs of motion sickness I will discontinue the experiment. The data might still be used unless requested otherwise.
- You can request for your data not to be used until 24 hours after the experiment. If this request is made after this time period, I will try to exclude the data, but this may not be possible in every case. In order to request the exclusion of your data in this experiment, see the contact information on the next page.
- You can remain completely anonymous. I will need to know your age, gender, experience with virtual reality and an estimation of your own susceptibility to motion sickness. No names or addresses will be used.

If you have any questions regarding (VR induced) motion sickness, the setup of the experiment, your rights as a test user, or anything else, you can ask the experimenter (Joep Eijkemans) now. If any questions arise later in time, you can contact the experimenter via the contact information below.

Contact information for questions, problems, information about your rights as a participant, requesting exclusion from this experiment or suggestions for other participants.

Telephone and WhatsApp: (+31)6 1977 9165

E-mail: j.w.eijkemans@student.utwente.nl

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary pro tem of the Ethics Committee of the department of EEMCS, mrs J Rebel-de Boer.

E-mail: ethics-comm-ewi@utwente.nl

1) Ask the experimenter for the exact number of trials.

2) Experienced a virtual environment via a head mounted display for at least 5 minutes. Augmented reality can also suffice for this criterion, if a sufficient percentage of the environment was virtual, discuss this with the experimenter.

3) If you know yourself to be susceptible to motion sickness in virtual reality you cannot participate in this experiment. If unsure, discuss with the experimenter.

Appendix 3D: Information brochure final test (Dutch)

Onderzoek naar VR geinduceerde bewegingsziekte in een fiets simulatie

Kinderen met DCD hebben moeite met leren fietsen en krijgen hiervoor bij het Roessingh centrum voor rehabilitatie extra hulp. Om interactie met andere verkeersgebruikers te trainen, zonder de kinderen bloot te stellen aan de risico's van het verkeer is een VR fiets simulatie ontwikkeld. Dit is de simulatie waarmee we vandaag zullen testen.

Deze simulatie heeft een probleem, namelijk dat hij erg geneigt is bewegingsziekte te induceren. VR geinduceerde bewegingsziekte is een fenomeen dat in elke VR/AR simulatie kan ontstaan. VR geinduceerde bewegingsziekte heeft een hoop symptomen, die achteraf gemeten worden op een 4 punt schaal (Op verzoek kan de gehele lijst ingezien worden voor het tekenen van dit document). De meest voorkomende symptomen zijn misselijkheid, disorientatie, hoofdpijn en duizeligheid. Iedereen kan VR geinduceerde bewegingsziekte krijgen, het is niet besmettelijk, en het gaat na een tijdje vanzelf weer weg.

Voor dit experiment zal je door een virtuele omgeving fietsen op een echte, fysieke fiets. Het stuur en de trappers zullen gebruikt worden om de virtuele fiets te besturen. De route duurt ongeveer 5 minuten om te fietsen.

Het doel is om de route 3 maal te fietsen, en telkens een aspect dat gerelateerd is aan VR geinduceerde bewegingsziekte aan te passen. Dit zijn 1) een ventilator die op de fietser gericht is toevoegen, 2) het zichtveld kleiner maken en 3) null test, niks veranderd.

Tussen de testsessies zal een korte pauze zijn waarin de tester een enquête invult en verbale feedback kan geven. Deze pauzes zijn ongeveer 5 minuten lang, maar kunnen verlengt worden op verzoek van de tester. De totale duratie van het experiment zou niet langer dan een half uur moeten zijn.

Als tester is het belangrijk bewust te zijn van de risicos met betrekking tot deelname aan dit experiment. Je loopt het risico (tijdelijke) bewegingsziekte op te lopen.

Criteria voor de testers:

- De tester is tenminste 18 jaar oud.
- De tester is tenminste één keer in een virtuele omgeving geweest[2].
- De tester is niet uitzonderlijk gevoelig voor VR geinduceerde bewegingsziekte[3].

Belangrijke dingen waar testers zich bewust van moeten zijn:

- Je hebt het recht om op elk moment te stoppen met het experiment. Als ik, als onderzoeker, tekenen van bewegingsziekte zie zal ik het experiment stoppen. De gegevens kunnen misschien nog gebruikt worden, tenzij anders verzocht wordt.
- Je kunt tot 24 uur na het experiment verzoeken dat de verzamelde data niet gebruikt wordt. Als dit verzoek na deze periode wordt gemaakt zal geprobeerd worden de data niet te gebruiken, maar dit is niet in elk geval mogelijk. Zie de contact informatie op de volgende pagina om exclusie van de data aan te vragen.
- Je kunt volledig anoniem blijven. Ik moet je leeftijd, geslacht, ervaring met virtual reality en een schatting van jouw gevoeligheid voor bewegingsziekte weten. Geen namen of adressen worden gebruikt.

Als je vragen hebt over VR geinduceerde bewegingsziekte, de setup van het onderzoeker, jouw rechten als tester, of wat dan ook, kun je ze nu stellen aan de onderzoeker (Joep Eijkemans). Als er later nog vragen ontstaan kun je de experimenter bereiken via de contact informatie hieronder.

Contact informatie voor vragen, problemen, informatie over jouw rechten als tester, exclusie van de data verzoeken of suggesties voor nieuwe testers.

Telefoon en WhatsApp: (+31)6 1977 9165

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Als je vragen hebt over jouw rechten als deelnemer aan een onderzoek, informatie wilt verkrijgen, vragen wilt stellen, of bedenkingen over dit onderzoek wilt bespreken met iemand anders dan de onderzoeker, neem dan contact op met de secretaris pro tem van de Ethics committee of the department of EEMCS, mrs J Rebel-de Boer.

E-mail: ethics-comm-ewi@utwente.nl

1) Vraag de onderzoeker naar het precieze aantal experimenten.

2) Een virtuele omgeving ervaren via een op het hoofd gemonteerde display voor tenminste 5 minuten. Augmented reality kan hiervoor ook volstaan, gegeven dat een voldoende percentage van de omgeving virtueel was, overleg dit met de onderzoeker.

3) Als je jezelf kent als zijnde gevoelig voor bewegingsziekte in virtual reality kun je niet meedoen aan dit experiment. Overleg bij twijfel met de onderzoeker.

Appendix 3E: Informed consent form (English)

Informed consent form

Title research:
Researcher responsible:

To be filled in by the participant

I acknowledge that I've been clearly and adequately informed about the nature, method, goal and [if present] risks and duty/load of this research. I know that the data and results of this research will only be shared anonymously and confidentially with third parties. My questions have been answered to satisfaction.

My participation in this research is completely voluntarily. I will remain the right to withdraw from this research at any given time without statement of reason.

Name participant: ………………………………………………………………………..

Date: ……………   Signature participant: …..

To be filled in by the researcher that will conduct the experiment

I have provided verbal and written explanation about this research. I will answer any remaining questions about this research to the best of my ability. The participant will not experience any disadvantageous consequences for prematurely discontinuing the experiment.

Name researcher: …………………………………………………………………………..…………..

Date: ……………   Signature researcher: ....

Appendix 3F: Informed consent (Dutch)

Toestemmingsverklaringformulier (informed consent)

Titel onderzoek:
Verantwoordelijke onderzoeker:

In te vullen door de deelnemer

Ik verklaar op een voor mij duidelijke wijze te zijn ingelicht over de aard, methode, doel en [indien aanwezig] de risico's en belasting van het onderzoek. Ik weet dat de gegevens en resultaten van het onderzoek alleen anoniem en vertrouwelijk aan derden bekend gemaakt zullen worden. Mijn vragen zijn naar tevredenheid beantwoord.

Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud me daarbij het recht voor om op elk moment zonder opgaaf van redenen mijn deelname aan dit onderzoek te beëindigen.

Naam deelnemer: …………………………………………………………………………..

Datum: ……………   Handtekening deelnemer: …..…………………………………….

In te vullen door de uitvoerende onderzoeker

Ik heb een mondelinge en schriftelijke toelichting gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beëindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.

Naam onderzoeker: ……………………………………………………………………………..…………..

Datum: ……………   Handtekening onderzoeker: ...…………………………………….

Appendix 4A: The unedited open feedback of the testers (Pilot test)

Tester 1:
Breaking feels weird since you cannot slow down. You can only stop

*Bike resistance is low. You don’t need the expected amount of force for cycling.

Steering is funky.

Nose was annoying but kinda stoped nosesing after a while. *(Edit: interpreted as “kind of stopped noticing”)*

Wind was pleasant and darker at the edge of screen felt natural.
The corner when collecting way points was a bit to sharp.

Tester 2
In de bocht gaan is heel onnatuurlijk. Je gaat opeens veel sneller en je gaat rechtdoor terwijl je je stuur schuin houdt.
Bij de bolletjes (Pac-Man) run had ik het gevoel alsof ik minder heen en weer zwabberde
Ik had een grote neiging om de eendjes aan te rijden XD
Misschien in plaats van eendjes autos gebruiken, dan zou je het gevaar misschien eerder herkennen

Tester 3
Na trial 2 pauze
De bolletjes leken alsof je moest slingeren, omdat de bolletjes al heel snel wisselden van baan (kan komen doordat de bolletjes heel dicht achter elkaar stonden en daardoor veranderingen erger leken)
De grote bocht die gemaakt moet worden, is heel lastig. Dit komt doordat je niet met de fiets mee kan bewegen en de fiets dus niet reageert zoals in het dagelijks leven
Trial 3: null stopt voor de bocht al, bocht is niet te doen, vanaf deze trial wordt verder de hele tijd voor de bocht gestopt.
Het lijkt alsof je niet heel ver kan kijken in het scherm. De bomen lijken ongeveer op dezelfde afstand van je vandaan te staan, maar als je verder doorfietst, dan zit hier geen verandering in.
Trial 4: beeldqualiteit lijkt slechter, stopt voor de bocht,
Ventilator was wel chill. Deze zorgde voor wat verkoeling aan het hoofd, waardoor de misselijkheid een stuk langzamer optreedt.
Trial 5: 3 keer de bug nadat er is geremd, dat er niet meer gefietst kan worden
De neusvleugel was vooral heel erg wennen, door de bug niet helemaal goed uit kunnen testen. De onderkant van je eigen neus is altijd is beter zichtbaar dan de bovenkant, misschien dat dit iets aangepast kan worden om de echte situatie wat beter na te bootsen.

Tester 4
Kan soms door het asfalt heen kijken (waar de objects elkaar overlappen)
Die paaltjes die een beetje flikkeren dus

Tester 5:
The steering is way off at the last corner, also the speed could be more adapted to the speed of the paddling of the test subject

Tester 6:

Algemeen:

- De fiets trekt te langszaam op dus is niet het zelfde als wat je zou verwachten
- Het remmen is ook niet het zelfde als je doet met het fietsen
- Het stuur (maar die weet je al)
- Renderen geeft een beter beeld

Met neus:

- De neus loopt vertraging op waardoor ik denk dat ik juist net iets meer misselijk wordt.

Waypoints:

- Ze lopen op sommige punten niet helemaal recht waardoor je meer bochten maakt als je zou moeten en je net iets missleijker wordt. Dit is vooral op het zand gedeelte, op de verharde weg is het recht en een stuk beter.
- Het leid heel erg af van de omgeving en aangezien dit ook bedoelt is voor kinderen met dcd, adhd, etc zou dit niet goed doen aan het doel van de simulatie.

Vignette

- Beste van allemaal
- Loopt nog wel iets achter

Blur:

- Iets wennen, maar eenmaal aan het fietsen is hij zeer comfortabel

Tester 7:

Ik word dizzier dan verwacht, voornamelijk tijdens het maken van bochten

Vanaf trial drie is de bocht geskipt

De ventilator hielp wel iets

Vooral van het remmen werd ik duizelig (ik was waarschijnlijk gedesorienteerd)

Appendix 4B: The unedited open feedback of the testers (Final test)

Tester 1

Het was een flink lastiger om mn balans te bewaren tijdens het testen met een increased vignet. Ik had ook pas door wat er anders was nadat ik dit achteraf aan Joep had gevraagd. Ik weet niet waarom het precies lastiger was, maar mijn lichaam voelde een sterker gevoel van inbalance tijdens deze test.

Met een fan was het veel aangenamer fietsen. Het is een goede vorm van feedback. Het maakte de ervaring voor mij confortabeler. Ik voelde me beter tijdens het fietsen, maar dat zou ook temaken kunnen hebben met het feit dat ik al 2 keer geoefend had en dus ervaring had met de setup.

Tester 2

-

Tester 3

With the ventilator I was a lot less dizzy.

Making the turn at the end did make me feel a bit dizzy and unsteady throughout the trials.

The visuals of the last one were the nicest (although I did not notice anything had changed), combined with the feeling of the fan from the 2^{nd} trial.

Tester 4

Maybe my results got a little biased towards the end because the nausea from the first time didn't entirely wear off. I think you get more motion sickness when turning the wheel of the bike rather than anything else, especially when you turn the wheel and you have to turn it back. Then the motion sickness really hits. The fan seemed like the best solution to combat it since a cool breeze felt comforting and more like you were outside.

Tester 5

Na test 1

Het maken van bochten gaat al een stuk makkelijker en soepeler in vergelijking met de vorige keer testen, wel wordt ik nog steeds duizelig en misselijk van het fietsen in de simulatie. De ventilator helpt wel mee om hef hoofd wat meer koel te houden. Het stuur zat niet helemaal goed gekalibreerd voor mijn gevoel, waardoor ik naar rechts moest sturen om rechtdoor te gaan.

Na test 2

Voor mij voelde het alsof de fiets telkens naar links ging, ook al had ik het stuur recht. Kreeg last van het feit dat ik me minder kan focussen.

Na test 3

Ik merkte niets van de vignette, dus het zat niet in de weg. Ik had wel moeite om de grote bocht te maken tijdens het fietsen. En ik had nogmaals last van een mogelijk verkeerde kalibratie, zo voelde het tenminste.

Tester 6

The first test (vignette) felt like it gave me more stability that the last one (none)

It was quite hot in the room, this might cause some of the checked things.

Tester 7

I wear glasses with ca. 5 dioptries, but did not wear them during the trials. Hence my blurry vision.

I did not experience a noticeable difference (in the second trial) w.r.t. the first trial.

In the third trial, the wind really helped me feel easier, although vision didn’t change much.

Tester 8
My eyes are hurting a bit like I played computer games for 3-4 hours.

Tester 9
Whilst I was on the bike I felt a little bit dizzy/difficulty to balance.
Second round it takes a little less time to adjust to the real world

Tester 10
After testing and standing up I was quite dizzy, but after sitting down it was gone
Slightly dizzy, but much less
Even less dizziness, but still some

Tester 11
-

Tester 12
Vorige ervaringen met VR resulteerden over het algemeen in wazigheid en onscherpte van het zicht (wanneer gebruik gemaakt van de VR). Deze test had echter helemaal niet dit effect. Misschien omdat de meeste onderdelen in de VR-omgeving allemaal van een verder afstand waren en dat het daardoor een invloed heeft op de scherpte van het beeld.
Test2 fan
We kwamen een bug tegen waardoor naar links sturen niet mogelijk was, hierdoor was het te lastig om de test af te maken. Echter heb ik wel genoeg meegekregen dat de ventilator wel fijn is wanneer je gebruik maakt van deze VR.

Tester 13
Er is een limiet aan de snelheid, wat behoorlijk jammer is als je die eendjes voorbij wilt.

Haperde bij de 2de test.

Tester 14
Low framerate (werd ik niet misselijk van maar is wel storend)
Als je niet trapt rem je in vr heel erg snel af, een wat natuurlijkere acceleratie/deceleratie zou nice zijn
Eigenlijk alleen last van duizeligheid tijdens het sturen
Lijkt hoger op de fiets in vr dan irl

Tester 15
I feels the gear does not match the speed, and this feeling makes me feel weird.
I hit my left eye with the glasses before trial 3

Tester 16
Het fietsen voelde steeds natuurlijker aan. In de laatste test voelde het bijna als normaal fietsen.

Tester 17

During the running with the bike, I naturally leaned into the corner, but in real life that wasn't possible. That caused all the dizziness and slight nausea. While riding straight there was no problem with me.
After the second test I figured out how not to lean into the steering. But it felt unnatural to me and kinda awkward.

Tester 18
-

Tester 19
I really did not expect the experience to be like this; the fear of falling and bumping into obstacles was prominently present. I must admit that cycling in VR is significantly more scary than cycling in real life, which is a daily activity for me. I did not expect the immersion to be this intense. For the first time ever, I have experienced motion sickness in VR. In some cases, it felt like I lost control over steering the bicycle.
The second time around, it was much easier for me to control the bicycle. I suppose it was a matter of getting used to the environment. However, I do experience a considerable amount of motion sickness now.
The third time around, the fan made the experience considerably more pleasant. Not only regarding motion sickness, but also temperature-wise; very nice to cool down. However, I do think that most of my nausea is due to the accumulation of multiple encounters in the virtual environment.

Tester 20
Braking is a bit slow. Stop peddling and the braking is too fast. Steering was sometimes a bit weird in the bend.
Niet meeleunen voelt raar. Lijkt wel alsof je echt aan het fietsen bent en vooruit gaat, vooral met de ventilator.

Tester 21
Test1
De refreshrate lijkt laag. Dit valt voral op bij de lijnen op de grond die lijken sprongen naar je toe te maken inplaats van een soepele beweging naar je toe te maken
Test 2
Bij hoog tempo word het beeld heel naar, het effect wat eerder beschreven staat is veel heftiger merkbaar
Test3
Voel me een betje zweverig, daarmee bedoel ik dat bewegingen raar voelen alsof ik gewend ben aan hoe de vr fiets zou reageren op mijn beweging en verbaast ben dat ik een andere reactie krijg, namelijk hoe dingen buiten vr ebeuren.

Tester 22
-

Tester 23
It was a bit weird when turning because usually when I turn with my bike I lean towards the direction I want to turn. In this experiment while I was turning I felt the need of leaning.
If I go up hill with the bike or over a bump I would expect to feel that. If I don't feel it and I see it I don't have a full immersive experience.

Before the last right turn, if I stop before turning I don’t feel the need of leaning anymore.

Tester 24
Bochten zorgen er wel voor dat je duizeling wordt. Ik denk omdat er een soort van lag in zit tussen beweging en beeld.
Windmachine helpt al veel met duizeligheid en evt misselijkheid. Omdat je toch meer het gevoel hebt dat je echt fiets. Al helemaal met afremmen en versnellingen.
Ik merkte niet heel veel veschil tussen de eerste en laatste test.

Tester 25
Toevoegen van realistische aspecten bij fietsen, zoals de wind, verminderde het gevoel van duizeligheid achteraf. Wat mogelijk ook invloed had op mijn duizeligheid was dat het fietsen zelf, zoals optrekken en remmen, in de VR vreemd aan voelde.

Tester 26
Maybe remove the speed limitation. It is quite tough otherwise

Tester 27
I liked that the feeling the fan gave when cycling. Also liked that the intensity increased with speed

Appendix 4C: The rated severity of VR induced motion sickness symptoms (Pilot test)

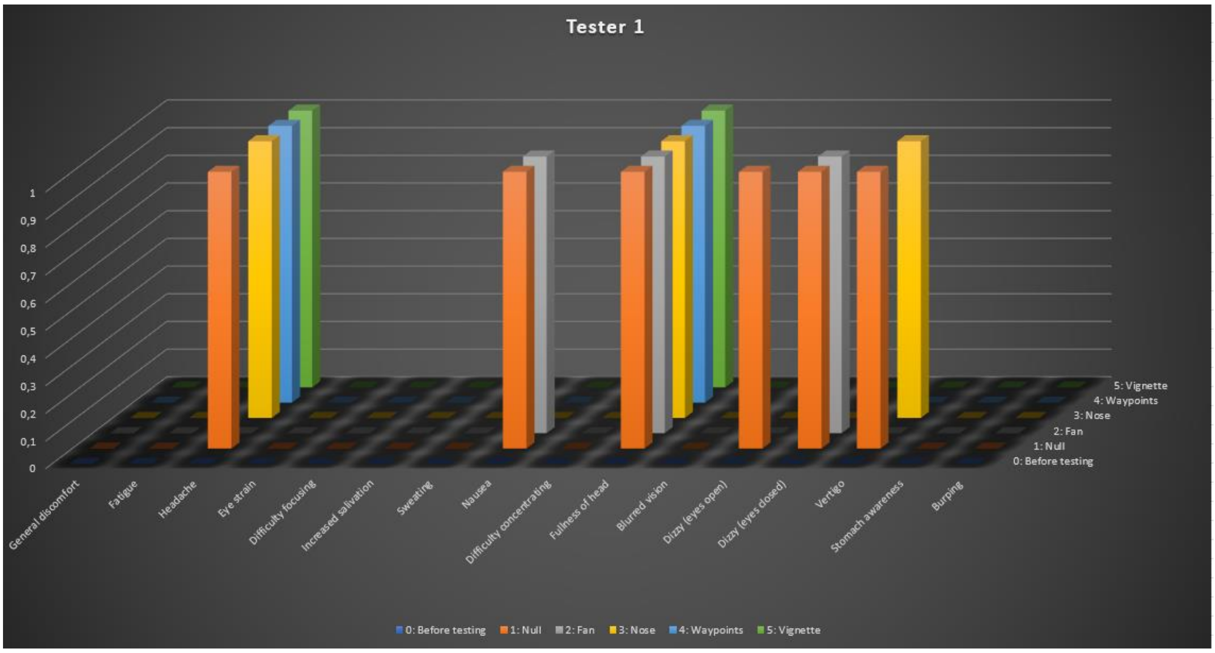
Please note that not all of the following graphs are the same scale, meaning a graph with higher bars may represent a lower rating than a graph with lower bars. Check the Y axis for the correct, relative values.

Also note that the original rating options of the symptoms are translated to numerical values to allow statistical analysis. The following table shows how the original assesments are translated to numbers:

Original	Number
“None”	0
“Slight”	1
“Moderate”	2
“Severe”	3

Tester 1

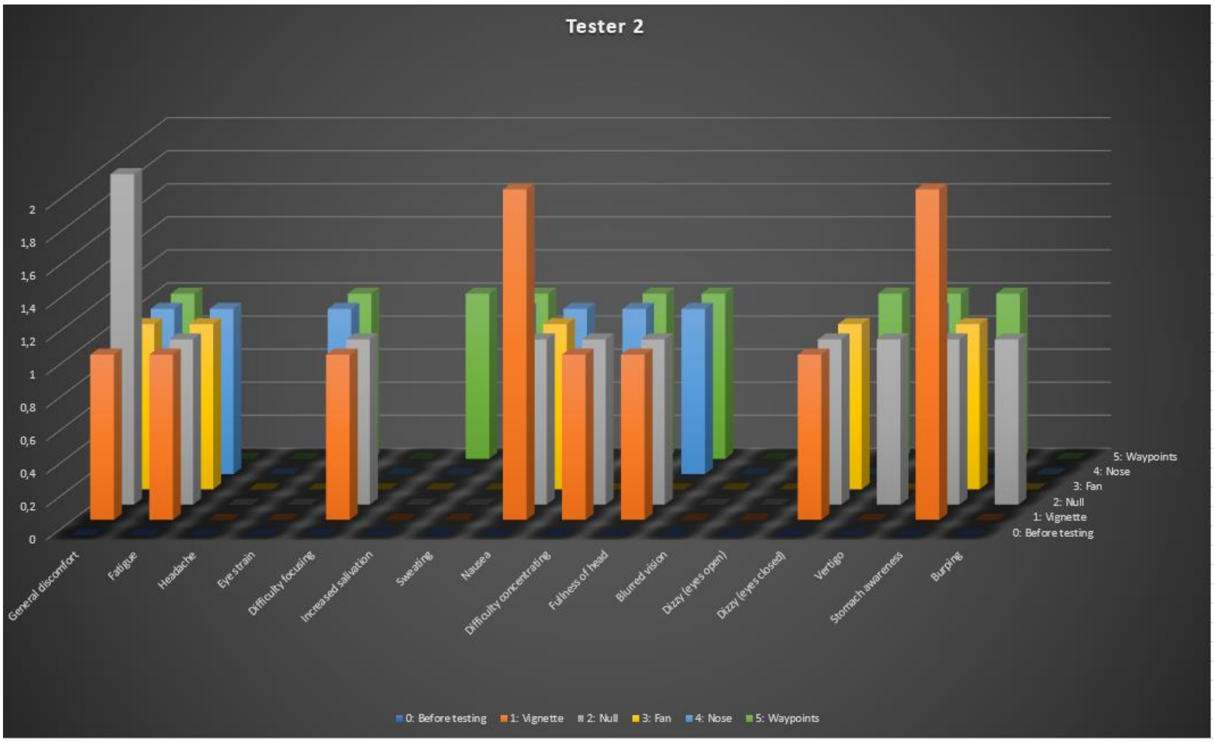
Trial	General di	Fatigue	Headache	Eye strain	Difficulty f	Increased	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eyes	Dizzy (eyes	Vertigo	Stomach a	Burping
0: Before testing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1: Null	0	0	1	0	0	0	0	1	0	1	0	1	1	1	0	0
2: Fan	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0
3: Nose	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0
4: Waypoints	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
5: Vignette	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0



This tester was pretty consistent. Only rating the symptoms either 1 or 0 (None or Slight). What you can clearly see however, is that the symptoms only arise after being in the simulation, once again indicating that this simulation does induce motion sickness.

Tester 2

Trial	General di	Fatigue	Headache	Eye strain	Difficulty f	Increased :	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye:	Dizzy (eye:	Vertigo	Stomach a	Burping
0: Before testing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1: Vignette	1	1	0	0	1	0	0	2	1	1	0	0	1	0	2	0
2: Null	2	1	0	0	1	0	0	1	1	1	0	0	1	1	1	1
3: Fan	1	1	0	0	0	0	0	1	0	0	0	0	1	0	1	0
4: Nose	1	1	0	1	0	0	1	1	1	1	0	0	0	1	0	0
5: Waypoints	1	0	0	1	0	1	1	0	1	1	0	0	1	1	1	0

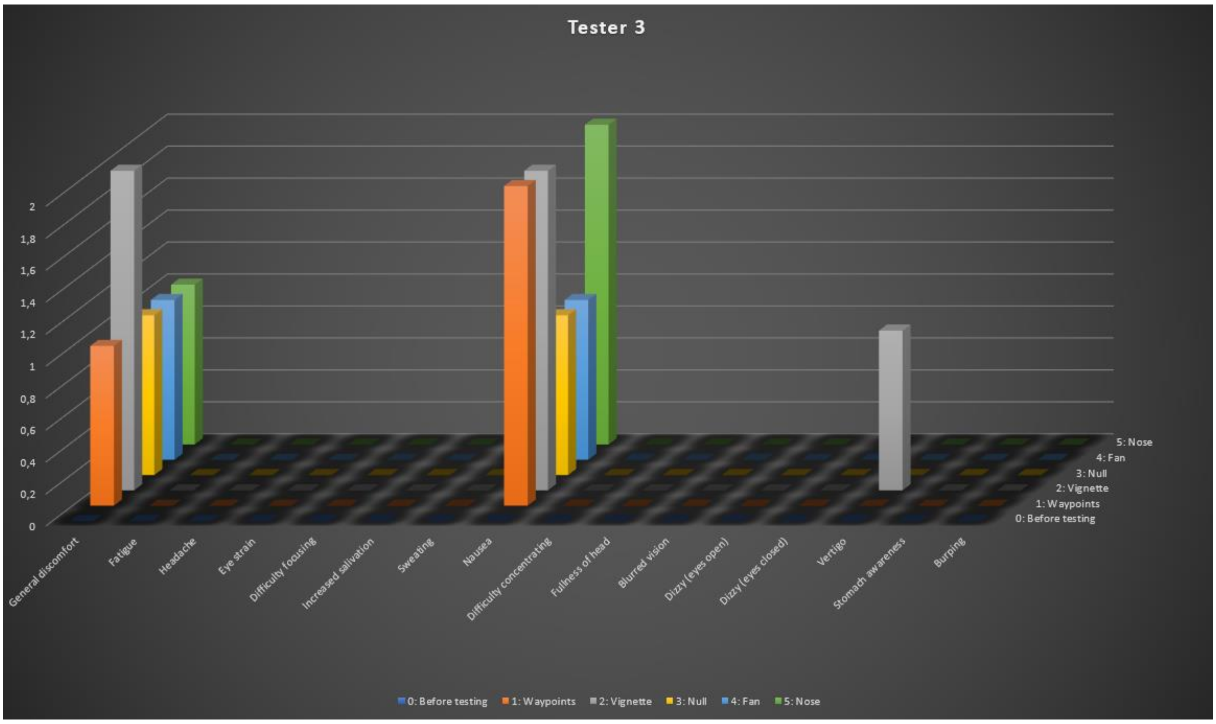


This tester also only starts to show symptoms of VR induced motion sickness after having been in the simulation once. The ratings are pretty consistent being either 1 or 0 (None or Slight), with 3 outliers with a rating of 2 (Moderate). These outliers are present in the Vignette and Null trials.

You can also clearly see that the Fan was a good solution here, as it shows lower rated symptoms than the previous and next trial. The opposite is true for the waypoints, as it displays ratings of the most symptoms.

Tester 3

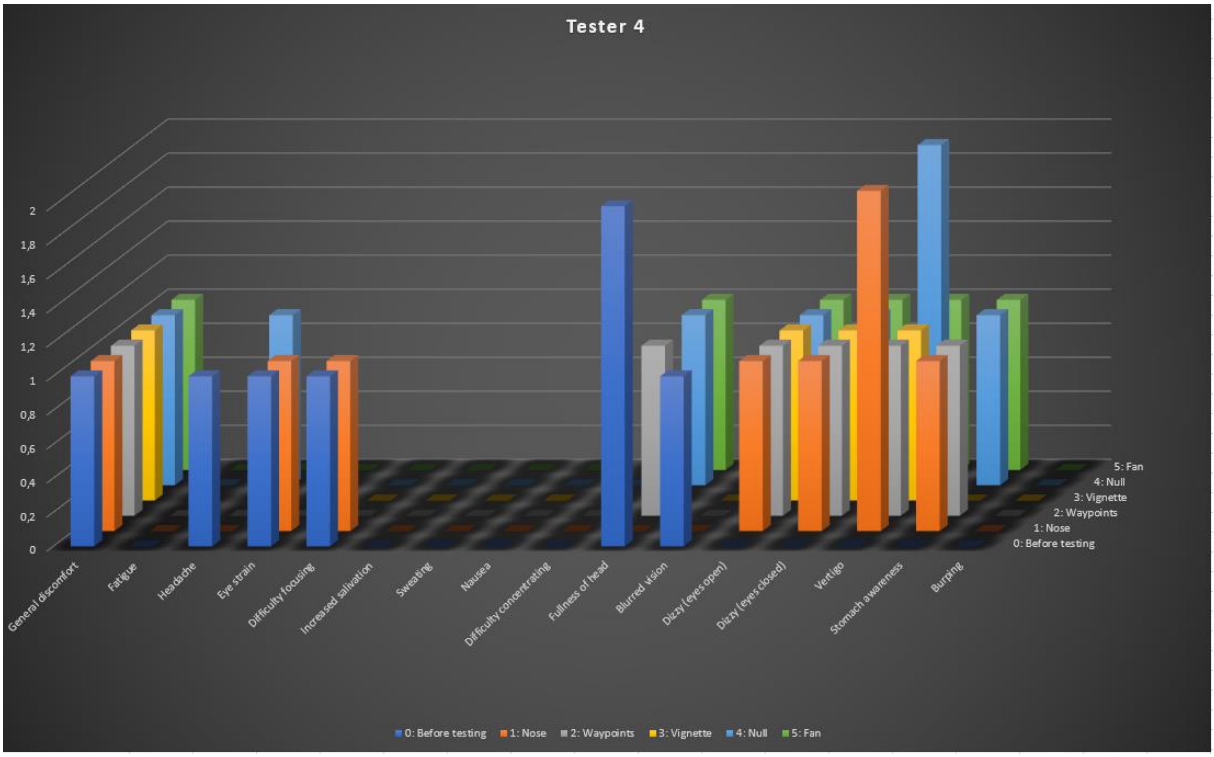
Trial	General di	Fatigue	Headache	Eye strain	Difficulty f	Increased :	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye:	Dizzy (eye:	Vertigo	Stomach a	Burping
0: Before testing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1: Waypoints	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
2: Vignette	2	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0
3: Null	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
4: Fan	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
5: Nose	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0



This tester is clearly quite resistant to VR induced motion sickness. Or at least only susceptible to specific symptoms (General discomfort and nausea in this case). This person rated the symptoms to be more slightly severe with the Waypoints, Vignette and Nose.

Tester 4

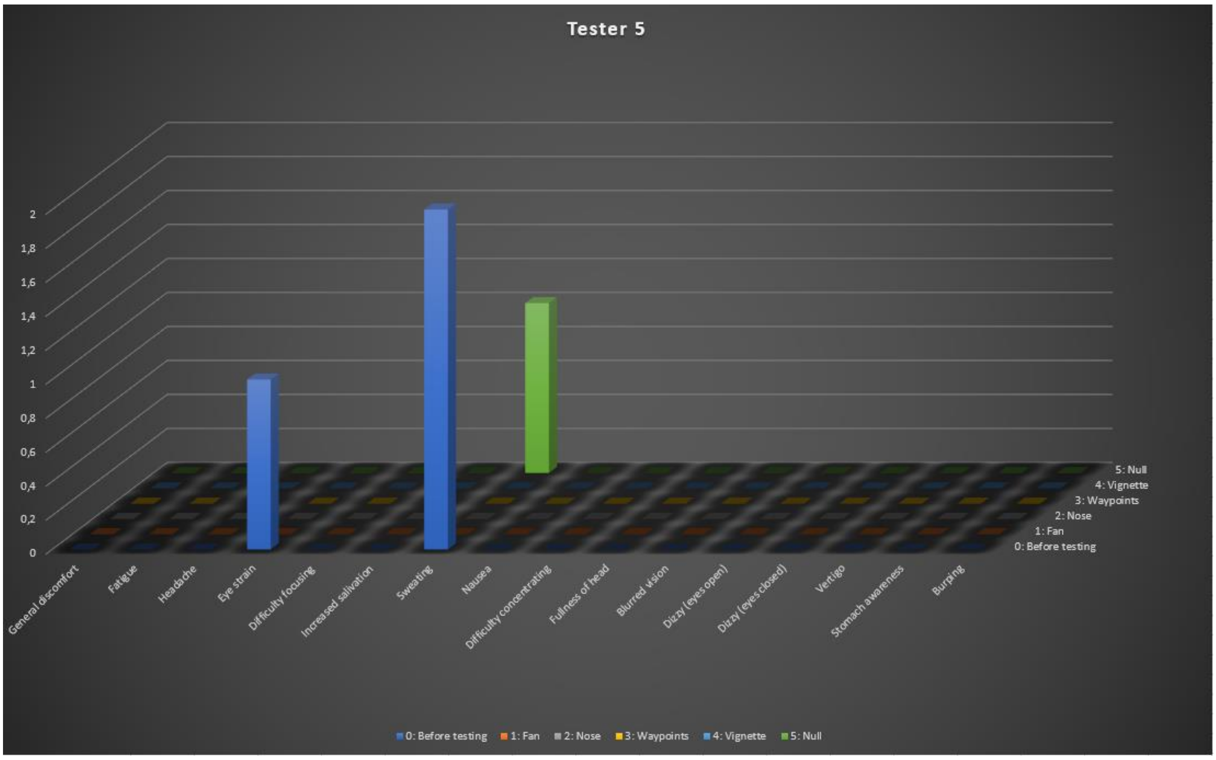
Trial	General di	Fatigue	Headache	Eye strain	Difficulty f	Increased :	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye:	Dizzy (eye:	Vertigo	Stomach a	Burping
0: Before testing	1	0	1	1	1	0	0	0	0	2	1	0	0	0	0	0
1: Nose	1	0	0	1	1	0	0	0	0	0	0	1	1	2	1	0
2: Waypoints	1	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0
3: Vignette	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
4: Null	1	0	1	0	0	0	0	0	0	1	0	1	1	2	1	0
5: Fan	1	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0



This tester was again very consistent, rating the symptoms only 0 or 1 (None or Slight), with only 3 outliers where a symptom was rated 2 (Moderate). This tester disliked the Nose the most and had the lowest rating with the Vignette trial. Also note that this tester already experienced some of the symptoms before starting the experiment.

Tester 5

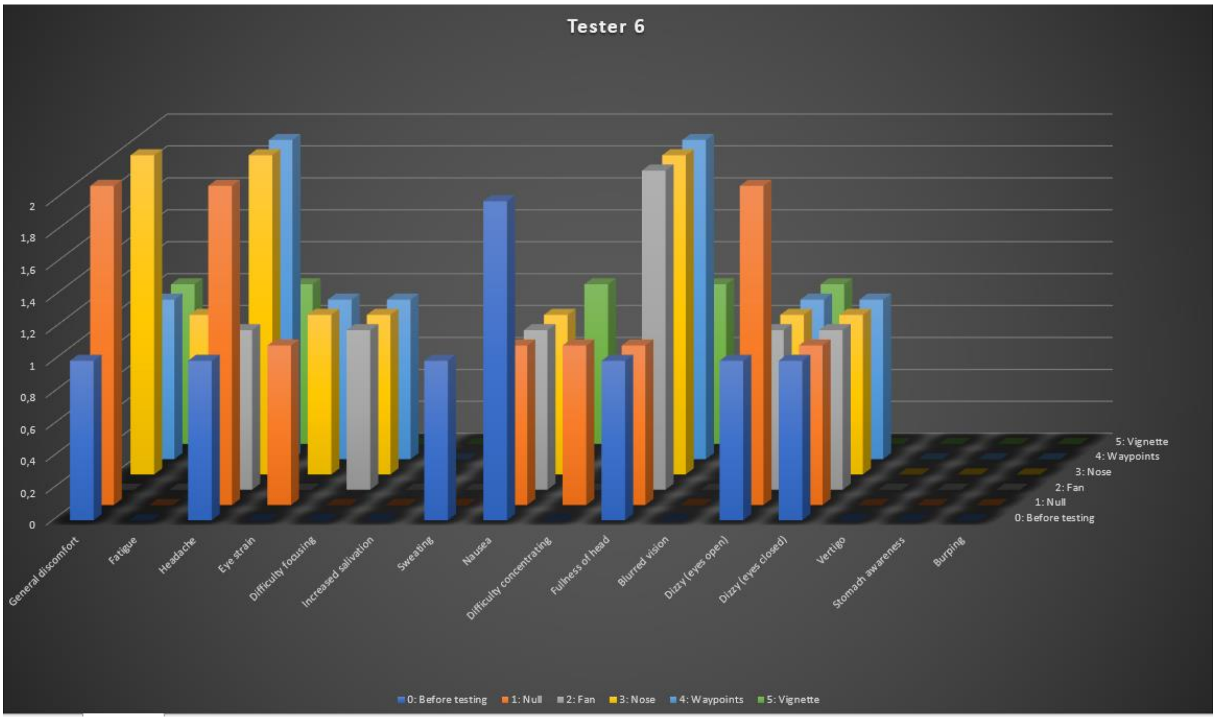
Trial	General di	Fatigue	Headache	Eye strain	Difficulty f	Increased	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0: Before testing	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0
1: Fan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2: Nose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3: Waypoints	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4: Vignette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5: Null	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0



Once again, a tester who is very resistant against VR induced motion sickness. The symptoms even get better after the first trial. This tester mentioned he was sweating before because he had been cycling already. This tester also completed the trials faster than any other, which is likely to be the reason that this tester was sweating again towards the end.

Tester 6

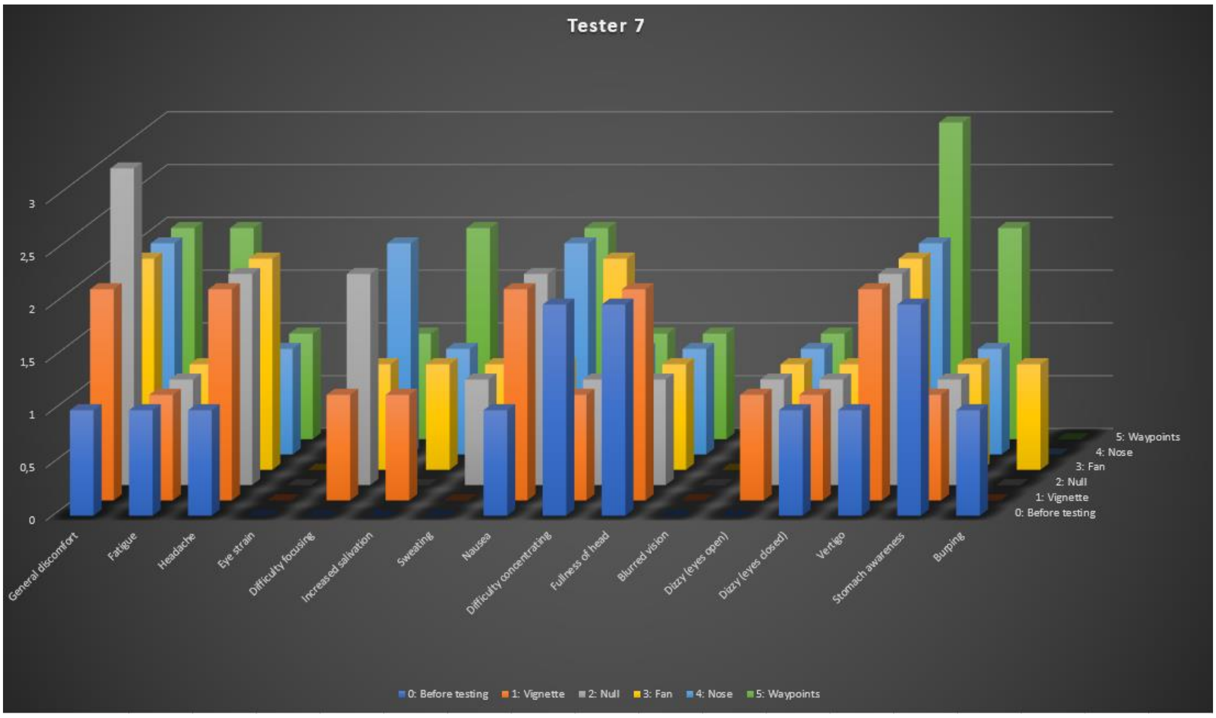
Trial	General di	Fatigue	Headache	Eye strain	Difficulty f	Increased :	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye:	Dizzy (eye:	Vertigo	Stomach a	Burping
0: Before testing	1	0	1	0	0	0	1	2	0	1	0	1	1	0	0	0
1: Null	2	0	2	1	0	0	0	1	1	1	0	2	1	0	0	0
2: Fan	0	0	1	0	1	0	0	1	0	2	0	1	1	0	0	0
3: Nose	2	1	2	1	1	0	0	1	0	2	0	1	1	0	0	0
4: Waypoints	1	0	2	1	1	0	0	0	0	2	0	1	1	0	0	0
5: Vignette	1	0	1	0	0	0	0	1	0	1	0	1	0	0	0	0



This was a tester who yielded interesting results. Some higher ratings of symptoms can be found. The ratings indicate that this tester disliked the Null (simulation as it is), the Nose and the waypoints the most. The vignette received the lowest symptom rating.

Tester 7

Trial	General di	Fatigue	Headache	Eye strain	Difficulty f	Increased :	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye:	Dizzy (eye:	Vertigo	Stomach a	Burping
0: Before testing	1	1	1	0	0	0	0	1	2	2	0	0	1	1	2	1
1: Vignette	2	1	2	0	1	1	0	2	1	2	0	1	1	2	1	0
2: Null	3	1	2	0	2	0	1	2	1	1	0	1	1	2	1	0
3: Fan	2	1	2	0	1	1	1	1	2	1	0	1	1	2	1	1
4: Nose	2	1	1	0	2	1	1	2	1	1	0	1	1	2	1	0
5: Waypoints	2	2	1	0	1	2	1	2	1	1	0	1	1	3	2	0



This tester was not very resistant to VR induced motion sickness. This tester is also the only one to ever rate a symptom 3 (Severe), doing so with general discomfort in the Null trial and with vertigo in the Waypoints trial. Also note that this tester already had quite high ratings for some symptoms when entering the experiment. This experiment was held towards the end of the day. This could explain the relative high symptom ratings before even starting.

Appendix 4D: The rated severity of VR induced motion sickness symptoms (Final test)

Due to the increased number of participants in this experiment (N = 27) compared to the pilot test (N = 7) no personal analysis or graphs will be provided in this appendix.

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
1	17-6-2019	21	Male	20+ times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	0	0	0	0	1	0	0	0	1	1	0	2	0
1	Null	0	0	0	0	0	1	1	1	0	0	0	1	2	1	1	0
2	Vignette	1	0	1	0	1	1	1	1	2	0	0	1	2	1	1	0
3	Fan	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0

Trial number	Trial condition	N score	O score	D score	T Score
0		28,62	0	41,76	22,44
1	Null	38,16	0	69,6	33,66
2	Vignette	66,78	37,9	83,52	67,32
3	Fan	28,62	15,16	13,92	22,44

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
2	17-6-2019	19	Male	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		1	0	0	1	1	0	0	1	1	0	0	0	0	0	1	0
1	Fan	1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0
2	Null	1	0	1	1	0	0	0	2	0	2	0	0	0	0	1	0
3	Vignette	1	0	1	1	0	0	0	2	0	1	0	0	0	0	2	0

Trial number	Trial condition	N score	O score	D score	T Score
0		38,16	30,32	27,84	37,4
1	Fan	28,62	7,58	27,84	22,44
2	Null	38,16	22,74	55,68	41,14
3	Vignette	47,7	22,74	41,76	41,14

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
3	17-6-2019	21	Female	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		2	2	0	2	2	0	0	0	0	0	2	0	0	0	0	0
1	Vignette	2	2	0	3	3	0	0	0	0	1	2	3	3	0	0	0
2	Fan	0	1	0	1	1	0	0	0	1	1	2	2	2	0	0	0
3	Null	0	1	0	2	1	0	0	0	1	0	1	1	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		19,08	75,8	55,68	59,84
1	Vignette	19,08	90,96	167,04	97,24
2	Fan	9,54	45,48	111,36	56,1
3	Null	9,54	45,48	41,76	37,4

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
4	17-6-2019	21	Female	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
1	Null	2	1	2	1	2	0	0	3	2	3	3	1	1	0	0	0
2	Vignette	1	1	2	0	2	0	0	2	2	1	0	1	0	0	0	0
3	Fan	1	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		9,54	15,16	13,92	14,96
1	Null	66,78	98,54	180,96	123,42
2	Vignette	47,7	60,64	83,52	71,06
3	Fan	28,62	30,32	27,84	33,66

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
5	17-6-2019	20	Female	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Fan	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
2	Null	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0
3	Vignette	1	0	1	0	1	0	0	1	1	1	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	7,58	0	3,74
1	Fan	9,54	15,16	27,84	18,7
2	Null	19,08	15,16	27,84	22,44
3	Vignette	28,62	30,32	41,76	37,4

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
6	17-6-2019	22	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0
1	Vignette	1	0	0	0	1	1	1	0	1	1	0	0	1	0	0	0
2	Fan	1	2	0	0	1	0	1	1	0	0	0	0	0	0	0	0
3	Null	1	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		19,08	22,74	27,84	26,18
1	Vignette	38,16	22,74	41,76	37,4
2	Fan	28,62	30,32	27,84	33,66
3	Null	19,08	22,74	27,84	26,18

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
7	17-6-2019	31	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	0	0	0	3	0	0	0	1	1	0	0	0	0
1	Null	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2	Vignette	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
3	Fan	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		28,62	7,58	27,84	22,44
1	Null	0	7,58	27,84	11,22
2	Vignette	0	7,58	27,84	11,22
3	Fan	0	7,58	13,92	7,48

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
8	17-6-2019	21	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	1	1	0	2	0	1	0	0	0	0	0	0	0
1	Fan	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
2	Null	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0
3	Vignette	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1

Trial number	Trial condition	N score	O score	D score	T Score
0		28,62	22,74	13,92	26,18
1	Fan	9,54	7,58	0	7,48
2	Null	9,54	22,74	13,92	18,7
3	Vignette	28,62	15,16	0	18,7

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
9	17-6-2019	18	Female	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		2	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
1	Vignette	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2	Fan	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
3	Null	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		19,08	30,32	27,84	29,92
1	Vignette	0	15,16	13,92	11,22
2	Fan	0	7,58	27,84	11,22
3	Null	9,54	7,58	41,76	18,7

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
10	17-6-2019	19	Female	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Null	1	1	1	0	0	0	0	0	0	0	0	2	1	0	0	0
2	Vignette	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0
3	Fan	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	15,16	0	7,48
1	Null	9,54	22,74	41,76	26,18
2	Vignette	9,54	22,74	27,84	22,44
3	Fan	0	7,58	13,92	7,48

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
11	17-6-2019	19	Female	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Fan	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2	Null	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3	Vignette	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	7,58	0	3,74
1	Fan	0	7,58	13,92	7,48
2	Null	0	7,58	13,92	7,48
3	Vignette	0	7,58	13,92	7,48

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
12	18-6-2019	19	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0
1	Vignette	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
2	Fan	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
3	Null	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	30,32	27,84	22,44
1	Vignette	9,54	0	0	3,74
2	Fan	9,54	0	0	3,74
3	Null	9,54	7,58	13,92	11,22

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
13	18-6-2019	21	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Null	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0
2	Vignette	0	1	0	1	1	0	1	0	0	1	0	0	0	0	1	0
3	Fan	1	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	0	0	0
1	Null	9,54	15,16	13,92	14,96
2	Vignette	19,08	22,74	27,84	26,18
3	Fan	9,54	22,74	41,76	26,18

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
14	18-6-2019	22	Male	20+ times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
1	Fan	1	0	0	0	0	0	1	1	0	0	0	0	0	2	1	0
2	Null	1	0	0	0	0	0	1	1	0	0	0	0	0	2	0	0
3	Vignette	1	0	0	0	0	0	1	1	0	0	0	0	0	2	1	0

Trial number	Trial condition	N score	O score	D score	T Score
0		9,54	0	0	3,74
1	Fan	38,16	7,58	41,76	29,92
2	Null	28,62	7,58	41,76	26,18
3	Vignette	38,16	7,58	41,76	29,92

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
15	18-6-2019	23	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		1	1	1	1	2	1	1	1	1	1	0	1	1	0	0	0
1	Vignette	1	1	1	1	1	0	0	1	0	0	0	1	1	0	0	0
2	Fan	1	1	1	1	0	0	0	1	0	0	0	1	1	0	0	1
3	Null	1	1	2	1	1	0	2	1	1	1	0	1	1	0	1	1

Trial number	Trial condition	N score	O score	D score	T Score
0		47,7	53,06	83,52	67,32
1	Vignette	19,08	37,9	55,68	41,14
2	Fan	28,62	30,32	41,76	37,4
3	Null	66,78	53,06	69,6	71,06

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
16	18-6-2019	20	Female	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Null	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Vignette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Fan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	0	0	0
1	Null	0	0	0	0
2	Vignette	0	0	0	0
3	Fan	0	0	0	0

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
17	18-6-2019	21	Male	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
1	Fan	1	0	0	1	2	0	0	2	0	0	0	0	0	0	0	0
2	Null	0	0	0	1	0	0	0	2	0	0	1	0	0	0	0	0
3	Vignette	0	1	0	0	0	0	2	1	0	0	1	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	15,16	13,92	11,22
1	Fan	28,62	30,32	55,68	41,14
2	Null	19,08	15,16	41,76	26,18
3	Vignette	28,62	15,16	27,84	26,18

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
18	18-6-2019	21	Female	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Vignette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Fan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Null	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Trial number	Trial condition	N score	O score	D score	T Score
0		9,54	7,58	0	7,48
1	Vignette	0	0	0	0
2	Fan	0	0	0	0
3	Null	9,54	0	0	3,74

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
19	18-6-2019	21	Male	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		1	0	0	0	2	0	1	0	1	1	2	0	0	0	0	0
1	Null	3	2	0	0	1	0	2	2	1	0	1	2	0	0	0	0
2	Vignette	2	1	0	0	1	0	2	3	1	0	0	2	0	0	0	0
3	Fan	2	1	0	0	1	0	1	2	1	1	1	1	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		28,62	45,48	69,6	52,36
1	Null	76,32	60,64	83,52	82,28
2	Vignette	76,32	37,9	83,52	71,06
3	Fan	57,24	45,48	83,52	67,32

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
20	18-6-2019	22	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Fan	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0
2	Null	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Vignette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	7,58	0	3,74
1	Fan	0	7,58	41,76	14,96
2	Null	0	0	0	0
3	Vignette	0	0	0	0

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
21	18-6-2019	18	Male	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0
1	Vignette	1	0	1	1	0	1	0	0	0	0	0	1	0	0	0	0
2	Fan	2	0	2	1	0	0	0	2	0	0	0	0	0	0	3	0
3	Null	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	15,16	13,92	11,22
1	Vignette	19,08	22,74	13,92	22,44
2	Fan	66,78	37,9	27,84	52,36
3	Null	0	0	27,84	7,48

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
22	19-6-2019	21	Female	20+ times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		1	1	1	1	0	0	0	1	0	0	0	2	1	0	0	0
1	Null	0	1	0	0	0	0	0	1	0	0	0	1	1	0	0	0
2	Vignette	1	0	0	0	0	0	0	1	0	0	0	2	1	0	0	0
3	Fan	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		19,08	30,32	55,68	37,4
1	Null	9,54	7,58	41,76	18,7
2	Vignette	19,08	7,58	55,68	26,18
3	Fan	9,54	0	41,76	14,96

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
23	19-6-2019	22	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0
1	Fan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Null	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Vignette	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	15,16	27,84	14,96
1	Fan	0	0	0	0
2	Null	0	0	0	0
3	Vignette	0	0	0	0

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
24	19-6-2019	21	Female	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	Vignette	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0
2	Fan	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
3	Null	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	7,58	13,92	7,48
1	Vignette	0	7,58	41,76	14,96
2	Fan	0	7,58	13,92	7,48
3	Null	0	7,58	13,92	7,48

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
25	19-6-2019	25	Male	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
1	Null	1	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0
2	Vignette	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Fan	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		9,54	7,58	13,92	11,22
1	Null	19,08	22,74	13,92	22,44
2	Vignette	9,54	15,16	0	11,22
3	Fan	0	7,58	0	3,74

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
26	19-6-2019	25	Female	1 - 4 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Fan	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Null	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Vignette	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	0	0	0
1	Fan	0	7,58	0	3,74
2	Null	0	7,58	0	3,74
3	Vignette	0	7,58	0	3,74

Tester ID:	Date:	Age:	Gender:	Amount of experience in VE:
27	19-6-2019	24	Male	5 - 9 times

Trial	Trial conditio	General (	Fatigue	Headache	Eye strai	Difficult	Increas	Sweating	Nausea	Difficulty c	Fullness of	Blurred vis	Dizzy (eye	Dizzy (eye	Vertigo	Stomach a	Burping
0		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Vignette	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2	Fan	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Null	1	1	0	0	0	0	1	1	0	0	0	0	0	1	0	0

Trial number	Trial condition	N score	O score	D score	T Score
0		0	7,58	0	3,74
1	Vignette	0	15,16	13,92	11,22
2	Fan	0	7,58	0	3,74
3	Null	28,62	15,16	27,84	26,18