Master Thesis

The influence of depth cues on cybersickness

Aafke van Welbergen

Applied Cognitive Psychology

27.5 ECTS

Author: Aafke van Welbergen

Date: 03-07-2020

Student number: 4269594

a.g.vanwelbergen@students.uu.nl

TNO Soesterberg

Prof. Dr. J.E. Bos

jelte.bos@tno.nl

Universiteit Utrecht

L.L. Meijer

l.l.meijer@uu.nl

Abstract

The simulation of a (non-)realistic world with Virtual Reality (VR) is gaining in popularity. However, VR has some drawbacks. A big concern is the causation of cybersickness, a form of visually induced motion sickness. It is caused by a conflict between visual and vestibular self-motion cues. To reduce, minimize or eventually prevent cybersickness, this conflict between actual and virtual self-motion needs to be reduced. This reduction can be established in several ways, depending on the presence of actual self-motion and the visual quality of the virtual environment. Since depth cues are a determining factor in this visual quality, this study aimed to research the influence of depth cues on cybersickness in relation to self-motion. More specifically, it ought to compare the effect of virtual environments with motion parallax and stereoscopic viewing of this environment versus no motion parallax and monoscopic viewing. Due to safety measures regarding COVID-19, only a pilot study has been conducted, limited to testing motion parallax as a depth cue in only situations where actual self-motion is present. The results show no significant effect of motion parallax on cybersickness. However, the data of individual subjects suggests that cybersickness might increase faster in case motion parallax is absent. Further research with a larger sample size and in situations with and without actual self-motion is necessary to gain more insight on the influence of depth cues on cybersickness in relation to self-motion. In addition, the used method could be adjusted to prevent distraction from the virtual environment and to further explore the influence of eye and head movements. Consequentially, virtual environments can be improved reckoning the (absence of) self-motion, leading to a better usability of VR in the future.

Keywords: Cybersickness, motion parallax, monoscopic, stereoscopic, Virtual Reality visual-vestibular conflict

Acknowledgments

First of all, I would like to thank my supervisor Jelte Bos for his positive guidance through each stage of the process. Each ‘tegeltjeswijsheid’ has put all the setbacks and unnecessary stress back into perspective and I will never forget that “Less is more”.

Also, I would like to thank my second supervisor Larissa Meijer for helping me out with the structure of my thesis, providing me useful feedback and being always available for ‘short’ questions.

Besides my supervisors I would like to thank TNO for the opportunity to carry out my internship, the AHEAD team for the sometimes chaotic but always interesting meetings and my fellow interns for their help and energizing Ping-Pong breaks.

Further, I would not have been able to complete my thesis without Django den Boer from the University of Utrecht who helped designing the VR environment, and my neighbor who lent me his VR glasses for the experiments.

Finally, a special thanks to all my housemates who have voluntarily participated in my experiment, my friends and family for encouraging me along the road and Ted for providing the best emotional support I could have wished for.

Introduction

Simulating a world with a computer, better known as Virtual Reality (VR), has become more and more popular in the last decades (LaViola, 2000; Martirosov & Kopecek, 2017). The associated technology is used for entertainment purposes such as tourism, marketing and the gaming industry, but also in serious domains such as surgery and the military (Martirosov & Kopecek, 2017; Mousavi, Jen, & Musa, 2013). A reason for this rise in popularity is the ability to immerse the user in pseudo realistic environments that are normally not or not easily accessible (LaViola, 2000). For instance, stressful and dangerous environments such as war scenarios, can be simulated without the risks posed by poor performance of the trainee (Moss & Muth, 2011).

However, VR also has some drawbacks. A major problem is the causation of cybersickness, a form of visually induced motion sickness (Van Emmerik, De Vries, & Bos, 2011). Symptoms of cybersickness include sweating, headaches, disorientation, typically followed by nausea, and ultimately vomiting (Bos, Bles, & Groen, 2008; LaViola, 2000). Early studies found that 80-95% of all users experience some level of disturbance or cybersickness (Liu & Uang, 2016).

These symptoms pose multiple limitations for the usability of VR. First of all, people will stop using a virtual environment if it causes sickness, as people try to avoid getting sick in general. (LaViola, 2000). Studies indicate that up to 80% of trainees drop out due to simulator sickness, leading to a major concern for usability in training purposes (Bos, Ledegang, Grootheest, Kooi, & Houben, 2017). Also, physical performance, such as the precision of manipulations, postural stability or reaction time, is often reduced when cybersickness symptoms are present (Nalivaiko, Davis, Blackmore, Vakulin, & Nesbitt, 2015; Van Emmerik et al., 2011). Furthermore, since symptoms of cybersickness can last hours or even days after the exposure to VR, this could lead to dangerous situations (LaViola, 2000). For example, a decreased postural stability might influence driving behavior after exposure to a virtual environment (Van Emmerik et al., 2011). As such, the influence on performance measurements constitutes a restriction for the growing use of VR in scientific research (Cipresso, Giglioli, Raya, & Riva, 2018).

To reduce these limitations, the causation of cybersickness needs to be minimized. Cybersickness is caused by a conflict between the vestibular system, with the sense organs located in the inner ear, and the visual system (Wolfe et al., 2015). This conflict is also known as the cue conflict theory or sensory conflict theory (Bos et al., 2008; Kolasinski, 1992; LaViola, 2000). A

recent refinement suggests that when the central nervous system is confronted with contradictory information from the organs of balance, and an expectation thereabout in particular, the body reacts with symptoms of motion sickness (Bos et al, 2017). A visual-vestibular conflict then can be assumed to modulate this vestibular-expectation conflict. As such, motion sickness can be reduced by aligning visual and vestibular cues, for example by looking out of the window when driving in a car. To prevent cybersickness in particular, the mismatch needs to be reduced between virtual self-motion as inferred from the virtual environment, and actual self-motion as inferred from the vestibular motions in the real world (Bos et al., 2017; LaViola, 2000). This reduction can be established in several ways. However, the options depend on both the presence or absence of actual self-motion and the perception of virtual self-motion.

In case of actual self-motion, a conflict will arise if the vestibular cues do not correspond with the expectations from the visual cues. This happens for example in a moving-based simulator, where self-motion is present. Due to limitations of the motion platform, this self-motion is different from what is suggested by the visual imagery, leading to cybersickness (Bos et al., 2017; Kolasinski, 1992). Apart from trying to adapt the platform motion such that the perception thereof equals the perception of the real motion (Mousavi et al., 2013), this mismatch could also be reduced by providing the user with less visual cues. The latter can most simply be realized by using a smaller Field of View (Lin, Duh, Parker, Abi-Rached, & Furness, 2002).

In case of no actual self-motion, a conflict will arise if the visual system senses motion while the vestibular system does not (Kolasinski, 1992). This often happens when using a virtual environment, for example with gaming on a computer. Here, the environment is moving but the user sits still (Bos, Van Leeuwen, & Bruintjes, 2018; Van Emmerik et al., 2011). This conflict can be resolved by adapting the environment in such a way that the user concludes that there is no actual movement, for example with an artificial horizon (Bos et al., 2018) or with rest frames (LaViola, 2000; Mousavi et al., 2013). Additionally, the quality of the visual input could be reduced, resulting in a less realistic virtual environment. This is an interesting, and maybe even counterintuitive solution, since it diverges from the current trend in developments of improving the quality of virtual environments (Bos et al., 2018).

In both cases the quality of the virtual environment matters for the perception of the virtual self-motion. Depth perception plays an important role in the quality of a virtual environment and

therefore in this perception (Bos et al., 2017). There are various visual depth cues, which can be further categorized into monocular and binocular depth cues (Liu & Uang, 2016). An important notion here is the difference between the terms monocular and binocular on one hand and monoscopic and stereoscopic on the other hand. Monocular and binocular are both terms referring to the senses, respectively when one eye is used, or two eyes are used (Wolfe et al., 2015). Monoscopic and stereoscopic, however, are both terms referring to the stimulus, when respectively a single image is presented to one or both eyes, or two different images are presented to each eye individually (Kolasinski, 1992; Wolfe et al., 2015).

Which depth cues arise depends on the chosen display, which can be either monoscopic or stereoscopic (Figure 1). Monocular depth cues, such as occlusion, relative size, perspective and texture gradients can be present in a monoscopic display (Wolfe et al., 2015). In this case, the two identical images captured with both eyes are merged in the brain to form a single one-dimensional retinal image. With the use of the present monocular depth cues, however, this one-dimensional image still provides a two-dimensional (2D) representation of objects in the three-dimensional (3D) world (Rosas, 2011). Additional binocular depth cues, such as binocular disparity, arise with the use of a stereoscopic display where the two eyes capture two different views of a 3D object. These two different 2D images allow for an estimate of the 3D geometry of the environment looked at, in addition to the present monocular depth cues (Kim, Angelaki, & DeAngelis, 2016; Kolasinski, 1992; Rosas, 2011).

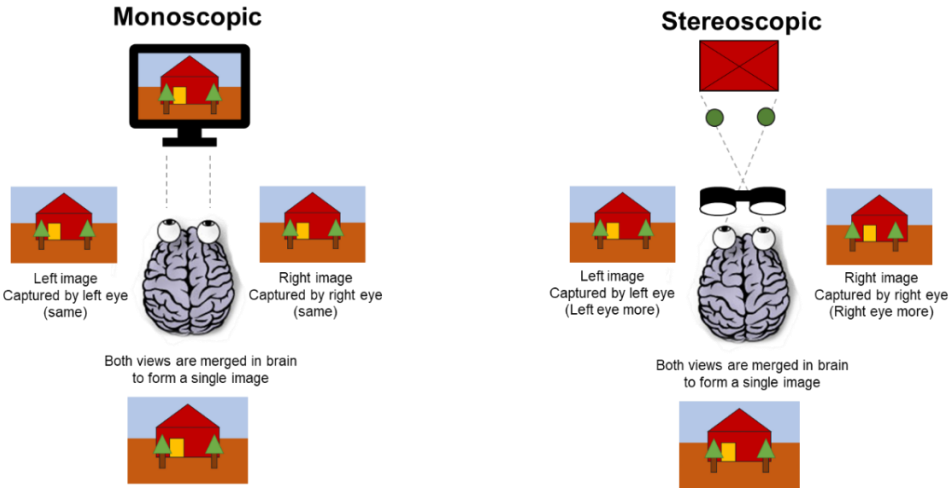

Figure 1. A schematic overview of the difference between viewing monoscopic/2D displays (left) and stereoscopic/3D displays (right). In this example, respectively a tv screen (front view) and virtual reality glasses (top view) are used.

Another important depth cue for the perception of virtual self-motion is motion parallax (Figure 2). Motion parallax is present in both monoscopic and stereoscopic displays and refers to the difference in image motion between objects located at different depths. (Kim, Angelaki, & DeAngelis, 2016). An environment is seen differently from different points of view at different moments in time when a camera or eye moves in that environment (Bos et al., 2017). When observed from these different positions, objects at different depths will have a different parallax (Liu & Uang, 2016). This can be demonstrated with a short experiment you could do yourself. Close one eye and hold one finger in front of you. Then, move your head to your right and left ear. When you shift your viewpoint, objects closer to you shift positions more than objects farther away, this is motion parallax (Wolfe et al., 2015). Moreover, if both your head displacement and the distance in depth between two objects would be known (e.g., that between your eye and your finger), your distance to other objects can be inferred from their relative visual displacements with respect to that of your finger. The fact that in many conditions our heads are moving, makes motion parallax an important contributor to our estimation of the 3D geometry of the world about us, from close by to infinity (Bos et al., 2017).

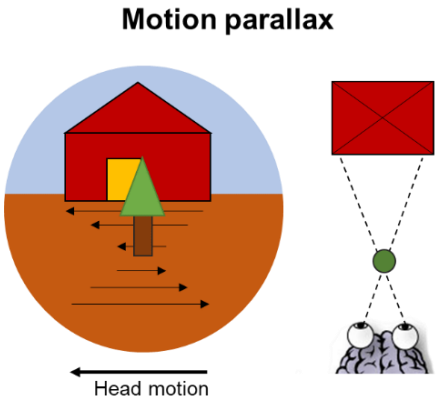

Figure 2. A schematic overview of motion parallax. When the head is moving from right to left with focus on a static object (in this example the tree) objects closer to this static object will move in opposite direction as the head movement and objects further than the static object will move in similar direction. The size of these movements (arrows) depends on the distance of the objects.

Earlier studies focusing on the influence of depth cues on cybersickness have led to various insights, but more research is needed. For example, Liu & Uang (2016) showed that in case of poor qualitative depth cues, stereoscopic displays are not recommended due to even more cybersickness than monoscopic displays. An interesting question is if this also would be the case with depth cues

that arise from motion, such as motion parallax. Bos et al. (2017) focused on the role of motion parallax in a flight simulator but found no significant results due to several constraints of the hardware used. The results of their experiment gave rise to follow-up studies, focusing on the influence of motion parallax while using a more immersive and motion-based simulator. Furthermore, despite the importance of the presence of actual self-motion, research is missing into the influence of depth cues on cybersickness in relation to this self-motion.

Therefore, this study will focus on this influence of depth cues. More specifically it will compare the influence of depth cues present in monoscopic versus stereoscopic displays. The latter of which are commonly used in VR applications, even though early research has already found that stereoscopic displays increase symptoms of cybersickness (Hale & Stanney, 2006; Howarth, 1996). Furthermore, monoscopic displays are often used in simulators such as driving simulators or flight simulator where an environment is created with a screen on the outside of the vehicle. It is therefore interesting to see how the (viewing of the) chosen display influences cybersickness. In addition to the chosen display, this study will focus on the influence of motion parallax since motion is a key variable in the use of virtual reality and more importantly one of the primary factors in causing cybersickness.

In this way, this study aims to answer the following question: What is the influence of depth cues in VR on cybersickness in relation to self-motion? More specifically, it tests the following hypotheses:

1. In case of no actual self-motion and virtual self-motion, a virtual environment with more depth cues will lead to more cybersickness as compared to a virtual environment with less depth cues.
2. In case of actual self-motion that corresponds with virtual self-motion, a virtual environment with more depth cues will lead to less cybersickness as compared to a virtual environment with less depth cues.

To answer this research question, an experiment has been conducted with the use of VR glasses to ensure a high immersion of the user. This also poses the ability to apply the results on a wider field, since VR glasses are less expensive and therefore more easily accessible than more complex simulator environments.

COVID-19

Unfortunately, due to the outbreak of COVID-19 the intended experiment could not be performed regarding safety measurements. In order to provide at least some insights for future research, a pilot study with multiple necessary adjustments has been conducted. Additionally, fictious data has been used to give an overview of expected results and possible analysis. Hence, the intended method from which the fictious data followed is presented in the method section first, followed by the adjustments taken for the pilot study.

Method (intended)

Conditions

Four experimental conditions were designed to test the two hypotheses as described in the introduction (see Table 1).

Table 1. Four experimental conditions of the experiment that follow from a combination of self-motion (real or only virtual) and depth cues. MP stands for Motion Parallax

	More depth cues *Stereoscopic & +MP*	**Less depth cues** *Monoscopic & -MP*
Real self-motion *Body still, head moving, virtual environment is earth still*	1	2
Virtual self-motion *Body still, head still, virtual environment is moving*	4	3

Design

The experiment followed a within-subject design. The independent variables were the absence or presence of motion parallax, the display used and the absence or presence of real self-motion (head movements). The dependent variable was the amount of motion sickness.

Questionnaires

Motion sickness has been measured during the experiment with multiple subjective questionnaires which can be found in appendix A.

MSSQ; Prior to the experiment, subjects filled out the Motion Sickness Susceptibility Questionnaire (MSSQ) (Golding, 1998). This questionnaire asks for previous sickness occurrences in different vehicles as well as swings, merry-go-rounds, and leisure park attractions for ages up to twelve, as well as for the past twelve years. Four extra questions were included regarding virtual devices to predict cybersickness specifically. This resulted in two MSSQ ratings: the original MSSQ-rating ranging from 0 (no problems in any condition) to 54 (severe problems in all conditions), and an elaborated MSSQ-rating ranging from 0 (no problems in any condition) to 66 (severe problems in all conditions). Both estimate visually induced motion sickness for each subject.

SSQ; Before and after each condition subjects filled out a Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The SSQ explicitly rates sixteen symptoms,

clustered in three categories: nausea, oculomotor, and disorientation, that can be pooled resulting in a total score (Table 6, Appendix A). Each symptom can be scored between 0 and 3, resulting in an index of the combined categories (Table 7, Appendix A). The goal of the pre-exposure questionnaire was to set an individual baseline of the subjective symptoms that could be subtracted from the post-exposure questionnaire. This pre-exposure rating also allowed for compensating a possible change in this individual baseline between the conditions.

MISC; To track motion sickness symptomatology during each experimental condition, subjective misery has been obtained verbally by means of the single answer ordinal MIsery Scale (MISC) (Bos, MacKinnon, & Patterson, 2005). As specified by Bos et al. (2005, p. 1112), this scale is based on the knowledge that "nausea is generally preceded by other symptoms such as dizziness, headache, (cold) sweat and stomach awareness". The MISC gives a single number ranging from 0 (no problems) to 10 (vomiting), based on a variety of symptoms (Table 8, Appendix A).

Materials and apparatus

Virtual environment. A 3D virtual environment has been created with Unity. This environment contained several objects placed at different depths contained multiple monocular depth cues, such as occlusion, perspective, and texture gradient. Four viewing settings were included: monoscopic or stereoscopic viewing and both with or without motion parallax. The environment was shown with the use of Oculus Rift CV1 VR glasses.

Video; To allow for image motion while sitting still, a recording of the virtual environment during self-motion has been made during the execution of the tasks in conditions 1 & 2. These videos were shown in respectively conditions 4 & 3, e.g. the conditions with the same combination of depth cues (see Table 1).

Task

During each experimental condition, every subject was given a cognitive task. This task was divided in eight separate movement-tasks with a duration of 110 seconds each, resulting in a total duration of accordingly 16 minutes.

During the movement-tasks in experimental conditions 1 and 2 (see Table 1), subjects were tasked to rotate and move their head by imitating the movement of a smiley in the virtual

environment. Simultaneously they were tasked to perform a dual cognitive task that consisted of a 1-back task (Kirchner, 1958), combined with a memory task. In this dual task, a sequence of characters was displayed, and subjects were asked to count the pairs of similar characters during this sequence. In other words, they had to count how many times a character was the same as the previous character shown. The goal of this dual task was to keep subjects alert during the experiment and to minimize variability in the mental workload of the subjects. The dual task has been incorporated in the movement-task in the following way as also shown in Figure 3:

First, subjects were asked to look at the smiley which was visible in the virtual environment (1). Then, subjects had to rotate their head as displayed by the smiley (2) and follow the smiley with their head while it moved through the environment (3). After this movement, a character appeared which they were asked to remember (4). Then, the smiley changed head position and moved to another position. Again, the subjects were asked to rotate their head as displayed and follow the movement of the smiley. A new character appeared, which they had to remember and compare with the previous one. Then, the smiley changed the rotation and started moving again, etc.

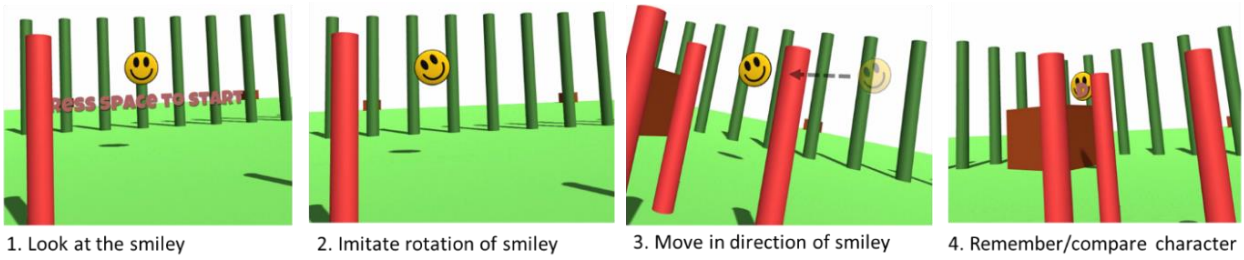

Figure 3. Schematic overview of the movement of the smiley and appearance of the character in the movement-task.

These movements continued for 110 seconds. After each movement-task, 10 seconds followed to obtain the results of the dual-task (Figure 4), ask the subjects how they felt (with use of the MISC) and ask them to return with their eyes to the central point: the smiley located in the center of the virtual environment. An important notion is that the rotation (2 in Figure 3) and the movement (3 in Figure 3) did not follow entirely sequentially, resulting in both a rotiation and a tilt during each head movement, which is important since motion parallax is only present during translation as a consequence of this tilt.

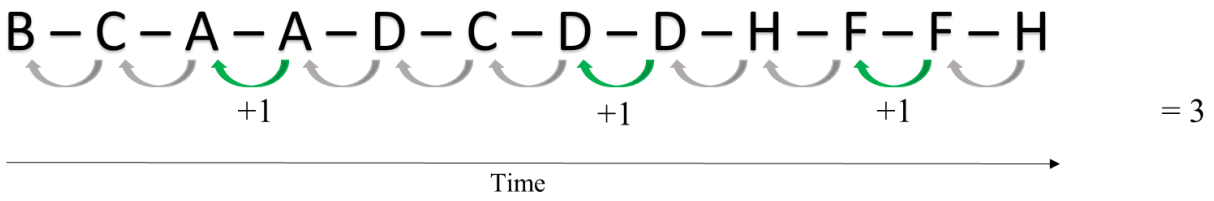

Figure 4. Example of correct result of the dual task. In this example, the previous character is three times the same as the current character, resulting in a correct answer of 'three'.

Experimental conditions 3 and 4 (see Table 1) consisted of a similar cognitive task. However, subjects had to sit still and watch a video (see materials) in the VR environment. Instead of moving their head, they were requested to imitate the shown movement with a little ball in their hand. These hand movements were implemented to equalize the experimental conditions and their mental load with respect to performing a motor task. As in conditions 1 and 2, subjects conducted the dual task with the characters that were shown, followed by a sickness measurement with use of the MISC.

Prior to the execution of the cognitive task in each experimental condition, subjects performed a practice task. This task consisted of one short movement-task task to get familiar with the corresponding actions of this condition. This movement-task was displayed using a desktop monitor instead of using the VR glasses to reduce the influence of exposure during familiarization on the emergence of cybersickness.

Subjects (fictitious)

The fictitious data has been generated with the hypotheses in mind. First of all, 24 fictitious subjects (12 male, 12 female) have been 'designed' with a random age between 18 and 60. Then, random MSSQ (and extended MSSQ) scores, based on a normal distribution and ranging from 10 to 60, were randomly assigned to them. Finally, based on their MSSQ scores and expected outcomes regarding the hypotheses and test data, fictious SSQ and MISC scores have been designed for each individual subject. To simulate individual differences, some random adjustments were made. This resulted in the following description of subjects:

Twelve female subjects and twelve male subjects aged between 19 and 51 participated in this experiment (M= 31.08 years, SD = 8.57 years). All of them had a normal or normal to corrected vision and a normal stereovision (<= 120 seconds of arc).

Procedure

A schematic overview of the procedure can be found in Figure 5. Since this procedure has not been conducted, only a general description is provided in this section. The procedure of the pilot will be described in more detail.

For practical reasons, the experimental conditions were tested in pairs in two sessions, allowing subjects to participate in these two sessions on two days only. The first session started with an introduction of 30 minutes in which the experiment was explained and informed consent forms were signed. Also, the MSSQ was conducted and stereovision was tested. After this introduction, subjects participated in two experimental conditions of 30 minutes each with a break of 30 minutes in between. The second session again consisted of two experimental conditions and a break of 30 minutes in between. Both sessions took place with at least 48 hours in between to minimise possible after-effects. Furthermore, the order of the conditions has been counterbalanced to account for habituation.

Each experimental condition started with the pre-exposure SSQ. Then, subjects performend a practice task after which the cognitive task of 16 minutes followed (8 movement-tasks of 120 seconds). Finally, subjects filled out the post-exposure SSQ. All experimental procedures were approved by the local ethics committee of TNO (memorandum 2020-016).

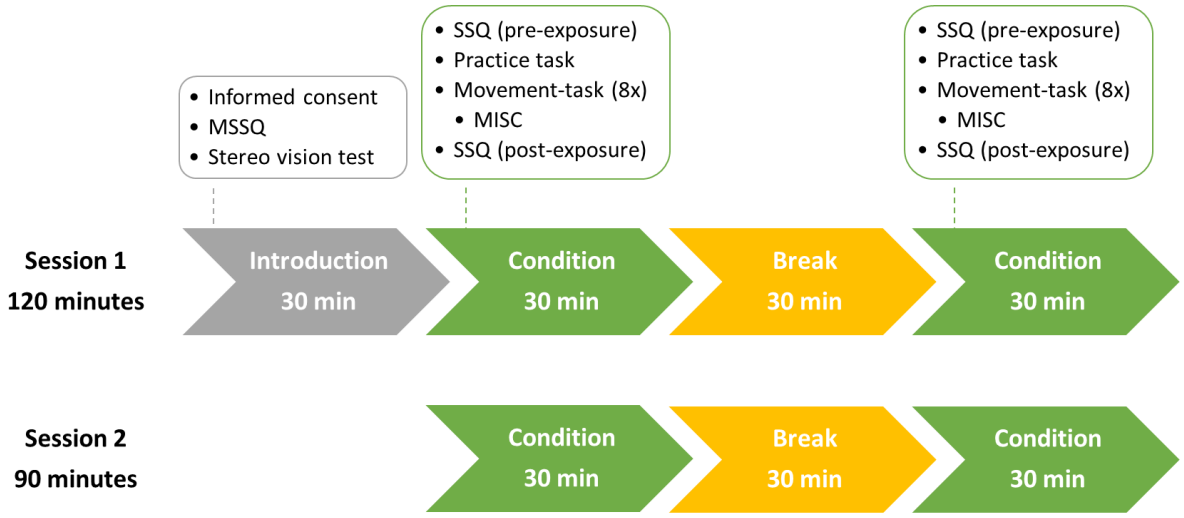

Figure 5. Schematic overview of the experimental procedures and measurements taken during the intended method.

Method (pilot)

Adjustments

The method was adjusted in multiple ways due to safety measures regarding COVID-19. First of all, it was impossible to test the intended number of subjects due to the safety measures that were taken by both the government and TNO. Alternatively, it was decided to test only six subjects (including the research leader) that were already living in the same household. Secondly, both the monocular settings and video recordings could not be realized within the timespan of this internship. Consequently, the subjects within this pilot could only participate in the two conditions with actual self-motion and with or without motion parallax, i.e. conditions 1 and 2 (see Table 1). Besides these adjustments, multiple hygiene measurements were taken to ensure the safety of the subjects which can be found in Appendix C.

Subjects

Six subjects aged between 24 and 26 participated in this experiment (M = 25.1 years, SD = 0.75 years). Four of them were female, two of them were male. All of them had a normal or normal to corrected vision, however some minor eye defects were present: one subject suffered from minor color blindness and another subject had an impaired stereovision (240 seconds of arc). The other five subjects did have a normal ability to see in stereo (<= 120 seconds of arc).

Procedure

An adjusted schematic overview of the procedure can be found in Figure 6. The procedure was almost identical to the procedure of the intended method (see Figure 5). However, the introduction and two sessions took place on three different days, with at least 24 hours in between to minimize possible after-effects.

During the first session of 30 minutes the experiment was explained. Also, subjects signed informed consent forms. Further, the MSSQ was conducted to be able to compare the susceptibility of the subjects for motion-sickness with other studies. Finally, a stereopsis test (TNO stereopsis test, Walraven, 1975; Walraven & Janzen, 1993) has been conducted to ensure that subjects had a normal or corrected-to-normal stereo vision (stereoacuity <= 120 seconds of arc). After this

introduction, subjects participated in two experimental conditions of 30 minutes. The order of these conditions has been counterbalanced to account for habituation.

Each experimental condition started with the pre-exposure SSQ. Since the task was similar in both conditions, subjects only performed a practice task previous to their first cognitive task. This practice task took approximately one minute. After this task or directly after the pre-exposure SSQ, the VR glasses were placed in the right position. Subjects were instructed to sit in an upright position with their back touching the backrest. Further, subjects were asked to keep their heads straight in a forward position. When everything was prepared, the cognitive task of 16 minutes followed (8 movement-tasks of 120 seconds) in which misery was measured with use of the MISC. Finally, subjects filled out the post-exposure SSQ.

All experimental procedures were approved by the local ethics committee of TNO (memorandum 2020-016).

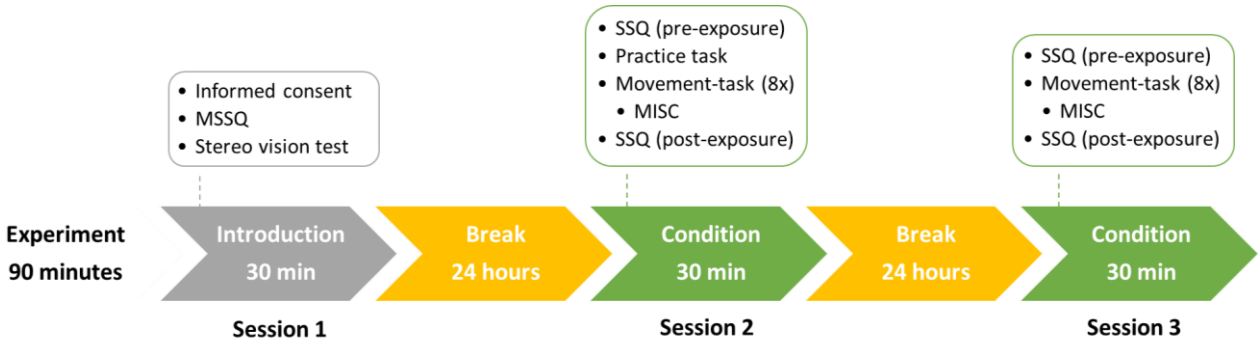

Figure 6. Schematic overview of the experiment and measurements taken during the pilot study

Results

Pilot study

MSSQ

Average susceptibility

The MSSQ data was normally distributed, as assessed by Shapiro-Wilk's test ($p > .050$) and no extreme outliers were found. The MSSQ yielded a mean score of 21.6 (minimum 8, maximum 43.3, SD = 14.5). Since this is below the 50th percentile of a normal population (mean MSSQ = 37), this indicates that most of the test subjects were less prone to motion sickness than average (Golding, 1998). The MSSQ with additional questions regarding virtual devices yielded a mean score of 23.4 (minimum 8, maximum 47.3, SD = 16.4). Since these additional questions have not been added in studies before, no average score for a normal population is known. However, the average extended MSSQ score for a normal population is expected to be higher than the traditional MSSQ score since it ranges from 0 to 66, in contrast to a range of 0 to 54. Therefore, this average extended MSSQ score similarly indicates a lower than average susceptibility.

Differences gender/age

Unfortunately, the sample size was too small to look for any significant differences of the MSSQ regarding age and gender.

SSQ

Average SSQ scores

The total sickness scores (T) and the three sub scores disorientation (D), nausea (N) and oculomotor (O) were obtained by subtracting the pre-SSQ data from the post-SSQ data for both conditions (Figure 7). The data was normally distributed as assessed by Shapiro-Wilk's test ($p > .050$) and no extreme outliers were found. An ANOVA was conducted to test the difference of each SSQ score between the conditions with and without motion parallax. The results indicate that the absence of motion parallax has no significant effect on all the sub scores and the total sickness score (D: $F_{1,5} = 0.077$, $p > .050$; N: $F_{1,5} = 0.676$, $p > .050$; O: $F_{1,5} = 5$, $p > .050$; T: $F_{1,5} = 0.971$, $p > .050$).

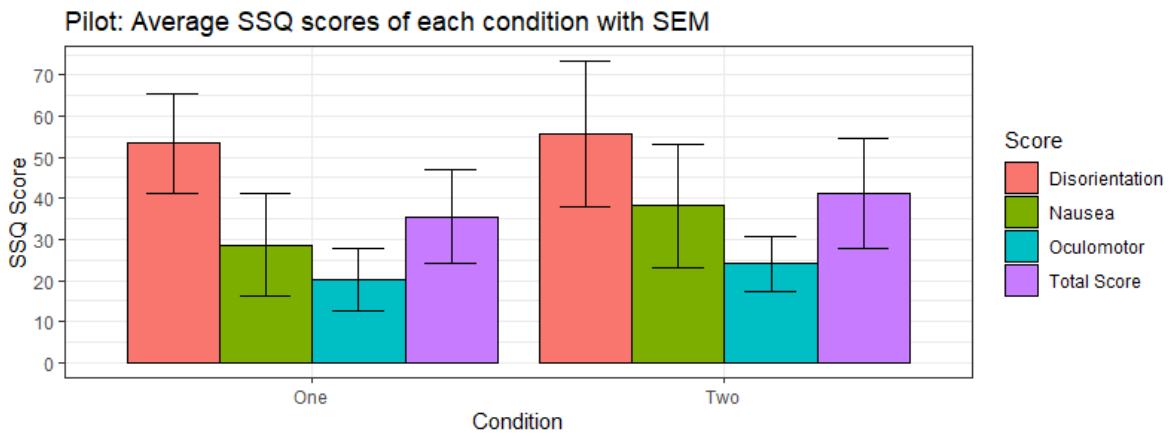

Figure 7. Average SSQ scores in both conditions with Standard Error of the Mean (SEM). Condition one is with motion parallax, condition two is without motion parallax.

Order SSQ sub scores

Since the SSQ clusters symptoms in three categories which seems to appear in different order dependent on the type of simulator, it is interesting to look at the pattern of the SSQ sub scores (Stanney & Kennedy, 1998). Following from the average sub scores in Figure 7, the average order from high to low was D > N > O. However, the observed order of the sub scores of SSQ was not similar for all subjects, as can be seen in Figure 8. The most observed order was D > N > O (four times), followed by D > O > N (three times). Also, one subject had a similar value for nausea and oculomotor but the highest value for disorientation. This indicates that symptoms of disorientation were mostly present after the experiment, which corresponds with the average SSQ scores in Figure 7.

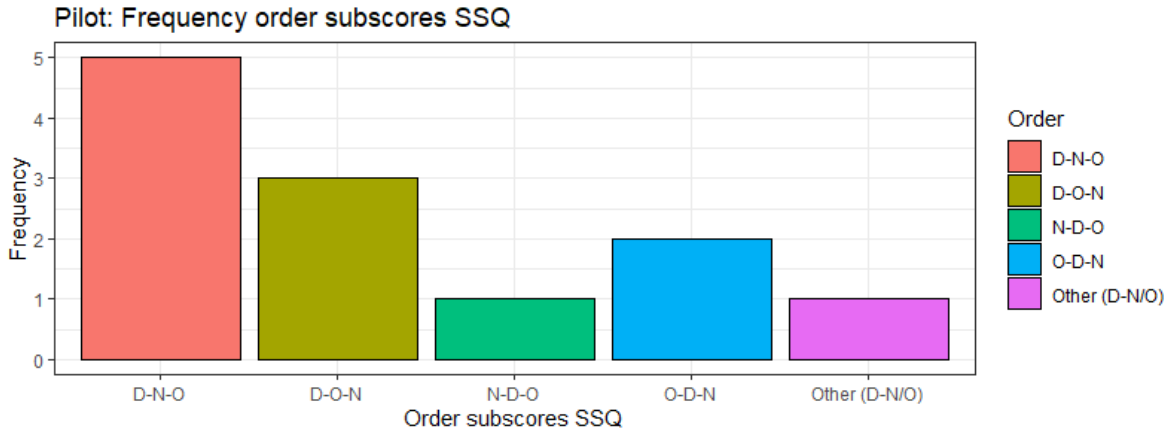

Figure 8. The observed order of SSQ sub scores during each condition in order of size (high to low). One subject had the order D – N/O (similar value for N and O).

MISC

Individual data

Due to the small sample size it was decided to qualitatively analyze the individual MISC data. Some interesting observations can be made by looking at this individual data (Figure 9). First of all, it is interesting to notice that two subjects (3,4) do not only follow an increase of MISC during time but also some decreases appear. Secondly, three of the subjects (1,4,5) did not have much rise in misery at all in both conditions (maximum MISC = 3), although two of them (1,4) did reach higher MISC values in the condition without motion parallax. Furthermore, an interesting observation is that in the condition with motion parallax, three of the six subjects have reached a MISC value of six or higher (2,3,6) in contrast with only two subjects in the condition without motion parallax (2,6). On the other hand, the two subjects that have reached this value in both conditions have reached it faster in the condition without motion parallax, in contrast to subject '3', who does not have reached a high MISC value in the condition without motion parallax at all.

Altogether, this data suggests that four of the six subjects follow the expected pattern: the emergence of more sickness symptoms or a faster emergence of similar sickness symptoms in case motion-parallax is absent.

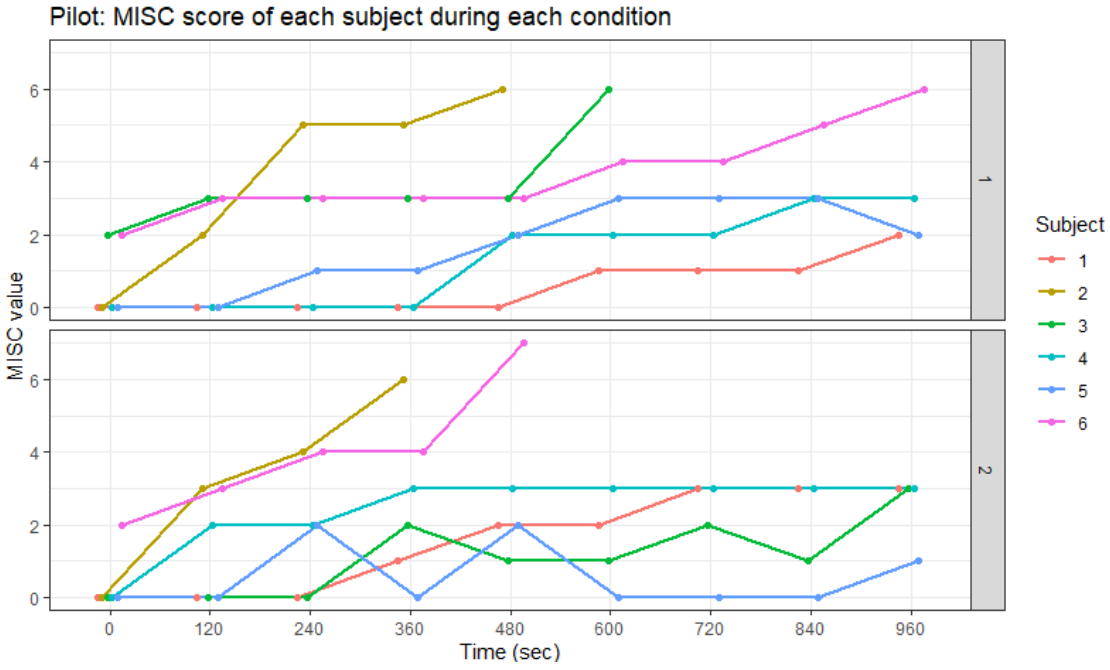

Figure 9. The MISC value during time in both conditions for each individual subject. Condition 1 is with motion parallax, condition 2 is without motion parallax.

Average data (timepoints)

In addition to the qualitative analysis, the average MISC data also has been analyzed. To compare the increasement of misery during time it is interesting to look at the average MISC values for each timepoint during both conditions, which are shown in Figure 10. Note, that the missing MISC values of people who have stopped during the experiment (as a result of a MISC value of 6 or higher) have been filled by repeating the last MISC value achieved. Since the data was not normally distributed and the MISC has an ordinal scale, a Friedman test has been performed to test the differences between both conditions. The results indicate no significant differences between the conditions with and without motion parallax at any timepoint ($X(2)=5$, $p > .050$).

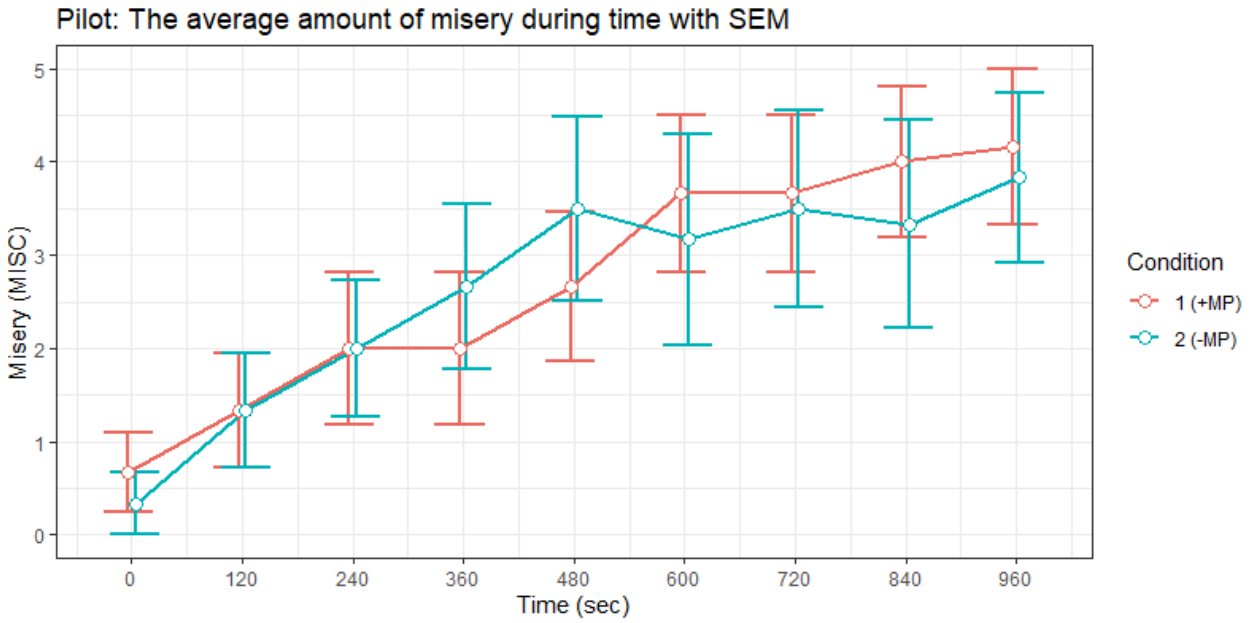

Figure 10. The average amount of misery during time for each condition with Standard Error of the Mean (SEM). Condition 1 is with motion parallax, condition 2 is without motion parallax.

Normalized average data (timepoints)

To control for the variability in MISC values as seen in the analysis of the individual data, the MISC data has been normalized by dividing all individual MISC values within each condition by the individual maximum MISC value observed in both conditions. This resulted in a normalized MISC value between zero and one at each timepoint for each individual subject. The average normalized MISC values are shown in Figure 11. Again, a Friedman test indicates no significant

differences between the average of these normalized MISC values at any timepoint (X(2)=5, p > .050). However, there is an indication that in the condition with motion parallax (condition 2), misery increases faster from 120 to 480 seconds than in the condition without motion parallax (condition 1), being slightly more pronounced in normalized data shown Figure 11 as compared to the raw averaged data shown in Figure 10.

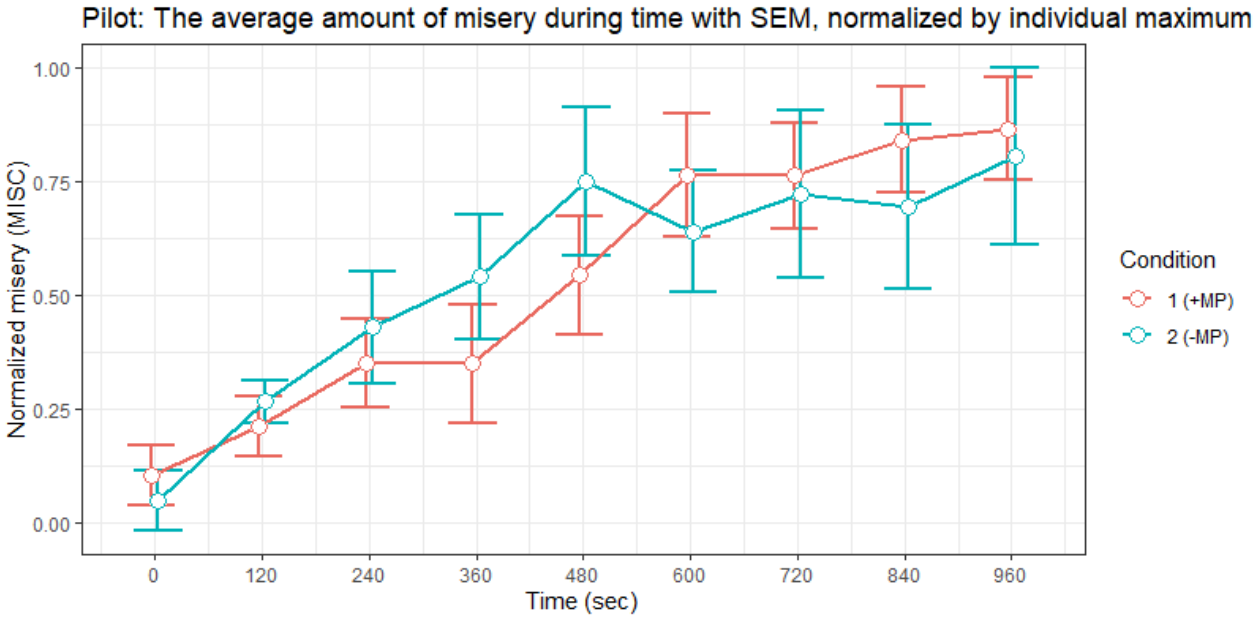

Figure 11. The average amount of misery during time, normalized by individual maximum misery (MaxMISC) in both conditions with Standard Error of the Mean (SEM). Condition 1 is with motion parallax, condition 2 is without motion parallax.

Average data (maximum value)

Besides the comparison of each timepoint, the maximum MISC value reached during each condition (MaxMISC) also has been compared since this gives an indication for the developed amount of cybersickness (Figure 12). As the experiment stopped when the MISC value was reported as 6 or higher, some subjects reached this MaxMISC before the end of the experiment. To control for this, and taking advantage of the observation that on average sickness increases with the square root of time (Lawther & Griffin, 1987), the MaxMISC has been divided by the square root of the time in seconds (T) at which this last value was obtained: $Corrected\ MISCmax = \frac{MISCmax}{\sqrt{(T)}}$.

A Friedman test indicates no significant differences between the two conditions for both the uncorrected MaxMISC (X(2)=5, p > .050) and the corrected MaxMISC (X(2)=5, p > .050).

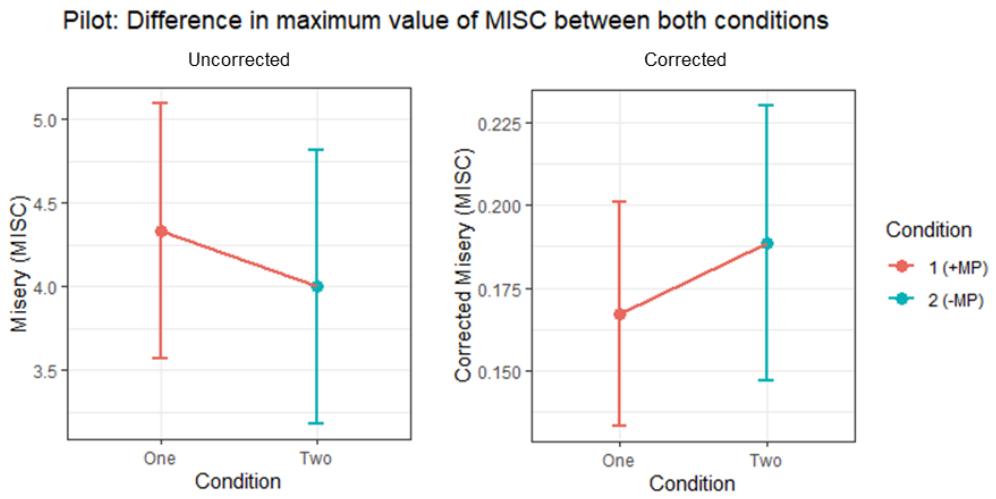

Figure 12. Comparison of the difference in average maximum value of the MISC (MaxMISC) between both conditions, both uncorrected (left) and corrected (right). Condition 1 is with motion parallax, condition 2 is without motion parallax.

Normalized average data (maximum value)

Additionally, as with the time plots, both the uncorrected and corrected MaxMISC have been normalized by the MaxMISC of each individual subject during both conditions (Figure 13). Again, no significant differences have been found between the two conditions for both comparisons: the uncorrected and normalized MaxMISC ($X(2)=5$, $p > .050$) and the corrected and normalized MaxMISC ($X(2)=5$, $p > .050$).

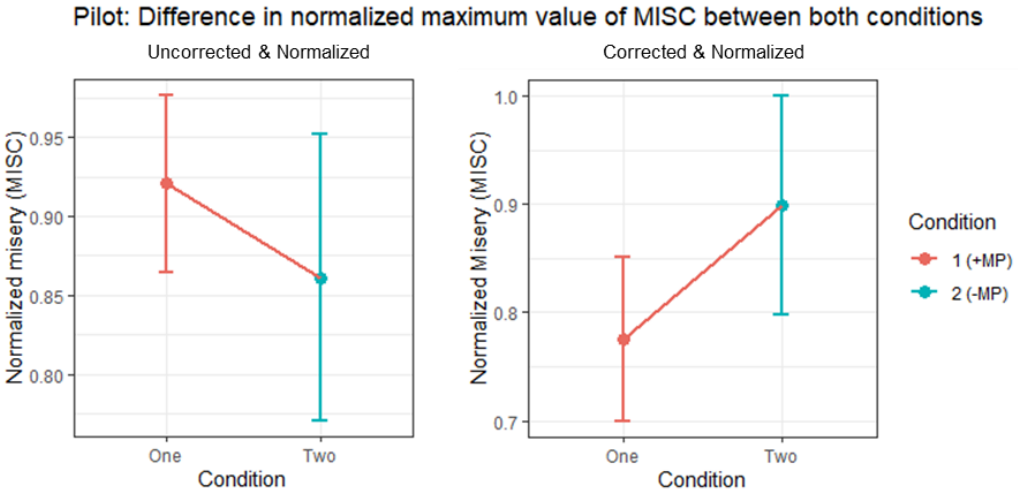

Figure 13. Comparison of the difference in normalized average maximum value of the MISC (MaxMISC) between both conditions, both uncorrected (left) and corrected (right). Condition 1 is with motion parallax, condition 2 is without motion parallax.

Average data (timepoints - comparison sessions)

Because the conditions were counterbalanced, the MISC values of the first and second session have been compared for each timepoint to test for a possible habituation effect (Figure 14). Despite the indication following from the visual representation that the first session has higher MISC ratings, only a significant effect of session was found at 0 seconds ($X(2)=5$, $p = .025$), 120 seconds ($X(2)=5$, $p = .025$) and 240 seconds ($X(2)=5$, $p = .025$) with use of a Friedman Test.

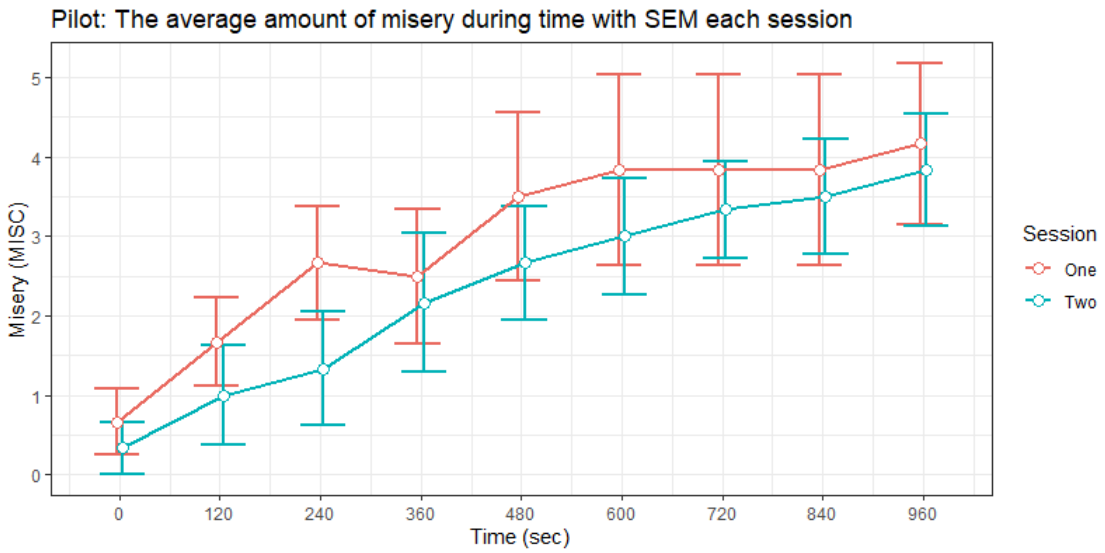

Figure 14. The average amount of misery during time for each session with Standard Error of the Mean (SEM).

Correlations

To validate the predictive value of the MSSQ and to compare the values of the uncorrected and corrected MISC with the SSQ scores, correlations between all measurements have been tested (Table 2). Since the data was not normally distributed, Kendall's correlation coefficient was used to test these correlations. Following from the results in Table 2, there seems to be a correlation between the MSSQ and SSQ scores. Also, the total sickness score (T), nausea sub score (N) and oculomotor sub score (O) seem to correlate with both the MaxMISC and corrected MaxMISC. However, there does not seem to be a correlation between the MSSQ and both the MaxMISC and the corrected MaxMISC. Furthermore, it is interesting to notice that this correlation is the strongest for nausea, which seems a confirmation for the idea that the MISC predicts nausea best (Bos et al., 2005).

Table 2. Overview of correlations and corresponding p values during both conditions/sessions (n.s.: p > .050, *: p <= .050, **: p <= .010, ***: p <= .001). 'MaxMISC (cor)' stands for maximum MISC value corrected by time reached

			SSQ				MISC	
			TS	N	O	D	MaxMISC	MaxMISC (cor)
	MSSQ	*R*	0.516	0.516	0.487	0.6	-	-
		P	*	*	*	*	n.s.	n.s.
MISC	MaxMISC	*R*	0.625	0.708	0.558	-		
		P	**	**	*	n.s.		
	MaxMISC (cor)	*R*	0.59	0.668	0.509	-		
		P	*	**	*	n.s.		

Considering the influence of the order of conditions and the potential lower scores due to a habituation effect, the correlations left during session 2 are worth looking at. Again, correlations between the results of all measurements during have been tested with use of Kendall's correlation coefficient (Table 3). Following from the results in Table 3, only the correlation between MSSQ and SSQ sub scores nausea and disorientation and the correlation between MaxMISC and SSQ sub score oculomotor remain.

Table 3. Overview of correlations and corresponding p values during session 2 (n.s.: p > .050, *: p <= .050, **: p <= .010, ***: p <= .001). 'MaxMISC (cor)' stands for maximum MISC value corrected by time reached.

			SSQ				MISC	
			TS	N	O	D	MaxMISC	MaxMISC (cor)
	MSSQ	*R*	-	0.828	-	0.828	-	-
		P	n.s.	*	n.s.	*	n.s.	n.s.
MISC	MaxMISC	*R*	-	-	0.817	-		
		P	n.s.	n.s.	*	n.s.		
	MaxMISC (cor)	*R*	-	-	-	-		
		P	n.s.	n.s.	n.s.	n.s.		

Fictitious data

MSSQ

Average susceptibility

The MSSQ data was normally distributed as assessed by Shapiro-Wilk's test and no extreme outliers were found ($p > .050$). The MSSQ yielded a mean score of 31.2 (minimum 13, maximum 52.8, SD = 10.2). The MSSQ with extra questions regarding virtual devices yielded a mean score of 31.2 (minimum 13, maximum 50, SD = 10.11). As with the pilot, both the mean of the MSSQ and the extended MSSQ are below the 50th percentile of a normal population (mean MSSQ = 37). However, the mean of the normal population is located within one standard deviation from the mean of the fictitious data for both the MSSQ and the extended MSSQ, which indicates that these subjects have a similar susceptibility for motion sickness as a normal population.

Differences gender/age

On average, female subjects had a higher MSSQ score than male subjects, indicating a higher susceptibility (female: mean = 34.15, SD = 7.66, male: mean = 28.31, SD = 11.88). Also, younger subjects seemed to be slightly more susceptible to motion sickness than older subjects (age < 30: mean = 31.42, SD = 10.76, age > 30: mean = 29.88, SD = 6.4).

SSQ

Average SSQ scores

The total sickness scores (T) and the three sub scores: disorientation (D), nausea (N) and oculomotor (O) were obtained by subtracting the pre-SSQ data from the post-SSQ data for each condition (Figure 15). Since the SSQ data was not normally distributed, a Friedman Test has been conducted to test the differences between the four conditions. The results indicate that the total sickness score and all three sub scores differed significantly (T: $X(2)= 69.01$, $p < .001$, N: $X(2)= 70.09$, $p < .001$; O: $X(2)= 58.58$, $p < .001$; D: $X(2)= 69.01$, $p < .001$).

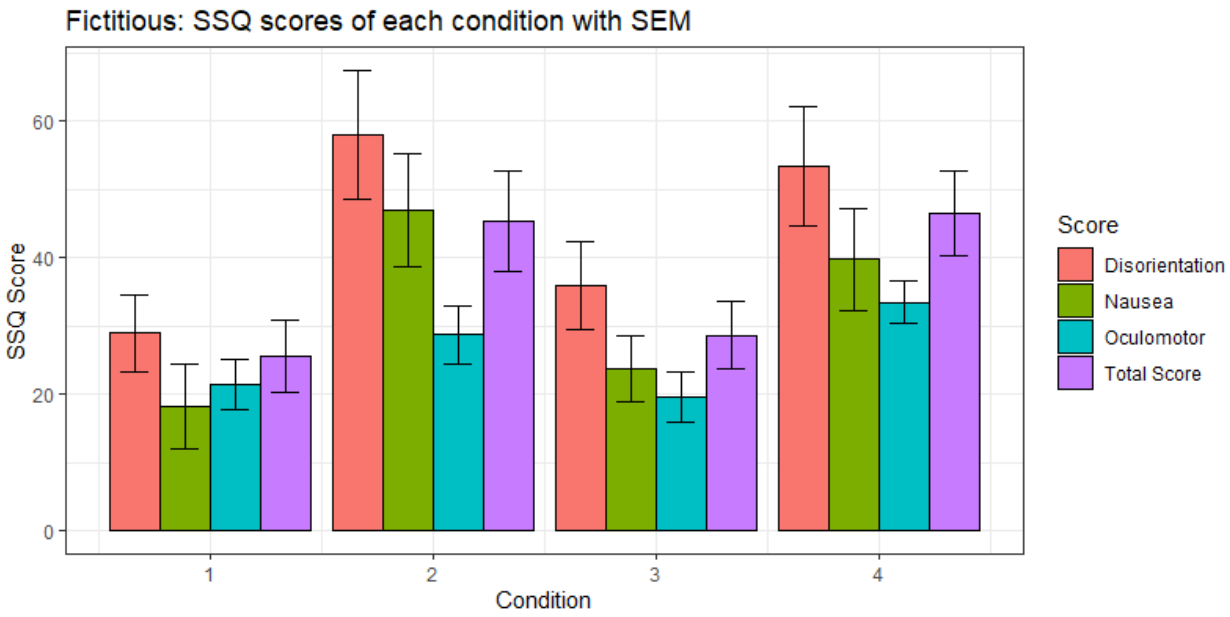

Figure 15. Average SSQ Total score and sub scores for each condition with Standard Error of Mean (SEM).

Post hoc analysis (SSQ scores)

Because the Friedman test showed significant differences between the conditions for all SSQ scores (total score and three sub scores), a post-hoc analysis for each individual SSQ score was performed to further specify the conditions in which this score differed significantly. This analysis can be found in Appendix D (Figure 18).

Order SSQ sub scores

Similar to the pilot, it is interesting to look at the pattern of SSQ sub scores. Following from the average data in Figure 15, the order of sub scores from high to low appears as D > O > N in condition 1, and D > N > O in the other three conditions. As with the pilot, more variation of this order can be seen when looking at the frequency of the observed orders of the SSQ sub scores in all conditions (Figure 16). However, the most observed pattern is still D > N > O, followed by the pattern D > O > N. Furthermore, oculomotor scores are most often the lowest of the three sub scores, in contrast to disorientation scores which are less often the lowest.

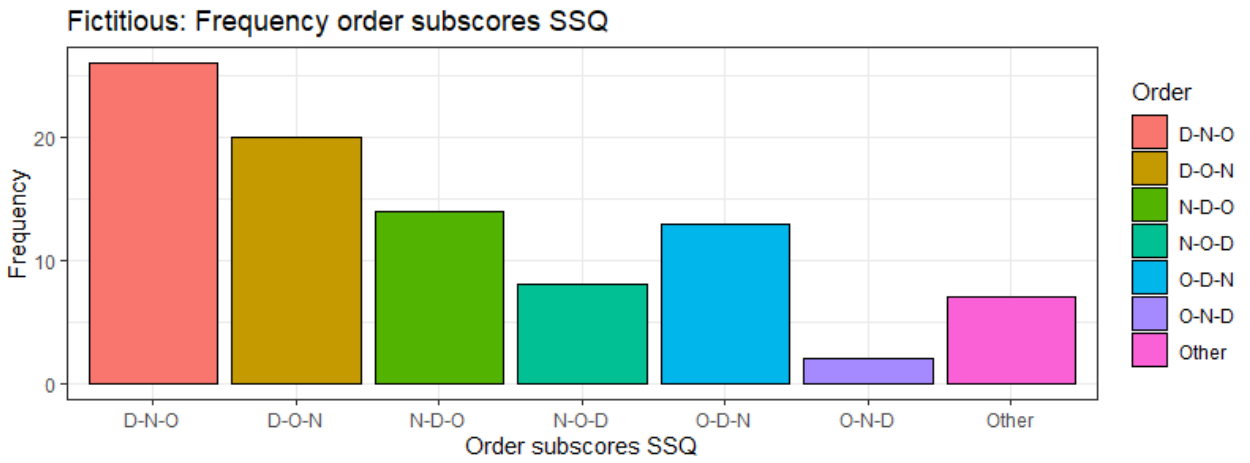

Figure 16. The observed order of SSQ sub scores during all conditions in order of size (high to low). 'Other' are sequences without a strict order (at least two similar values).

MISC

Average data (timepoints)

The average misery scores were obtained from the MISC data (Figure 17). As with the pilot, missing values have been filled by repeating the last MISC value achieved. Some extreme outliers were found, but only at t = 0 and t= 720 in condition 1 and t = 0 in condition 2. Since the data was not normally distributed and the MISC has an ordinal scale, a Friedman test has been performed to test the differences between all conditions at the separate timepoints. The results indicate that the MISC differs significantly at all timepoints, except for t = 0 ($p > .050$).

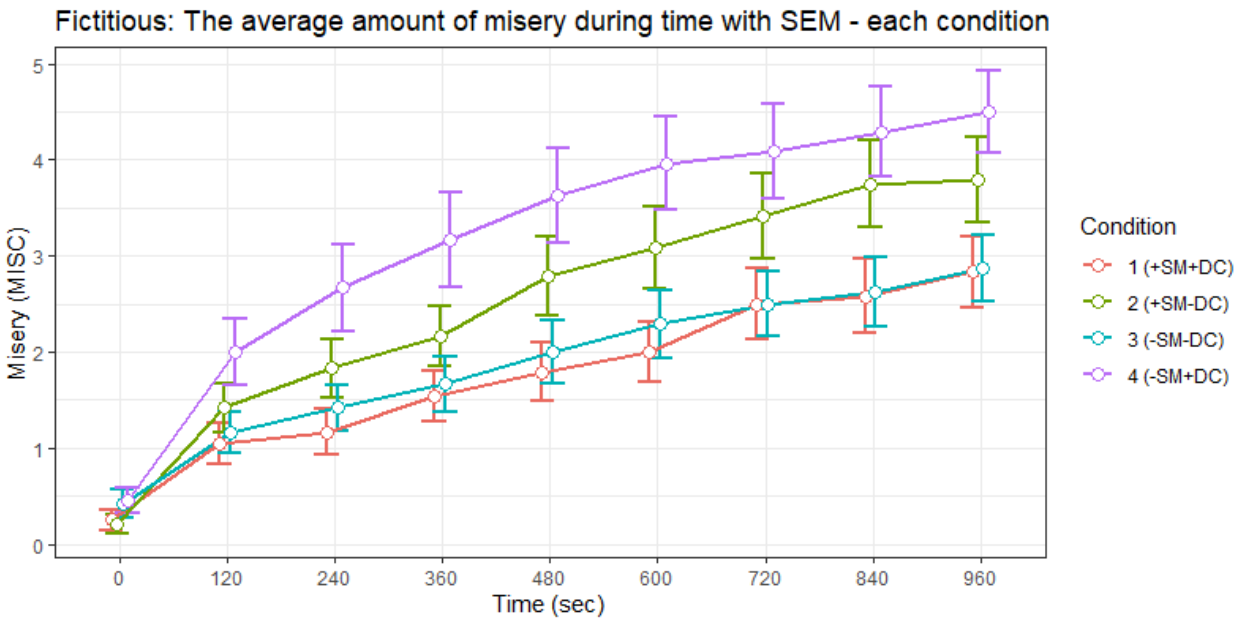

Figure 17. The average amount of misery during time for each condition with Standard Error of the Mean (SEM). SM stands for actual self-motion; DC stands for depth cues (both motion parallax and stereoscopic display).

Post hoc analysis (timepoints)

A post hoc analysis for each different timepoint has been performed to further specify in which conditions the MISC values differed from each other. A pairwise Wilcoxon signed rank test revealed statistically significant differences between all conditions, except for conditions 1 & 3 (Table 4). Furthermore, these differences were most significant between conditions 1 & 4 and between conditions 3 & 4.

Table 4. Results of pairwise Wilcoxon signed rank test of MISC scores between conditions at each different timepoint with p values (*: p <= .050, **: p <= .010, ***: p <= .001). The time (in seconds) is given in the top row, the conditions which have been compared are given in the left column.

	0	120	240	360	480	600	720	840	960
1 & 2			*	*	*	*		*	
1 & 3									
1 & 4		**	**	**	***	***	**	**	**
2 & 3					*		*	*	
2 & 4		*		*					*
3 & 4			**	**	***	**	**	**	**

Average data (maximum value)

Besides the comparison between each timepoint, also the individual maximum MISC value (MaxMISC) during each condition has been compared. The comparison of the uncorrected data indicates that the MaxMISC differed significantly between each condition ($X(2)=32.4$, $p < .001$). Similar as with the correction in the pilot, the MaxMISC has been divided by the square root of the time in seconds (T) at which this last value was obtained. Again, the results indicate that the corrected MaxMISC differs significantly between the conditions with use of the Friedman Test: $X(2)=29.7$, $p < .001$).

Normalized average data (maximum value)

Similar to the pilot, both the uncorrected and corrected MaxMISC have been normalized by the maximum MISC value of each individual subject to control for individual variability. Significant differences have been found between each condition for both the normalized uncorrected MaxMISC and the normalized corrected MaxMISC with use of the Friedman Test (normalized uncorrected: $X(2)=32.4$, $p < .001$; normalized corrected: $X(2)=35.8$, $p < .001$).

Post hoc analysis (maximum value)

As with the comparison of timepoints, a post hoc analysis has been performed to further specify the conditions in which the uncorrected MaxMISC, the corrected MaxMISC, the normalized uncorrected MaxMISC and the normalized corrected MaxMISC differed significantly. As with the post-hoc analysis of the SSQ values, the results of this analysis can be found in Appendix D (Figure 19 and Figure 20).

Average data (timepoints - comparison sessions)

Similar to the pilot, a Friedman test has been conducted to test the difference between each session to control for a habituation effect. The results indicate no effect of the order of sessions on the MISC values at any timepoint ($p > .050$).

Correlations

In the same manner as the data analysis of the pilot, the correlations between all measurements have been tested to validate the predictive value of the MSSQ and to compare the values of the uncorrected and corrected MISC with the SSQ scores. Again, these were tested with use of Kendall's correlation coefficient since the data was not normally distributed. Following from the results in Table 5, there seems to be a correlation between all measurements taken. These correlations were similarly shown in only the last session, from which can be concluded that there is no habituation effect regarding these questionnaires. The correlations between the MSSQ and both SSQ and MISC are stronger for the traditional MSSQ questionnaire than for the MSSQ with additional questions regarding virtual devices. The original MSSQ therefore seems to predict misery better than the elaborated questionnaire. Furthermore, as with the pilot, the correlation between the corrected MaxMISC and SSQ sub scores is again the strongest for nausea, followed by disorientation and then oculomotor.

Table 5. Overview of correlations and corresponding p values during all conditions (*: p <= .050, **: p <= .010, ***: p <= .001), 'MaxMISC (cor)' stands for maximum MISC value corrected by time reached.

			SSQ				MISC	
			TS	**N**	**O**	**D**	**MaxMISC**	**MaxMISC (cor)**
	MSSQ	*R*	0.278	0.320	0.214	0.228	0.336	0.350
		P	***	***	**	**	***	***
MISC	**MaxMISC**	*R*	0.252	0.168	0.168	0.210		
		P	***	***	*	**		
	MaxMISC (cor)	*R*	0.780	0.754	0.660	0.670		
		P	***	***	***	***		

Discussion

Because the fictious data has been based on the hypothesis with some random adjustments, no scientifically based conclusions can be drawn from these results. Apart from providing an insight of the possible statistical analysis and an overview of the expected outcomes with which the pilot results can be compared, these fictitious results will not further be discussed since the results of the pilot study provides enough material for discussion and recommendations.

The results of the pilot study do not confirm the hypothesis that the absence of depth cues leads to more cybersickness in case of both virtual and actual self-motion. More specifically, no significant differences in cybersickness ratings were found between the conditions with and without motion parallax at any timeframe. However, the comparison of normalized values did show some indication that cybersickness increases faster in the condition without self-motion. Furthermore, looking at the individual data, four of the six subjects did have a higher cybersickness rating in the condition without motion-parallax, or reached the maximum value earlier on. This again suggests there is an influence of the absence of depth cues, in this case motion parallax, on cybersickness.

Despite the absence of a significant effect, this study has led to some new insights. During both conditions, at least three subjects have reached a MISC value of 6 or higher which confirms the idea that a virtual environment leads to a higher level of immersion than a simulator as in the study of Bos et al. (2017). Also, a new method to test the influence of self-motion on cybersickness with use of head movements has been designed, which can be further developed for future research. Furthermore, despite the lack of significant results there is an indication that motion parallax does influence cybersickness. However, it is necessary to conduct the full experiment as proposed in the method section with a larger sample size to further explore this relationship and to investigate the influence of self-motion and monoscopic displays.

In fact, on the one hand it seems that the differences between the results of the pilot study and the expected outcomes are explained by the necessary adjustments taken. First of all, no firm conclusions can be drawn since the pilot study sample size was too small (n=6). The lack of significant results is likely due to individual differences, as early research has shown that individual differences such as gender and age seem to play a role in cybersickness (LaViola, 2000; Martirosov & Kopecek, 2017; Mousavi et al., 2013). Additionally, the minor visual defects present such as an

impaired stereovision or colorblindness could have reduced the level of perceived cybersickness as proposed in earlier research (Bonato, Bubka, & Alfieri, 2004; Liu & Uang, 2016).

Secondly, the adjustments regarding depth cues could have led to less differences between both conditions. Instead of using both motion parallax and type of display to create two environments with more and less depth cues, only the influence of the absence of motion parallax was tested. The use of a monoscopic display in addition to the absence of motion parallax was expected to further increase the amount of cybersickness since only monocular depth cues would remain. Therefore, the absence of this addition could explain the limited increase of cybersickness in the environment with less depth cues compared to the environment with more depth cues.

On the other hand, apart from these necessary adjustments, there are other explanations for the lack of significant results, which might also have existed in case the intended method would have been conducted. In other words, the results of the pilot study would then still not resemble the expected outcomes due to other variables, even when both a larger sample size and monoscopic display were used.

For instance, the design of the task also may have influenced the absence of cybersickness in multiple ways. First of all, the dual task made the subjects focus on the smiley. It could have been that this focus distracted them from the visual details in the surrounding virtual environment, as only the area around the smiley was looked at. This could explain the absence of a difference found between the two conditions since less visual differences could have been detected at all.

Secondly, this distraction could have led to less ‘presence’, the sense of being in a virtual environment, regarding the lack of interaction with the full environment except for this smiley (Schubert, Friedmann, & Regenbrecht, 2001). Since presence is known to correlate with cybersickness, the absence of presence could have suppressed the expected emergence of cybersickness in the condition without motion parallax (de Vries, Bos, van Emmerik, & Groen, 2007; Liu & Uang, 2016).

Thirdly, in addition to the distraction from the environment, the focus on the dual task might also have resulted in a distraction from the subjects’ feelings of nausea and misery. Since the dual task increased the mental load, which is known to reduce the amount of cybersickness, this could be a possible explanation for the absence or reduced sickness symptoms in both conditions (Bos, 2015).

Fourthly, another explanation for the absence of significant results due to the task can be given by the concept of 'quarantining' as proposed by Gresty et al. (Gresty, Waters, Bray, Bunday, & Golding, 2003). This concept yields that the mismatch between the visual input and the expected input is so extreme that the visual input is 'quarantined 'by the brain. This visual input is then not used in the detection of self-motion (Golding et al., 2009). Since both the used VR environment and head movements are quite unnatural, this 'quarantining' might have occurred and therefore explain the lack of cybersickness in both conditions.

Finally, the multiple head movements in the task could have led to high dizziness ratings resulting in the high disorientation SSQ sub score. However, this is not necessarily the case since the most observed pattern D > N > O is similar to the pattern for cybersickness reported in earlier studies (Ehrlich & Kolasinski, 1998; Stanney & Kennedy, 1998).

Furthermore, besides the effect of the task, the chosen measurements could also have played a role in the absence of significant results and correlations specifically. Even though the different questionnaires provide a broad overview regarding the predicted and obtained cybersickness, the SSQ and MSSQ do not focus on virtual environments specifically since these are relatively new technological developments. Consequently, it might be that cybersickness cannot be predicted as well as simulator sickness with the used questionnaires. This study tried to control for this by including questions on virtual devices. However, it is difficult to ask for experience of sickness symptoms of these devices during subjects' childhood (up to 12 years) since these new technological developments do not exist for such a long time. New questionnaires focusing on virtual environments such as the VIMSSQ or VRSQ might be a solution to this problem (Keshavarz, Saryazdi, Campos, Golding, & Kingdom, 2019; H. K. Kim, Park, Choi, & Choe, 2018).

In addition to these questionnaires, the chosen measurement for the missing MISC values could have limited the amount of significant results. These missing values were a result of the discontinuation of a condition when a subject reached a MISC score of 6 or higher. To be able to analyze the average data during time, these values were 'filled' with a repetition of the last MISC value reached for the missing timepoints. This is a quite conservative measurement, since it assumes that the misery would not have increased any further if the subject would have continued the experiment, even though the opposite is expected since it is known that misery increases during

time (Lawther & Griffin, 1987). A more progressive method, such as using a formula for predicting the following values of MISC scores (Van Emmerik et al., 2011) or a correction with time as with the analysis of the MaxMISC, could have increased the difference between conditions in the comparison of MISC values during time.

Apart from the necessary adjustments of the experiment and the limited sample size considering COVID-19, there were additional limitations of the experimental method. Firstly, although the task tried to control for head movements, some subjects made bigger movements then others or the size of the head movements of subjects differed between the two conditions. It was beyond the scope of this research to save the head movements and to analyze the correlation between the size of head movements and cybersickness but for future research it would be very interesting to further explore this relation.

Secondly, it was not possible to control for eye movements that subjects made. The use of VR glasses with eye tracking could provide insight of where the subjects look and what kind of eye movements they make to see how this interacts with the perceived sickness. Especially because early research has shown that eye fixation reduces cybersickness (Webb & Griffin, 2002). Also, this could test the idea that during the task subjects focusses on the smiley instead of the environment as discussed before. Furthermore, one subject hinted that he "wanted to cheat by closing his eyes", to control for such viewing behavior, the eye movements need to be analyzed.

A final suggestion for future research is to adjust the manner in which self-motion was simulated in the conditions where self-motion was absent. The task in these conditions would have contained a recording of the environment, as if the subject was making head movements themself. However, in this situation, the subject would not expect any movements to appear, in contrast to when they can decide themselves to move. The aspect of not 'expecting' these movements could have resulted in symptoms of cybersickness, instead of the aspect of not actually moving by yourself (Bos et al., 2017). Therefore, future research might use another option to simulate these movements such that the expectations stays similar to the conditions with actual self-motion, for example by moving the VR camera with a controller in their hand.

Conclusion

This research aimed to show the influence of depth cues on cybersickness in relation to self-motion. Due to the limitation imposed by COVID-19, only a pilot study could be conducted to test the influence of motion parallax in case of actual self-motion. The results do not confirm that the absence of motion parallax increases symptoms of cybersickness when real self-motion is present. However, the individual data does suggest that motion parallax speeds up the increase of sickness. Furthermore, while the small sample size limits the generalizability of the results, a new approach to test these influences with more immersion has been provided. Future research is needed to determine the effect of both motion parallax and mono- versus stereoscopic views in both situations with and without actual self-motion. The intended method as presented in this research can be adjusted to take the influences of head and eye movements into account and to prevent distraction from the virtual environment. As such, the research question could be answered in a more extensive and accurate way in the future. Such future studies can then be used to improve virtual environments in general reckoning the situation in which it is used (with or without self-motion), thus leading to a better usability of VR in the future.

Literature

Bonato, F., Bubka, A., & Alfieri, L. (2004). Display Color Affects Motion Sickness Symptoms in an Optokinetic Drum. *Aviation Space and Environmental Medicine*, *75*(4 SEC. I), 306–311.

Bos, J. E. (2015). Less sickness with more motion and/or mental distraction. *Journal of Vestibular Research: Equilibrium and Orientation*, *25*(1), 23–33. https://doi.org/10.3233/VES-150541

Bos, J. E., Bles, W., & Groen, E. L. (2008). A theory on visually induced motion sickness. *Displays*, *29*(2), 47–57. https://doi.org/10.1016/j.displa.2007.09.002

Bos, J. E., Ledegang, W. D., Grootheest, H. A., Kooi, F. L., & Houben, M. M. . (2017). Motion parallax in flight simulation An exploratory experiment. *TNO Report R10800*.

Bos, J. E., MacKinnon, S. N., & Patterson, A. (2005). Motion sickness symptoms in a ship motion simulator: Effects of inside, outside, and no view. *Aviation Space and Environmental Medicine*, *76*(12), 1111–1118.

Bos, J. E., Van Leeuwen, R., & Bruintjes, T. (2018). Bewegingsziekten in beweging : Van wagen ziekte naar 'cybersickness'. *Nederlands Tijdschrift Voor Geneeskunde*, *162*(13), 1–6.

Cipresso, P., Giglioli, I. A. C., Raya, M. A., & Riva, G. (2018). The past, present, and future of virtual and augmented reality research: A network and cluster analysis of the literature. *Frontiers in Psychology*, *9*(NOV), 1–20. https://doi.org/10.3389/fpsyg.2018.02086

de Vries, S. C., Bos, J., van Emmerik, M. L., & Groen, E. L. (2007). Internal and external field of view: computer games and cybersickness. *Proceedings of VIMS2007*, 89–95. Retrieved from http://www-ieem.ust.hk/dfaculty/so/pdf/Pages89-95-VIMS2007.pdf

Ehrlich, J. A., & Kolasinski, E. M. (1998). A Comparison of Sickness Symptoms between Dropout and Finishing Participants in Virtual Environment Studies. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *42*(21), 1466–1470. https://doi.org/10.1177/154193129804202101

Golding, J. F. (1998). Motion sickness susceptibility questionnaire revised and its relationship to other forms of sickness. *Brain Research Bulletin*. https://doi.org/10.1016/S0361-9230(98)00091-4

Golding, J. F., Arun, S., Wortley, E., Wotton-Hamrioui, K., Cousins, S., & Gresty, M. A. (2009). Off-vertical axis rotation of the visual field and nauseogenicity. *Aviation Space and*

Environmental Medicine, *80*(6), 516–521. https://doi.org/10.3357/ASEM.2433.2009

Gresty, M. A., Waters, S., Bray, A., Bunday, K., & Golding, J. F. (2003). Impairment of spatial cognitive function with preservation of verbal performance during spatial disorientation. *Current Biology*, *13*(21), 829–830. https://doi.org/10.1016/j.cub.2003.10.013

Hale, K. S., & Stanney, K. M. (2006). Effects of low stereo acuity on performance, presence and sickness within a virtual environment. *Applied Ergonomics*, *37*(3), 329–339. https://doi.org/10.1016/j.apergo.2005.06.009

Howarth, P. A. (1996). Empirical studies of accommodation, convergence, and HMD use. In *Proceedings of the Hoso-Bunka foundation symposium: The human factors in*.

Hwang, J., Jung, J., & Kim, G. J. (2006). Hand-held virtual reality, 356. https://doi.org/10.1145/1180495.1180568

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology*. https://doi.org/10.1207/s15327108ijap0303_3

Keshavarz, B., Saryazdi, R., Campos, J. L., Golding, J. F., & Kingdom, U. (2019). Introducing the VIMSSQ : Measuring susceptibility to visually induced motion sickness. *Proceedings of the Human Factors and Ergonomics Society 2019 Annual Meeting*, 2267–2271. https://doi.org/10.1177/1071181319631216

Kim, H. G. R., Angelaki, D. E., & DeAngelis, G. C. (2016). The neural basis of depth perception from motion parallax. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1697), 1–11. https://doi.org/10.1098/rstb.2015.0256

Kim, H. K., Park, J., Choi, Y., & Choe, M. (2018). Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment. *Applied Ergonomics*, *69*(March 2017), 66–73. https://doi.org/10.1016/j.apergo.2017.12.016

Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *Journal of Experimental Psychology*, *55*(4), 352–358.

Kolasinski, E. M. (1992). Simulator sickness in virtual reality. *The Journal of the Acoustical Society of America*. https://doi.org/10.1121/1.404501

LaViola, J. J. (2000). A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin*, *32*(1), 47–56. https://doi.org/10.1145/333329.333344

Lawther, A., & Griffin, M. J. (1987). Prediction of the incidence of motion sickness from the magnitude, frequency, and duration of vertical oscillation. *Journal of the Acoustical Society of America*, *82*(3), 957–966. https://doi.org/10.1121/1.395295

Lin, J. J. W., Duh, H. B. L., Parker, D. E., Abi-Rached, H., & Furness, T. A. (2002). Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. *Proceedings - Virtual Reality Annual International Symposium*, (February), 164–171. https://doi.org/10.1109/vr.2002.996519

Liu, C. L., & Uang, S. T. (2016). Effects of depth perception cues and display types on presence and cybersickness in the elderly within a 3D virtual store. *Journal of Ambient Intelligence and Humanized Computing*, *7*(6), 763–775. https://doi.org/10.1007/s12652-015-0317-4

Martirosov, S., & Kopecek, P. (2017). Cyber sickness in virtual reality - Literature review. *Annals of DAAAM and Proceedings of the International DAAAM Symposium*, (January), 718–726. https://doi.org/10.2507/28th.daaam.proceedings.101

Moss, J. D., & Muth, E. R. (2011). Characteristics of head-mounted displays and their effects on simulator sickness. *Human Factors*, *53*(3), 308–319. https://doi.org/10.1177/0018720811405196

Mousavi, M., Jen, Y. H., & Musa, S. N. B. (2013). A Review on Cybersickness and Usability in Virtual Environments. *Advanced Engineering Forum*, *10*, 34–39. https://doi.org/10.4028/www.scientific.net/aef.10.34

Nalivaiko, E., Davis, S. L., Blackmore, K. L., Vakulin, A., & Nesbitt, K. V. (2015). Cybersickness provoked by head-mounted display affects cutaneous vascular tone, heart rate and reaction time. *Physiology and Behavior*, *151*(October 2017), 583–590. https://doi.org/10.1016/j.physbeh.2015.08.043

Rosas, H. (2011). Perception and Reality in Stereo Vision: Technological Applications, Advances in Stereo Vision, Prof. Jose R.A. Torreao (Ed.). In *InTech*. https://doi.org/http://dx.doi.org/10.5772/57353

Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. *Presence: Teleoperators and Virtual Environments*, *10*(3), 266–281. https://doi.org/10.1162/105474601300343603

Stanney, K. M., & Kennedy, R. S. (1998). Aftereffects from Virtual Environment Exposure: How

Long do They Last? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *42*(21), 1476–1480. https://doi.org/10.1177/154193129804202103

Van Emmerik, M. L., De Vries, S. C., & Bos, J. E. (2011). Internal and external fields of view affect cybersickness. *Displays*, *32*(4), 169–174. https://doi.org/10.1016/j.displa.2010.11.003

Walraven, J. (1975). Amblyopia screening with random-dot stereograms. *American Journal of Ophthalmology*, *80*, 893–900.

Walraven, J., & Janzen, P. (1993). TNO stereopsis test as an aid to the prevention of amblyopia. *Ophthalmic and Physiological Optics*, *13*(4), 350–356. https://doi.org/10.1111/j.1475-1313.1993.tb00490.x

Webb, N. A., & Griffin, M. J. (2002). Optokinetic stimuli: Motion sickness, visual acuity, and eye movements. *Aviation Space and Environmental Medicine*, *73*(4), 351–358.

Wolfe, J. M., Kluender, K. R., Levi, D. M., Bartoshuk, L. M., Herz, R. S., Klatzky, R. L., … Merfeld, D. M. (2015). *Sensation and perception* (4th ed.). Sinauer Associates.

Appendix A

MSSQ

Motion Simulator Sickness Questionnaire (MSSQ, Golding, 1998)

Instructies: Omcirkel het antwoord wat het beste past bij de vraag. U kunt per vraag slechts één antwoord geven.

1. Hoe vaak voelde u zichzelf **als kind** (jonger dan 12 jaar) ziek in / bij:

	T	0	1	2	3
Auto's	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Bussen	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Treinen	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Vliegtuigen	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Kleine boten	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Grote schepen	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Schommels	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Draaimolens	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Pretpark attracties	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*

2. Heeft u hierbij **als kind** (jonger dan 12 jaar) wel eens moeten overgeven? *Ja / Nee*

3. Hoe vaak voelde u zichzelf **de afgelopen 12 jaar** ziek in / bij:

	T	0	1	2	3
Auto's	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Bussen	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Treinen	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Vliegtuigen	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Kleine boten	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Grote schepen	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Schommels	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Draaimolens	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Pretpark attracties	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*

4. Heeft u hierbij **de afgelopen 12 jaar** wel eens moeten overgeven? *Ja / Nee*

5. Hoe vaak voelde u zichzelf **de afgelopen 12 jaar** ziek bij/met het gebruik van:

	T	*0*	*1*	*2*	*3*
Smartphone of tablet	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
3d bioscoop of 3d televisie	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
VR bril of Head Mounted Display	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*
Televisie of spelcomputer	*N.v.t.*	*Nooit*	*Zelden*	*Soms*	*Vaak*

6. Heeft u hierbij **de afgelopen 12 jaar** wel eens moeten overgeven? *Ja / Nee*

Bedankt voor het invullen.

MSSQ = (Σall)*18/(18-*t*)

SSQ

Simulator Sickness Questionnaire

(SSQ, Kennedy, Lane, Berbaum, & Lilienthal, 1993)

Instructies: Zet een **X** in het hokje die het best past bij de mate waarin de symptomen u op dit moment belasten. U kunt per symptoom maximaal 1 hokje aankruisen.

	0	*1*	*2*	*3*	*N*	*O*	*D*
	Niet	**Beetje**	**Nogal**	**Ernstig**			
1. Algemeen beroerd gevoel					-	-	x
2. Vermoeidheid					x	-	x
3. Hoofdpijn					x	-	x
4. Last van de ogen					x	-	x
5. Moeite met scherp zien					x	-	-
6. Speekselvloed					-	x	x
7. Zweten					-	x	x
8. Misselijkheid					-	x	-
9. Concentratieproblemen					-	-	x
10. Duf gevoel in hoofd					x	x	-
11. Wazig zicht					x	-	-
12. Zweverig met de ogen open					x	x	-
13. Zweverig met de ogen dicht					x	x	-
14. Draaierigheid / duizeligheid					x	x	-
15. Naar gevoel in de maag					-	x	x
16. Boeren					-	x	x

Bedankt voor het invullen.

Table 6. Computation of SSQ scores

SSQ components	Computation
Nausea	[1] x 9.54
Oculomotor	[2] x 7.58
Disorientation	[3] x 13.92
Total	([1] + [2] + [3]) x 3.74

Note. Reprinted from "Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment", by Kim et al., 2018 (H. K. Kim et al., 2018)

Table 7. Symptoms in SSQ

SSQ items	Nausea	Oculomotor	Disorientation
1. General discomfort	X	X	
2. Fatigue		X	
3. Headache		X	
4. Eyestrain		X	
5. Difficulty focusing		X	X
6. Increased salivation	X		
7. Sweating	X		
8. Nausea	X		X
9. Difficulty concentrating	X	X	
10. Fulness of head			X
11. Blurred vision		X	X
12. Dizzy (eyes open)			X
13. Dizzy (eyes closed)			X
14. Vertigo			X
15. Stomach awareness	X		
16. Burping	X		
Total	[1]	[2]	[3]

Note. Reprinted from "Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment", by Kim, Park, Choi, & Choe, 2018

Misery Scale (MISC)

Table 8.a MIsery SCale (MISC). English version

Symptoms		***MISC***
No problems at all		0
Uneasy (no typical symptoms)		1
Dizziness, warmth, headache, stomach awareness, sweating, ..., but **no** nausea	vague slight fairly severe	2 3 4 5
Nausea	slight fairly severe (near) retching	6 7 8 9
Vomiting		10

Table 8.b MISC continued, Dutch version

Symptomen		***MISC***
Geen enkel probleem		0
Niet helemaal lekker (zonder herkenbaar symptoom)		1
Duizeligheid, warm, hoofdpijn, bewust van de maag, zweet, ..., maar ***geen*** misselijkheid	vaag beetje nogal ernstig	2 3 4 5
Misselijkheid	beetje nogal ernstig (bijna) kokhalzen	6 7 8 9
Overgeven		10

Appendix B

Informed Consent

Informed consent / toestemmingsverklaring

Ondergetekende,

Naam . _____

Geboortedatum _____

verklaart op vrijwillige basis deel te nemen aan het onderzoek getiteld “De invloed van visuele factoren in VR op welzijn” bij TNO.

- ☐ Ik bevestig dat ik de informatie over bovengenoemd onderzoek heb gelezen en ik begrijp de informatie.
- ☐ De bedoelingen van het experiment en de daarbij gevolgde aanpak zijn tot mijn tevredenheid uitgelegd.
- ☐ Ik heb de gelegenheid gehad om aanvullende vragen te stellen en deze vragen zijn naar tevredenheid beantwoord.
- ☐ Ik heb voldoende tijd gehad om over deelname na te denken.
- ☐ Ik weet dat mijn deelname aan het onderzoek geheel vrijwillig is en dat ik mijn toestemming op ieder moment kan intrekken zonder dat ik daarvoor een reden hoef op te geven.
- ☐ Ik ben ermee bekend dat de proefleider de deelname aan het onderzoek kan beëindigen als hij of zij dat nodig vindt
- ☐ Ik geef toestemming om mijn persoonsgegevens te verwerken voor de doelen zoals beschreven in de informatie.
- ☐ Ik geef toestemming om mijn onderzoeksgegevens te hergebruiken voor toekomstig onderzoek op het beschreven onderzoeksgebied op voorwaarde dat deze zo gecodeerd zijn, dat ze niet meer naar mij als persoon terug te leiden zijn.
- ☐ Ik geef toestemming voor het bewaren van de gegevens en dat bevoegde leden van het onderzoeksteam en bevoegde inspecteurs hier inzage in hebben.

Voorts verklaar ik geen mij bekende belemmeringen te hebben om aan het experiment deel te nemen.

Plaats, datum ……..

Handtekening proefpersoon: ……..

TOELATING
Ik heb me ervan vergewist dat ik deze proefpersoon goed geïnformeerd heb over het onderzoek waaraan hij/zij gaat deelnemen. Ik heb mij ervan overtuigd dat deze proefpersoon voldoet aan de selectiecriteria om aan bovengenoemd onderzoek deel te mogen nemen.

Naam proefleider ……..

Plaats, datum ……..

Handtekening ……..

General information subjects

Informatie voor deelnemers

1 Wat is het doel van het onderzoek?

Het gebruik van een virtuele omgeving, bijvoorbeeld voor games of training, kan je onwel of zelfs misselijk maken. Het doel van dit onderzoek is om te onderzoeken welke invloed bepaalde visuele elementen in deze omgeving hebben op het welzijn van de gebruiker. Daarnaast worden situaties met en zonder zelfbeweging vergeleken. Dit is belangrijk, omdat zo in de toekomst virtuele omgevingen gebruiksvriendelijker kunnen worden gemaakt, afhankelijk van de aanwezigheid van deze zelfbeweging.

2 Over TNO

De letters TNO staan voor Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek. TNO ontwikkelt kennis gericht op praktische toepassing en richt zich hierbij op de volgende aandachtsgebieden: Bouw, Infra & Maritiem; Circulaire Economie & Omgeving; Defensie & Veiligheid; Energie; Gezond Leven; Industrie; Informatie & Communicatie Technologie; Mobiliteit & Logistiek en tot slot Strategische Analyses & Beleid.

Het onderzoek dat in dit document omschreven is valt binnen het aandachtsgebied Defensie & Veiligheid. Het is voor welvaart en welzijn cruciaal dat de samenleving veilig is én veilig voelt. Daarbij is het belangrijk om partijen te ondersteunen die deze veiligheid mogelijk maken. Of het nu gaat om defensie, politie, brandweer of het bedrijfsleven, wij zetten onze kennis en technologie in om innovaties te creëren voor de mensen die zich dagelijks inzetten voor onze veiligheid.

3 Deelname aan onderzoek

Als u deelneemt aan het onderzoek zult u op drie dagen naar de experimentlocatie komen (Utrecht). De eerste dag één uur, de tweede en derde dag een half uur. De totale tijd voor het experiment komt daarmee op 2 uur. U bent een van de 6 proefpersonen die meedoet, maar het onderzoek zal individueel zijn.

4 Wie kan meedoen aan het onderzoek?

Voor de bepaling of u aan de proef deel kunt nemen zijn selectiecriteria opgesteld. U voldoet aan de toelatingscriteria van dit onderzoek als u:

1. gezond en fit bent (geen evenwichts- of oogproblemen);
2. vrijwillig deelneemt aan het onderzoek;
3. schriftelijk toestemming geeft voor deelname;
4. bereid bent zich te houden aan de regels van het onderzoek;
5. tussen de 18 en 60 jaar oud bent;
6. geen alcohol heeft gedronken en geen drugs heeft gebruikt in de 12 uur voordat het onderzoek plaatsvindt;
7. niet claustrofobisch bent;
8. geen medicatie gebruikt die uw evenwicht of alertheid beïnvloedt (medicijnen met een gele sticker);
9. niet geheel ongevoelig of juist heel erg gevoelig bent voor bewegingsziekte;

10. accepteert dat de verzamelde gegevens anoniem worden gebruikt bij analyse en rapportage, en 10 jaar worden gearchiveerd.

5 Hoe wordt het onderzoek uitgevoerd?

Het onderzoek bestaat uit drie sessies op drie verschillende dagen waarbij de eerste sessie één uur duurt en de tweede en derde sessie een half uur. De eerste sessie is opgedeeld in een introductie van 30 minuten en één experimentele conditie van 30 minuten. De tweede sessie en derde sessie bestaan enkel uit één experimentele conditie van 30 minuten. Tijdens elke conditie zult u maximaal 16 minuten een taak uitvoeren met gebruik van een VR-bril. Deze taak zal zittend uitgevoerd worden en bestaat uit het maken van hoofd of handbewegingen in combinatie met een geheugentaak. Tijdens de taak zal elke 2 minuten uw welbevinden worden gemeten op een schaal van 0-10. Deze schaal leggen we voor het experiment aan u uit. Ten slotte vult u voorafgaand en na afloop van elke taak een vragenlijst in die uitgebreider uw welzijn meet.

6 Wat wordt er van u verwacht?

U geeft een eerlijk antwoord op de vraag of u aan *alle 10 punten* voldoet die hierboven bij “4 Wie kan meedoen aan het onderzoek” zijn genoemd. Als u de eerste keer bij ons komt krijgt u uitgebreid instructie en de mogelijkheid om vragen te stellen.

7 Wat zijn mogelijk voor- en nadelen van deelname aan dit onderzoek?

In dit experiment kunt u last krijgen van bewegingsziekte (de overkoepelende term voor zaken als wagenziekte, zeeziekte, ect). We willen u echter niet onnodig belasten. We vragen u daarom tijdens het experiment regelmatig naar uw welzijn en de proefleider zal het experiment afbreken als de score die u daarbij geeft betekent dat u nogal misselijk bent. Zelf mag u op ieder moment sowieso aangeven dat u wilt stoppen. De vergoeding die u voor dit onderzoek krijgt (zie hieronder) hangt niet af van of u gestopt bent.

8 Wat gebeurt er als u niet (meer) wenst deel te nemen aan dit onderzoek?

Deelname is geheel vrijwillig. Als u niet meer deel wenst te nemen aan het onderzoek, kunt u op ieder moment uw deelname stoppen, zelfs zonder opgaaf van reden.

9 Wat gebeurt er met uw gegevens?

Uw gegevens worden zorgvuldig behandeld. Om uw privacy te waarborgen, worden uw naam en contactgegevens gescheiden van uw onderzoeksgegevens bewaard, geanalyseerd en gerapporteerd. Uw persoonlijke gegevens zijn slechts toegankelijk voor daartoe bevoegde leden van het onderzoeksteam. Inzage door bevoegde inspecteurs kan nodig zijn om de betrouwbaarheid en kwaliteit van het onderzoek na te gaan. Na afloop van het onderzoek worden de onderzoeksgegevens gedurende 10 jaar na afloop van het onderzoek bewaard.

10 Is er een vergoeding wanneer u besluit aan dit onderzoek mee te doen?

U krijgt vergoeding voor deelname aan het onderzoek. Deze bedraagt 55 euro als u deelneemt aan alle drie de condities. Daarbovenop worden uw reiskosten vergoed tot een maximum van 15 euro per bezoek aan TNO. TNO is verplicht de aan u betaalde vergoeding voor deelname op te geven aan de Belastingdienst.

11 Ethische aspecten

TNO gaat zorgvuldig met u om. U doet vrijwillig mee en u krijgt precies te horen wat u moet doen. Als u het daar mee eens bent en u bent geschikt om mee te doen dan begint u aan het onderzoek. U kunt ook stoppen gedurende het onderzoek als het u niet (meer) bevalt. U hoeft daarbij geen reden op te geven. Het onderzoek wordt uitgevoerd volgens alle van toepassing zijnde nationale en internationale wetgeving en richtlijnen die gericht zijn op het bewaken van uw gezondheid, veiligheid en privacy.

12 Verzekering

Voor iedereen die meedoet aan dit onderzoek heeft TNO een verzekering afgesloten. De verzekering dekt schade door deelname aan het onderzoek. Schade moet u zo snel mogelijk aan TNO melden.

13 Wilt u verder nog iets weten?

Als u vragen heeft, kunt u die altijd stellen aan aafke.vanwelbergen@tno.nl of ieder moment voor, tijdens of na het experiment aan de aanwezige proefleider.

14 Ondertekening toestemmingsformulier

Bij aanvang van het experiment heeft u tijd om alle informatie nog door te lezen en vragen te stellen, en tekent u een toestemmingsformulier voor deelname.

Appendix C

Hygiene measures

Several hygiene measures were taken based on the recommendations of the Dutch National Institute for Public Health and the Environment (RIVM) to ensure the safety of the subjects. In any case, subjects could only participate if they did not have any cold-like symptoms. Further measures are listed below.

During each condition:

1. 1,5-meter distance was kept between the subject and the research leader
2. Disposable VR masks were used
3. Hand sanitizer with 70% alcohol was available

Before and after each condition:

4. Subjects had to wash their hands with soap and water for 20 seconds
5. VR glasses, desk, and chair were cleaned by the research leader with disinfection spray

Appendix D

Post hoc analysis (SSQ scores)

A pairwise Wilcoxon signed rank test between all conditions, revealed statistically significant differences in Total Score between conditions 1 & 2 (p = .029); 2 & 3 (p = .013); 3 & 4 (p = .003) and 1 & 4 (p = .017). Similar statistically significant differences of nausea were found between conditions 1 & 2 (p = .010); 2 & 3 (p = .018); 3 & 4 (p = .019) and 1 and 4 (p = .045). Furthermore, oculomotor differed significantly between conditions 3 & 4 (p = .002) and 1 & 4 (p = .049). The difference in disorientation score was only significant between conditions 1 & 2 (p = .047).

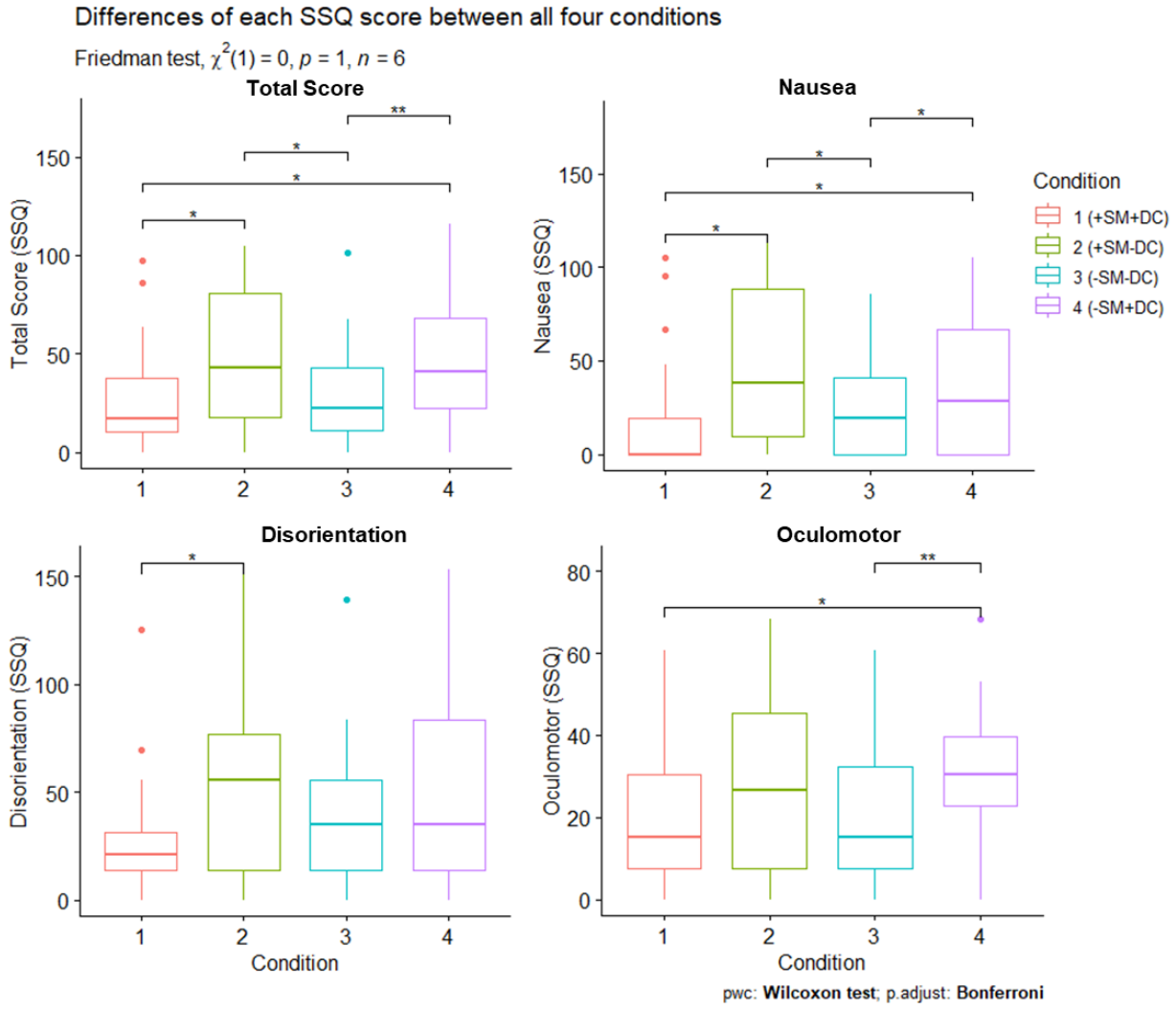

Figure 18. Schematic overview of the statistical differences of each SSQ score between the four conditions (*: p <= .050, **: p <= .010). SM stands for actual self-motion; DC stands for depth cues (both motion parallax and stereoscopic display).

Post hoc analysis (maximum value)

A pairwise Wilcoxon signed rank test between conditions revealed statistically significant differences in uncorrected MaxMISC between conditions 1 & 4 ($p < .001$), 2 & 4 ($p = .021$) and 3 & 4 ($p = .001$). The corrected MaxMISC was statistically significant between more conditions: 1 & 2 ($p = .030$), 1 & 4 ($p < .001$), 2 & 3 ($p = .033$), 2 & 4 ($p = .024$) and 3 & 4 ($p < .001$).

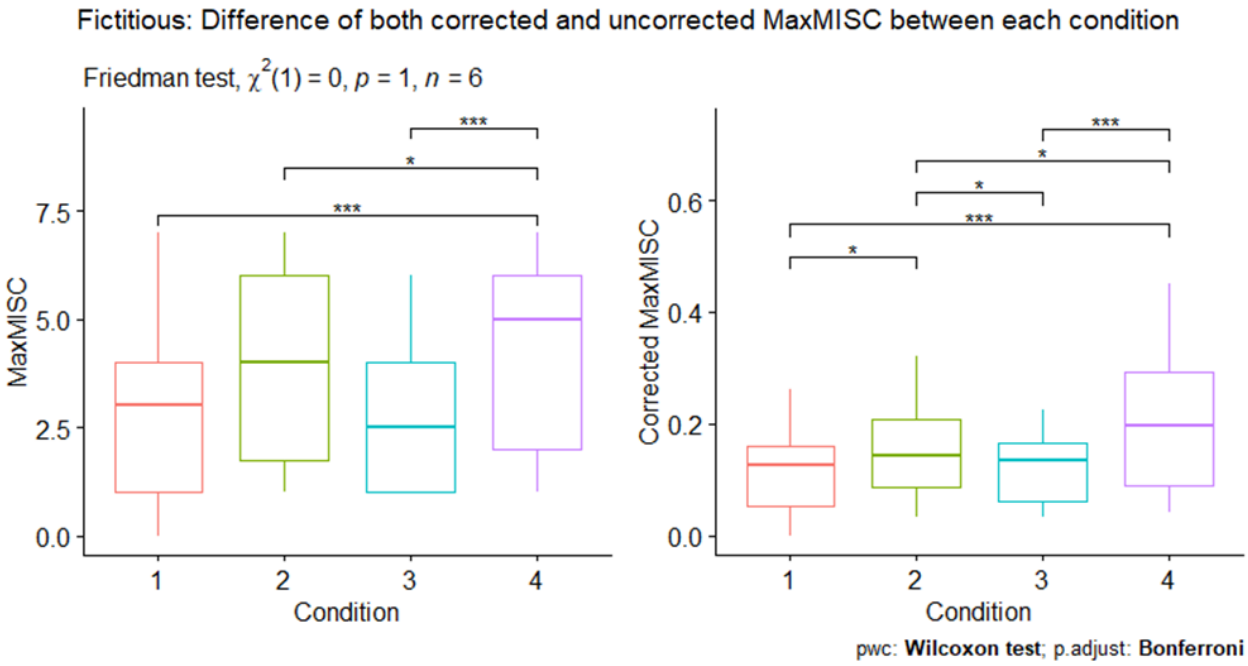

Figure 19. Schematic overview of the statistical differences in MaxMISC, both uncorrected (left) and corrected by time (right), between the four conditions (*: p <= .050, **: p <= .010, ***: p <= .001).

Post hoc analysis (normalized maximum value)

A pairwise Wilcoxon signed rank test between all four conditions revealed statistically significant differences in the normalized uncorrected MaxMISC between conditions 1 & 4 ($p < .001$) and 3 & 4 ($p = .001$). Similar significant differences were found in the normalized corrected MaxMISC between conditions 1 & 2 ($p = .017$), 1 & 4 ($p < .001$), 2 & 3 ($p = .024$), 2 & 4 ($p = .034$) and 3 & 4 ($p < .001$).

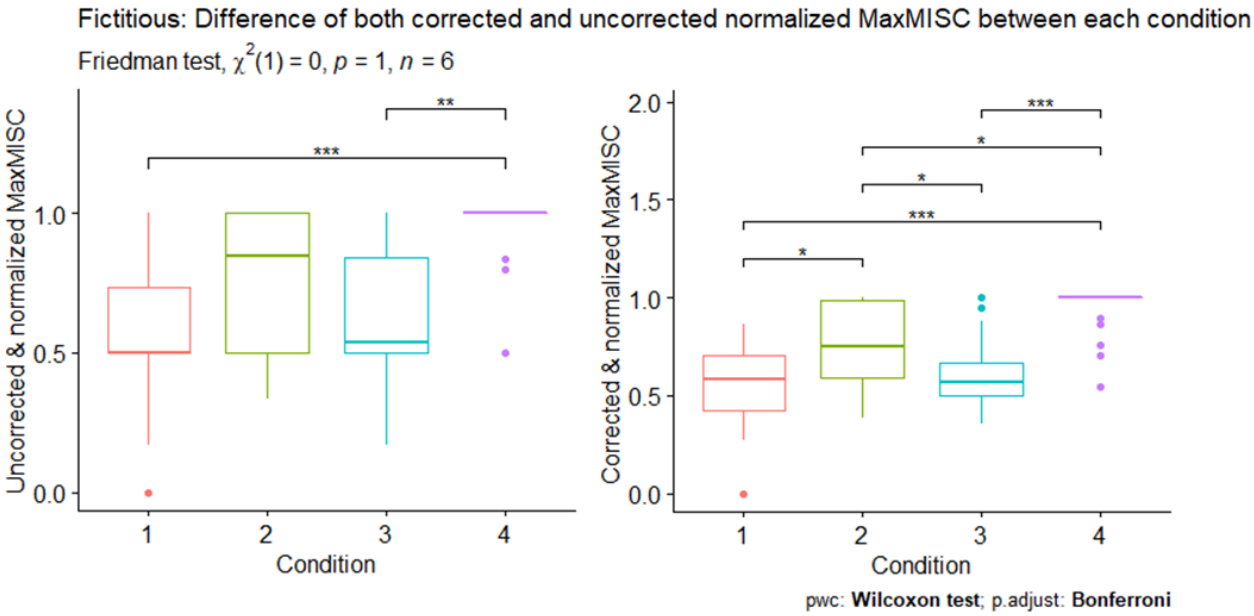

Figure 20. Schematic overview of the statistical differences of the normalized MaxMISC scores, both uncorrected (left) and corrected (right), between the four conditions (*: p <= .050, **: p <= .010, ***: p <= .001).