The Effects of Rest Frames on Cybersickness and Habituation to its Symptoms in a Virtual Environment

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Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

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Abstract

Even with modern and easily accessible technology the field of virtual reality faces a major and largely unresolved problem: cybersickness. A large amount of the general population displays a number of symptoms such as nausea and dizziness when exposed to a virtual environment. With a potentially wide range of applications—for example in medical fields, industry and entertainment—a solution to the problem of cybersickness in virtual reality must be sought. Using the rest frame hypothesis—which is largely built upon the widely accepted sensory conflict theory—this thesis investigates whether an additional point of reference in an environment has a positive impact in reducing the effects of cybersickness. Through a mixed-subject design participants were exposed to a virtual environment in which they had to traverse a set course in two separate sessions. The test condition had a 10m by 10m wireframe which was stationary relative to the real world, whereas the control condition did not. The potential symptom-alleviating and habituation effects were measured using the simulator sickness questionnaire, a discomfort score and the Slater, Usoh and Steed presence questionnaire. A previous study has shown that such effects exist although the extent of the habituation was not entirely clear, which this thesis aims to clarify. The results indicate a significant reduction in cybersickness in the rest frame condition. Furthermore, in the second session the general symptom scores are significantly lower compared to the first session, indicating a habituation effect. This effect, however, does not seem to be affected by the rest frames at all. Lastly, presence scores were not significantly impacted by the additional element in the virtual environment. Due to a small sample size not all results are clear and sometimes show only a trend rather than a significant effect. Still, considering these results, rest frames seem to be a cost-effect method of reducing cybersickness in a potentially wide range of applications.

Chapter 1

Introduction

Virtual reality (*VR*) has an increasing application range in both scientific research and the entertainment industry. Technological developments and a sizeable reduction in cost of the technical equipment necessary enabled a rapid growth of the field. The applications of *VR* are manifold. While the most known use of this technology is for entertainment purposes, a large number of studies have looked at the medical and therapeutic uses of *VR*. It has been used as a tool to reduce acute pain during painful medical procedures such as redressing burn wounds of children and adolescents [14, 33, 50]. In general, the pain-relieving effect of the immersion caused by *VR* has is well documented [26]. *VR* further gains increasing traction as a method to treat psychological maladies as an addition and alternative to medication and cognitive behaviour therapy. It has successfully been used to treat anxiety disorders [22, 40] and phobias [6, 39]. Those fields are just a few of a wide array of potential medical applications and the need for further research is unquestionable.

Despite the broad capabilities of this new technology, a hindering factor—namely *cybersickness* (*CS*)—currently prevents wide-spread popularity among all possible fields. Individuals report a wide variety of negative symptoms when exposed to a *virtual environment* (*VE*) such as nausea, disorientation and stomach awareness [19]. The need for methods to prevent the appearance of *CS* is large and warrants further study.

1.1 Motivation

The existence of cybersickness requires solutions that target this wide-spread problem. Some efforts have been made to solve this issue using a variety of methods. These can be categorised into physical, sensory and medical methods. For example, Fernandes and Feiner [11] successfully developed a system that dynamically manipulates the *field-of-view* (*FOV*) of the *head-mounted display* (*HMD*) and therefore reduces symptoms. This can be considered an optical and thus sensory solution. Alternatively, Sra et al. [55] and Cevette et al. [7] found that inducing a current directly into the vestibular system alleviates effects of *CS* as well at a relatively cheap technological cost, which can be considered a mixture of physical and sensory solution.

These methods often come with a trade-off. The dynamic *FOV* modification actively reduces the visual field of the user and thus reduces the levels of immersion. The electrical current may be uncomfortable for some people as it essentially simulates the nerve-output of the vestibular system. Further additional equipment is necessary to implement that solution as well. For that reasons, Cao [4] added *rest frames* (*RF*) as an additional guide for the brain, based on the "rest frame hypothesis" by Prothero [41], and reduced *CS* symptoms significantly. Based on these works this thesis seeks to clarify and investigate the hypothesis in further detail and test what effects such additional frames have on individuals.

Cao [6] used a static *RF* which resembled a metallic mesh at the outer edge of the *FOV*. Participants walked a predestined course while seated in a cockpit and repeatedly reported their current levels of discomfort. A second session aimed to find whether a symptom-reducing effect persists. He found that the additional frame of reference positively impacted symptom-scores significantly and even detected a positive impact on adaptation to *CS*. The problem with this study was the fact that the metal mesh was relatively opaque and imposing on the participant. This means that instead of the *RF*, the narrower *FOV* may cause this alleviation of symptoms. Further, this method severely limits the number *VR*-applications. While a science fiction game can profit from this cockpit-like environment, a medieval fantasy game cannot use such an approach without negatively impacting immersion. For this reason, this thesis attempts to replicate the results of Cao's study by using a different reference frame. Instead of an imposing metal mesh an abstract and thin wire frame in the form of a cube with a length of about 10 meters will be placed around the user and deliver an additional positional and orientational cue.

1.2 Research Question and Hypotheses

Generally, the core research can be formulated as follows:

> What effects does an additional rest frame in the field of view of an individual have in reducing symptoms of cybersickness over a short and long period of time? Further, how does this frame impact immersion for individuals?

Based on this core question, the following hypotheses can be formulated:

1. Hypothesis 1 (H1): Conditions with *RF*s will show significantly lower *CS* scores then without them.
2. Hypothesis 2 (H2): Participants will generally have higher *CS* scores in the first session than in the second one.
3. Hypothesis 3 (H3): Rest frames will worsen presence scores significantly for most participants.
4. Hypothesis 4 (H4): Rest frames will accelerate acclimation to the virtual environment for most people.

1.3 Research Approach

This study aims to answer the aforementioned questions in a similar way as Cao's study [4]. In order to limit and control the behaviour of participants a predefined course through a *(VE)* was created. This aims to reduce potential variance of exposure time and controls the movement the participants have to make to a certain degree, which makes comparing results easier. As shown by DiZio and Lackner [8], an exposure of more than 15 minutes leads to a habituation effect and a subsequent decline in symptom scores. Therefore, similar to Cao's experiment this study aims to limit the exposure time to a maximum of 15 minutes.

Two conditions, one with a rest frame and one without were used to get results over the course of two sessions. The participants wore the Oculus Rift CV1 *HMD* and controlled their movements with the Oculus Touch controllers. Participants wore a headset that played an ambient soundscape so that possible outside noise could be minimised. Over the course of 20 waypoints, participants reported their current levels of discomfort verbally, so a real-time progression could be analysed. After the session participants were asked to fill out the core questionnaire, namely the *simulator sickness questionnaire SSQ* [19]. This questionnaire was divided into four sub-scores: Oculomotor, Disorientation, Nausea and the main score. Using these, an accurate comparison between the two conditions was possible and a habituation effect—if existent—was measurable. In a short pre-questionnaire some demographic questions were asked in order to find any potential predictors of the effects of the experiment. All questionnaires and statistical results can be found in appendix B and C.

1.4 Outline

In this section a brief overview on the structure of the thesis will be given. The thesis contains the following chapter:

- **Chapter 2: Literary Review**—In this chapter a brief review of the current research and the main theories will be given. It is mainly composed of the two following sections:
  - Cybersickness
  - Presence
- **Chapter 3: Methodology**—This chapter describes and the experimental setup and the necessary prerequisites such as questionnaires and participant criteria. It is composed of the sections:
  - Experiment Design
  - Virtual Environment
  - Participants
  - Procedure
  - Measurements
- **Chapter 4: Results**—This chapter thoroughly lists the results of the study. Each of the four hypotheses is allotted an individual section in which a detailed statistical analysis is given.
- **Chapter 5: Discussion**—In this chapter the results of the previous chapter are examined. Further, the experiment is dissected based on how usable the results

are and whether further predictions can be made. Possible problems and errors of the results are also regarded.

- **Chapter 6: Conclusion and Future Research**—Lastly, The impact of this thesis and its results are discussed. An overview of potential future research in this area is also given.

Chapter 2

Literature Review

In this chapter, the present research around *VR* will be discussed. Current issues and concepts will be presented and an overview will be given. First, the key problem of *CS* that arises in many *VR*-users in a variety of forms will be thoroughly analysed by looking at the current theories and proposed solutions surrounding this issues. Further, a measurement of immersion called *presence* will be discussed. The concepts and theories in this chapter are essential to the experiment described in the following chapters.

VR, a technology in which people immerse themselves in a digital and 3D-rendered *VE* [25], has been gaining traction in the recent years. Advancements in technology in the form of cheap, easily accessible devices made it possible for a lot of people to access this relatively young form of media-consumption. *VR* has shown its usefulness in a variety of fields like entertainment, medical treatment, driving and flight simulation and education. Despite this, a core problem surrounds *VR* that keeps people away from this technology: *CS*. A large percentage of people experience symptoms commonly associated with motion sickness such as nausea and cold sweating [16].

2.1 Cybersickness

Cybersickness is a side effect a large number of people experience when exposed to *VR*. Before this sections delves into its origin and the theories it is important to understand that classical motion sickness and *CS* are not necessarily the same thing. Although studies have shown that there is a significant correlation between the two sicknesses and their symptoms [30], their exact relation is unknown. Further, there exists a third concept called simulation sickness where the differences to *CS* and motion sickness are not quite clear. This affliction arises when a person is exposed to, for example, a driving or a flight simulator. The symptoms are quite similar, but the focus and severity compared to *CS* are different [57]. Although there may be differences, these three terms are often used interchangeably in research, which is likely caused by the fact that the commonly accepted theory, called *Sensory Conflict Theory* coined by Reason and Brand [43], can be applied to all three concepts. Although each of these concepts have slightly different characteristics the underlying mechanism causing the symptoms associated with them are the same. Thus, for this thesis the three different terms will be considered as equal. However, for the sake of consistency the term *cybersickness (CS)* will be used throughout the thesis. A good review of motion sickness research is the research report by Johnson [16] and Lackner [24].

Heutnik et al. [13] categorise the factors that determine the occurrence and severity of simulator sickness symptoms into three groups:

1. technical limitations like image resolution, refresh rate, point-of-view and flickering.
2. simulation related factors such as exposure time to the *VE*, unnatural movement, velocity and scene content among others.
3. individual factors such as general susceptibility, age, experience in the *VE*, medications, general health and so on.

Several methods to measure the severity of symptoms caused by *CS* have been devised such as the motion sickness assessment questionnaire (MSAQ) by Gianaros et al. [12], the virtual reality sickness questionnaire (VRSQ) by Kim et al. [21] or the fast motion sickness scale (FMS) by Keshavarz and Hecht [20]. However, the most commonly used questionnaire is the *simulator sickness questionnaire* (*SSQ*) by Kennedy et al. [19]. This thesis uses the latter for measuring the symptom levels. The reason for this will be discussed in section 3.5. In short, the *SSQ* poses 16 questions on a four point scale, which then are weighted and grouped into three categories. These are then used to calculate the three sub-scale symptom scores nausea, oculomotor and disorientation. The *SSQ* identifies a variety of symptoms including nausea, fatigue, headache, eyestrain, sweating, blurred vision and vertigo.

2.1.1 Sensory Conflict Theory

The concept of the vestibular system's role in causing motion sickness symptoms was first described by Irwin in 1881 [42]. He noted that being on a ship exposed the vestibular system to an unusual "current force environment compared to prior (land) experience" [16] and reported the connection to the vestibular system. Thus, he was the first to note the role of both the vestibular system and the unfamiliarity of motion in motion sickness. The exact underlying concept, however, was not solved until 1975 by Reason and Brand.

Sensory Conflict Theory or Sensory Arrangement Theory, proposed by Reason et al. [42, 43] is currently the most widely accepted and successful theory of motion sickness. Later it was further developed into a quantitative model by Oman [36–38]. Reason et al. describe the theory as follows [42]:

> [. . .] all situations which provoke motion sickness are characterized by a condition of sensory rearrangement in which the motion signals transmitted by the eyes, the vestibular system and the nonvestibular proprioceptors are at variance with another, and hence with what is expected on the basis of previous transactions with the spatial environment.

For example, an individual is travelling by car and looks out of the window. The eyes indicate a constant motion while the vestibular system, which is based on acceleration, does not. Thus, a conflicting signal arrives at the brain, causing motion sickness symptoms. However, the existence of the conflict alone is insufficient to cause symptoms [42, 43], as continued interaction in the same environment reduces symptoms significantly; the individual adapts (or habituates) to the new environment [16]. Reason [42] also states that regardless of what other spatial senses are involved, "the vestibular system must be implicated, either directly or indirectly" for motion sickness to occur. This indicates that the vestibular system must be intact [32]. This can be confirmed by the fact that deaf people are seemingly immune to motion sickness in situations where it normally occurs [16]. Reason further notes that given the involvement of the vestibular system, motion sickness only occurs where an accelerating motion happens. This allows according to Reason the prediction of situations that cause motion sickness with some confidence.

Johnson summarises the components of the sensory conflict theory as [16]:

> (1) [S]ensory inputs from the eyes, vestibular system, proprioceptive system, and somatosensory system register motion in space; (2) a neural store of past patters of sensory input from prior motion history provides the expected motion baseline; (3) a comparator unit compares the current pattern of sensory inputs with the expected pattern from the neural store; (4) the current pattern of input from the motion sensors during motion is provided in parallel both to the neural store, for updates, and to the comparator unit for comparison; (5) individual differences in thresholds throughout the system account for the wide individual differences in the incidence, severity, and adaptation to MS; (6) a sustained suprathreshold mismatch between the current sensory pattern and the expected sensory pattern will generate a mismatch signal; and (7) this mismatch signal initiates both adaptation—the modification of the internal neural store or baseline—and the unpleasant signs and symptoms of MS.

A problem with this theory is that it cannot meaningfully predict the wide range of susceptibility of individuals. Further, the theory states nothing about the particular signs and symptoms of motion sickness [16]. Reason and Brand [43] showed that the time span in which symptoms arise during exposure to a relevant stimulation is highly variable, ranging from a few minutes to hours.

2.1.2 Postural Instability Theory

In 1991 Stoffregen and Riccio [58] published an article that expressed concerns over the theory of sensory conflict. Based on their criticism [46, 58] they attempted to formulate a theory that has predictive capabilities. They found, that postural instability precedes motion sickness [59]. They define posture as "the overall configuration of the body and its segments" [58] and postural instability as "the state in which uncontrolled movements of the perception and action systems are minimised" [45]. Further, they found that the duration of postural instability scales directly with the severity of motion sickness. Warwick-Evans et al. [61, 62] showed—contrary to the predictions of Stoffregen and Riccio—that physical restraint does not significantly impact motion sickness.

2.1.3 Rest Frame Theory

A fundamental aspect of this study is the *Rest Frame (RF) theory* proposed by Prothero in 1998 [41]. Prothero bases the theory on the assumption that our brain thinks of certain things as stationary relative to a moving object. He argues that this simplifies the brains calculations as the stationary object has no angular and/or linear velocity component. For example it is easier to assume the road as stationary when driving a car then the converse.

Prothero defines "[t]he particular reference frame which a given observer takes to be stationary" as the "*rest frame* for that observer" [41]. He states that:

> The nervous system has access to many rest frames. Under normal conditions, one of these is selected by the nervous system as the comparator for spatial judgements. We call this the *selected rest frame*. In some cases, the nervous system is not able to select a single rest frame.

This definition seemingly does not imply what constitutes a *RF*, however. Prothero argues that the selection of a certain *RF* is heavily influenced by the visual background as it contains a large set of visual cues. He states that, contrary to the sensory conflict theory, the actual discrepancy is not between two sensory inputs but between two rest frames deducted from those signals. If our brain is unable to correctly select a *RF* serious consequences could arise. Considering this, the *RF* hypothesis can be understood as more of a development of the sensory conflict theory rather than a distinct approach.

The theory also states that in order to avoid *CS* the motion cues that cause discrepancies in the brain's determination of *RF*s should be removed. Prothero conducted two experiments concering the effects of a *RF* on motion sickness in order to support his hypothesis. He argued that providing a visual background that is in agreement to the motion cues should reduce motion sickness. In one experiment, for example, participants were exposed to two separate three-minute circular motion stimulations, one session with an independent background and one without. He found a significant reduction in motion sickness in the session with an additional *RF*.

Considering technological advantages and the fact, that *CS* is often caused by the hardware and not the brains interpretation of the situation, the relatively old equipment of Prothero's study could influence the outcome negatively. However, recently Whittinghill et al. [63] attached a stationary virtual nose to the player, increasing the time they could stay in a *CS*-inducing VE. Other studies [4, 5] support this hypothesis as well. As such, the idea of helping the brain in generating an additional *RF* that accurately represents the incoming motion cues is a promising method of reducing motion sickness symptoms.

2.1.4 Habituation

Habituation is the process of adapting to the environment that causes *CS* and to the symptoms associated with it. Reason [42] derives three distinct phases from previous research on motion sickness:

1. An *initial exposure phase*, where symptoms of *CS* manifest. These are dependent on individual susceptibility and the nature and severity of the sensory conflict.

2. A *continued exposure phase* where adverse effects in the symptom-causing environment diminish over time and eventually disappear.
3. An *after-effect phase* where the return to the original force environment happens.

For example, some people get seasick when on a ship (1) and slowly adapt to the new environment (2). When leaving the ship again, however, an effect called *mal de débarquement* happens (3). Symptoms not unlike those of the original seasickness arise and a new adaptation process happens.

Reason and Brand [43] suggest that *CS*-habituation may occur after a certain amount of time spent in an environment with different movement patterns (in their case a change from a motionless state to the movements on a ship) due to a restructuring of the brains internal model. Bos et al. [3] suggest that the brain then starts a process of minimising the internal conflict of the model which results in a diminishment of symptoms.

2.1.5 Current Reduction Methods

Aside from habituation over time a variety of methods to reduce *CS* have been developed and can be broadly categorised into physical, sensory and medical methods. While technical advancements could still help alleviating symptoms. Simply increasing frame rates and/or resolution seems to have no impact on *CS* with current technology [51], even though technological limitations such as lag, flickering and tracking inaccuracy have been shown to cause *CS* [25].

Physical Methods

As stated by sensory conflict theory motion sickness arises when signals are at odds with each other. An obvious method to alleviate symptoms is therefore to artificially provide adequate signals. This can be achieved by adding a motion platform [25]. One such platform could be a chair similar to those in some modern cinemas, where some vibration and physical motion is added. This option is limited, however, as such installations can be expensive and space-consuming. Further, due to the inability to simulate constant and long-term motion those platforms have limited use. Take, for example, a VR game where the player is in a roller coaster. To accurately simulate all g-forces, the motion platform would basically have to be the actual attraction itself. However, it is still possible to simulate abrupt changes in velocity and rotations with relative ease, as those movements do not require a large setup.

Another—likely more convenient option—is to directly influence the vestibular system by inducing electrical currents. This technique is called galvanic vestibular stimulation. This works by simulating the currents that the vestibular system would produce and directly sending artificial signals to the brain. This has been shown to create a sense of self-motion [29]. Sra et al. [55] and Cevette et al. [7] have found that such a device can significantly reduce *CS* and even increase presence levels. Further, the device by Sra et al. is small enough to simply be attached to present *HMD*s. While this technology is still in development it seems to be a promising solution to the *CS* problem.

Sensory Related Methods

The second broad category of reduction methods is to somehow trick the senses of the user, such that *CS* does not occur. A variety options have been developed over time, most of them are visually based. The *RF*s used in this thesis are such an optical cue. By adding an additional frame of reference to the environment, it might be easier for the brain to determine the exact (or wrong, if intended by the application's creator) state of motion and position. A similar method has been tried by adding a virtual nose to the user's *FOV* [63, 64]. This has successfully reduced *CS*, albeit with a small effect size. A similar approach, also based on Prothero's *RF* theory, was by Lin et al. [27] by adding what they call a *virtual guiding avatar*. This was a 3D object projected into the environment with the intention of guiding the players and giving them a fixed point of reference, similar to following a car on the road. The results indicated a significant decrease in symptoms levels and even increased presence scores in the condition with the virtual guiding avatar.

Another important influence is (*FOV*). The effects *FOV* has are well documented [28] and indicate, that a larger *FOV* increases levels of presence while also inducing *CS*. For this reason Fernades and Feiner [11] dynamically manipulated the *FOV* when a sensory mismatch was expected to occur. The results indicated that only changing the *FOV* in moments necessary helps individuals prevent or at least reduce *CS* to a significant degree. Normally this *FOV*-change is done by adding a black frame on the outer edge and then growing or shrinking it accordingly. The obvious problem is the reduction in visual information which can be important for fast paced games such as shooters. Further, the reduced levels of presence may not be desirable for some applications. While the effect is useful, further and different methods are needed as well.

2.2 Presence

The term *presence* was first coined as the slightly longer word *telepresence* by Minsky in 1980 [31]. Since then, the abbreviated version is predominately used.

There are a variety of suggested definitions of the term presence. For example, 'experiential presence' is 'a mental state in which a user feels physically present within the computer-mediated environment' [9]. Sanchez-Vives et al. interpret this expression as the commonly used phrase of 'being there' in the *VE* or the sense of being in a virtual place rather than the real, physical place where the body is located [49]. A different approach is that presence is 'tantamount to successfully supported action in the environment' [66]. The argument used here is that when an action in an environment is made, the user expects a reaction within the given logic of the world.

Another term widely used in the field of VR is *immersion*. A good overview on a the large set of definitions of the term is provided by Nilsson et al. in their article *Immersion Revisited: A Review of Existing Definitions of Immersion and Their Relation to Different Theories of Presence* [35]. They split the definitions into four broad categories: Immersion is a property of the system, a perceptual response, a response to narratives or a response to challenges.

What is meant by a response of the system is essentially the technical component of how good the simulation is (as in tracking quality or pixel density). Perceptual response is something that is activated by all the senses available in the *VE*. Examples are visual, audio and the sense of touch (haptics). A narrative response can be seen when the participant is exposed to a story and preoccupied by it. This type of immersion can also be observed in media like books and movies. Lastly, immersion as a response to challenges can be seen as something which requires the mental capabilities of the player. For example, a difficult puzzle requires a lot of thought from the player, immersing them in the challenge. Another example would be a complex mystery story where the culprit can be predicted by assembling all known facts. It is important to note that a definition is not necessarily located in a single category or that immersion itself can be reduced to one. It is perhaps much more useful to use all categories when analysing immersion.

Generally, the terms presence and immersion are viewed as distinct. Slater et al. describe immersion as a quantifiable description of a technology [53]. They essentially argue that immersion is better if the technology represents the *VE* as accurately and realistically as possible. This means that presence can be defined as a consequence of high immersion. Examples of quantifiable descriptions of immersion are *FOV*, display resolution, tracking accuracy and latency. Presence on the other hand, so they argue, is a state of consciousness. Important here is the psychological sense of 'being there'. They conclude that behaviours of a user that experiences high levels of presence should be consistent with behaviours in our reality.

It has to be noted that because the distinction of the terms presence and immersion is not entirely clear, this thesis is using these terms interchangeably. However, as a general rule presence—or immersion for that matter—is considered as an only roughly defined sense of 'being there' in the *VE* as described by Sanches Vives et al. [49]. Further, the terms may also be interpreted as a property of how much individuals forget or ignore the fact that they are not in the real world or maybe even consider the *VE* as such. The importance of an exact definition lessens considering the use of a standardised questionnaire in the experiment.

Chapter 3

Methodology

This chapter aims to define and describe the experiment in further detail. It will give an overview about the study and then follow with an in-depth explanation about the *VE*, the technical setup, the participants, the condition called *simulated rest frame* and the procedure. Further, the questionnaires and other methods of measurements will be discussed and justified.

3.1 Experiment Design

To test the hypotheses, two groups of participants walked a preset course over two sessions. One group had a *RF* while the other acted as a control group and had no such visual cue. During and at the end of each session measurements were taken, which will be discussed in section 3.4 and 3.5.

The participants could move via the right hand joystick of the oculus touch controller (forward and backward) and rotate with the left hand one (right and left). The movement speed was 1.6 m/s and the rotational speed was about 0.65 rad/s maximum. Additionally, the participants could further fine tune their movement speed with how they held their right hand. By angling it up or down their movement speed was reduced or increased respectively where the highest speed could be achieved by holding the controller horizontally. The other buttons did not have any function, such that missclicks could be avoided.

In an informal pilot study, the movement and rotational speed of the controls were adjusted. However, due to a small sample size of this study final speeds were chosen additionally based on previous works [4, 11]. The angular velocity was higher, but findings in the pilot and in the final study generally did not indicate that is was too fast. Further, the size, line-thickness and height of the *RF* was adjusted with the goal that the frame was noticeable but not obstructing for the participants (see section 3.3.1).

3.2 Virtual Environment

The *VE* (Figure 3.2) was created using *Unity's* freely available assets from their real-time rendered short film *The Blacksmith* [67]. This environment was chosen because of its relatively high level of visual noise due to its realism. Research suggests that the complexity of a VE has a positive correlation on the symptoms of *CS* [17, 54]. In the case of this experiment, a relatively high level of symptom scores is desirable, as low scores could possibly lead to a smaller range of variance, thus making it difficult to find significant differences between the groups.

In the *VE*, 20 waypoints with a cross section of one meter were spread across the environment (Figure 3.1) which were marked by blue, translucent pillars (Figure 3.3). These waypoints were placed at various points of interest, so a correlation between specific points of the environment and *CS* can be found. For example, Waypoint 6 (W6) was placed after a bridge that spans across a rift and W11 after a long slope. This was to see whether, in the case of W6, acrophobia plays a role in causing *CS* symptoms. However, this is just to indicate where further research could be done as not enough data will be collected to make a justifiable conclusion. The *VE* also included a background sound of a wind blowing in order to create higher levels of presence and also to prevent outside noise from affecting the experiment.

Figure 3.1: Waypoints numbered by order of appearance.

Figure 3.2: Isometric view of the *VE* where Elevation differences are visible.

3.2.1 Technical Setup

For the *HMD* an *Oculus Rift CV1* with two infrared trackers was used to provide 6DOF position and orientation tracking. This means that the participant can translate and rotate their head which will then be accurately transferred to the *VE*. For the user input the *Oculus Touch* controllers were used in order to control translation and rotation of the user in the *VE*. The *VE* was created in Unity 2019.1.2f1 using the aforementioned free asset package from a short film and modifying it to make it usable in *VR*. Due to logistical reasons the experiment took place in two separate locations with different PCs. However, participants only used the same computer for their two sessions. The Headset stayed the same throughout the experiment. The first PC had an Intel i7-4930k (3.40 GHz) with 32 GB RAM, an AMD Radeon R9 290X and Windows 10 while the second had an Intel i7-8700 (3.20 GHz) with 32 GB RAM, a NVIDIA GeForce GTX 1080 and Windows 10.

3.3 Participants

All the 28 participants (8 female, age 17 to 51, $M = 25.5, SD = 7.03$) attended both sessions and thus were considered in the analysis. They were separated into two groups: *No Restframe* (*NF*) as the control group and *Restframe* (*RF*). Participants were num-

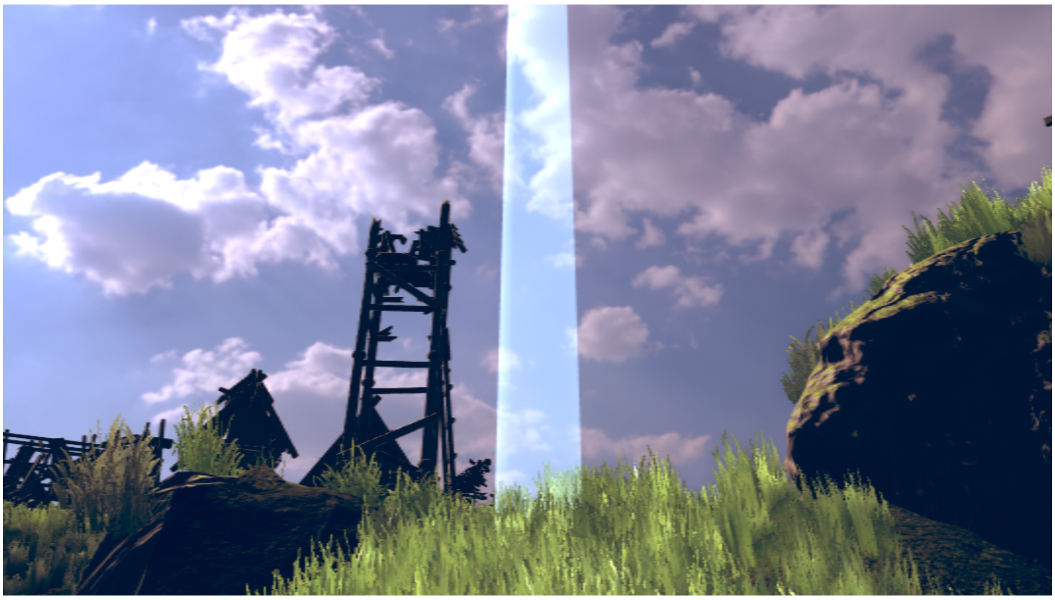


Figure 3.3: Waypoint marked by a blue pillar in the environment. It disappears once the player is in close proximity and the next pillar appears some distance away.

bered consecutively: The first person to take the test was number 1, the second number 2 and so on. Even numbers were assigned to the *RF* and odd numbers to the *NF* group. Both groups had two sessions each but were not counterbalanced with each other as the main goal of this study is to find whether *RF*s have a significant effect on *CS* over time. Further, a counterbalanced study was done by Cao et al. [5].

Stanney and Kennedy [56] noted that 30%–40% of participants in flight simulators do not suffer motion sickness symptoms, while only 5%–10% are asymptomatic in *VR*. However, considering advances in technology which may reduce *CS*, this percentage may not be up to date. According to the data of this experiment, three of 28 articipants (10.7% of the population sample, which is consistent with Stanney et al.'s findings) showed no symptoms at all (*SSQ* of 0) and as we want to measure the effects of people who have symptoms, those people are not used in the analysis of the *SSQ* scores. Further, one person forgot to fill out a question from the *SSQ*, and are therefore also excluded. The *discomfort scores (DS)* indicated that a few participants were close to immune to *CS*. For consistency reasons those are not excluded. Further, due to uncertain factors as to how participants exactly rate their *CS*, the *SSQ* was used as the only reason for exclusion. For example, some people didn't consider sweating as uncomfortable, although the *SSQ* treats it as a symptom [19].

3.3.1 Simulated Rest Frame

For the *RF* two options were considered. The first was to replicate Cao et al.'s [5] version of adding a stationary cockpit to the scene. This cockpit had a dense, but see-through metal placed around the user with a window in front of them. It was stationary relative to the real world but moved virtually with the cockpit. They wanted to create *RF*s without interrupting the field of view. However, considering that the areas where this grid was located was mostly in the peripheral areas of the eyes where visual acuity rapidly falls off [2], a difference to a limited *FOV* may not be noticeable or insignificant. Another disadvantage of this technique is the fact that this cockpit-like form cannot be used immersively in every application. Only when a sort of mech-suit or helmet is realistic does this sort of reduction technique make sense. Considering for example a setting in the medieval times, a metal grid around the player's *FOV* likely disrupts their immersion significantly. However, for some people with high susceptibility to *CS* this trade-off may be acceptable.

For the above reasons the second option was chosen. Instead of having a metal grid in front of the user, an abstract geometrical three-dimensional shape with a white, dashed grid texture on it was anchored to the player (Figure 3.4). The concept stayed very much the same compared to option 1, however. The frame is also stationary with respect to the real world and moves with the player in the *VE* (Figure 3.5). On a technical level the frame is locked to the player collider while the camera receives input from the *VR*-headset. When the player turns their head the frame does not move with it. An input from the controller, however, rotates the collider and hence rotating the frame as well.

The advantage of this form of frame is that the visual field is not as much obstructed compared to the cockpit-like method. Its inherently abstract nature makes is applicable to all settings, although likely for a trade-off in immersion. Further this sort of frame can be customised with regards to size, line-thickness and visibility. This makes it relatively easy to fade it whenever necessary.

3.4 Procedure

The experiment employed a two-session experimental design with two groups. One group had *RF*s while the other did not and acted as the control condition. For the two test sessions, a duration of 45 minutes for the first and 30 minutes for the second test run was calculated. The first session contained 30 minutes for questionnaires and surveys and 15 minutes for the actual *VR* experience while the second session had 15 minutes less time for the questionnaire as several questions would have been redundant. At the beginning of the first session, participants were asked to fill out an informed consent form which informed them about their rights concerning the experiment. They then were asked to fill out a general background survey concerning demographic data and experience with video games and *VR* in general.

Before the experience, participants were shown the technical equipment and how to handle it. Further, they were informed as to what could potentially happen in the simulation and that if they wanted to terminate the experiment for any reason, they could do so at any time. After that, they adjusted the *HMD* and controllers and a short tutorial scene was loaded. Here, the controls and the mechanic of the waypoints were explained and participants were given a short moment to accustom themselves with the controls. On reaching a certain point in the scene by walking there, the actual experiment began after a short loading sequence. The tutorial scene contained nothing except a floor, a horizon and two pillars, so that no *CS* would be induced. Before loading into the actual experiment no one reported any indication of motion sickness.

The participants had to move from pillar to pillar in order to complete the test where

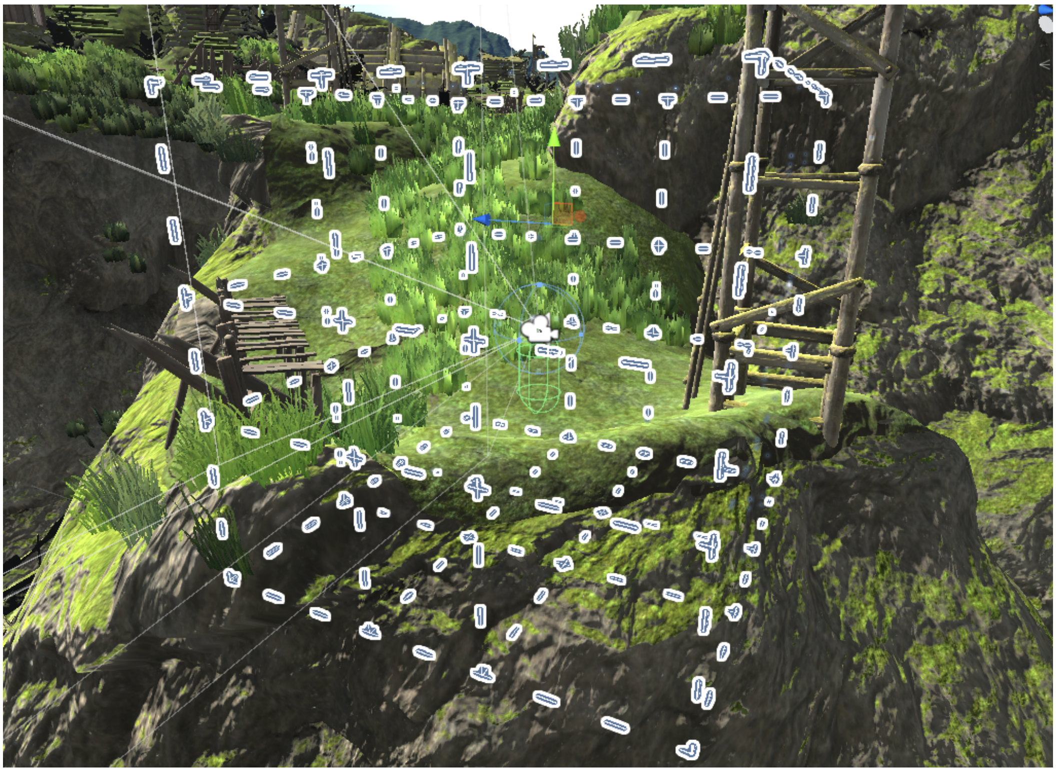


Figure 3.4: The capsule with the camera on top represents the player and their collider. The white frame is the aforementioned *RF* and its rotation is locked to the player-collider. The picture was edited to make the frame have thicker lines for better visibility and does not represent what the player sees.

only one was visible at any given moment. At each waypoint/pillar the participants had to report their current level of discomfort (see section 3.5). This was indicated by an audio signal and if the participant forgot, by a supervisor. Once the participants touched the pillar (their cylindrical colliders intersect) the pillar disappeared and the next one appeared while at the same time said audio signal was played. The test ended when the participant reached the twentieth waypoint or chose to terminate the test early. The participants were allowed to take short breaks during the test with the condition that the headset is to be left on. If the screen fogged up the *HMD* could be taken off for a short while in order to clean the displays.

After the experience, the participants had to fill out a short survey. This included a few general questions, the presence questionnaire by Slater, Usoh and Steed [52] and most importantly, the *SSQ* by Kennedy et al. [19]. For the second experiment, a minimal interval of two days was employed remove potential influences of the first session [19]. While it was recommended to use a maximum of 7 days between the two sessions, some participants were not available during this time frame, so a longer period (up to 2 weeks) was needed.

Figure 3.5: Reference from the player's point of view. The white, dashed lines are always visible and are on top of the *VE*. Notice that the white lines are generally more visible in the *HMD* due to a lack of surrounding light compared to the screenshot.

3.5 Measurement

Several different measurements were taken during the experiment. In order to measure *CS* two different systems were used: The *Simulator Sickness Questionnaire* (*SSQ*) [19] and a *Discomfort Score* (*DS*). The *DS* was inspired by Fernandes and Feiner's study [11].

The *SSQ* is the most widely used questionnaire for *CS* symptoms [1]. It consists of 16 symptoms on a four point scale. These are placed into three categories: Oculomotor, Disorientation and Nausea. These scores are then weighted and summed, which then results in four different scores after applying a conversion formula: A Score for each of the categories and a full score that incorporates every category. The questionnaire is filled out directly after exposure to the *CS*-inducing experience as was the case in this experiment. Examples of these 16 symptoms are nausea, dizziness (with eyes closed), stomach awareness and eye-strain.

The *DS* is used to find out which waypoints correspond to an overall increase in symptoms and to track the participant's well-being over the course of the experiment. Every time participants reached a pillar and heard the signal noise, they verbally reported their level of discomfort on a scale of 1 to 10, 1 being no discomfort and 10 meaning that they want to stop. The participants were instructed beforehand to report that score at every waypoint. Whenever anyone forgot to report this, the supervisor inquired about it. The problem with this type of measurements is its relatively high level of subjectivity. What exactly should be reported is not entirely clear to the participant. For example, while nausea is likely a clear factor for people to include, sweat caused by the heat the *HMD* creates may be not. Further, even if the participants use the same factors the weighting might not be the same. Some people may rate disorientation as the most important contributor to their score while others think the nauseating effect of the experiences constitutes most of the score. The *SSQ* solves this problem by having a larger variety of questions and thus different factors, which are each rated on a separate scale. Additionally, these are then also weighted. In this case, even if some people include the *HMD* caused sweating and some do not, the actual influence on the overall score is likely negligible.

In order to measure presence, the Slater, Usoh and Steed *(SUS)* questionnaire was applied [52]. Participants answer 6 questions on a 7 point scale. The final score is split into two sub-scores: A *SUS count* and a *SUS mean*. The count shows the amount of "6" or "7" while the mean is the average of all 6 questions.

In addition to the questionnaires and *DS*, a short survey was filled out by the participants which qualitatively asked about their overall experience. Further, the time spent for the participant to reach their next waypoint was recorded by the program. For example, one question asked about past experiences of motion sickness with regards to a specific vehicle such as a car or a ship. Through this, a predictor may be found. Another example is how much hours of exposure to *VR* a participant had prior to the experiment. Due to habituation, people with long term exposure likely have generally lower levels of sickness scores. All the questionnaires and qualitative questions can be found in the appendix (see B).

Chapter 4

Results

For the results two-sample t-tests and a mixed design *ANOVA* was used. All results were calculated in *SPSS*. The between-subjects factor was the condition (*RF* and *NF*) and the within-subjects factor was time (*RF1*/*RF2* and *NF1*/*NF2* respectively and completion time) and waypoints (W1 to W20). The dependent variables were *SSQ*-score, *DS* and *SUS*-score. Although the progression of *DS* is discreetly measured, slope lines were used in the plots to indicate a steady, slow increase or decrease in score. Although jumps in score may exist, it is assumed that a slow progression is more realistic. The results are significant with an alpha of 5%.

4.1 Hypothesis 1: Rest Frames vs. No Rest Frames

Tables 4.1 and 4.2 show the results of the t-tests of session 1 and 2 respectively. They will be discussed individually in the following subsections.

	t	df	M_{RF1}	SD_{RF1}	M_{NF1}	SD_{NF1}	p
SSQ	-2.113	22	35.020	28.789	62.142	33.296	.046*
N	-1.162	22	39.895	34.875	56.506	34.935	.258
O	-2.215	22	22.051	13.751	41.398	26.004	.037*
D	-2.609	22	31.636	35.810	72.812	40.645	.016*
DS	-.702	22	2.791	1.965	3.323	1.752	.490

* $p < .05$ ** $p < .01$

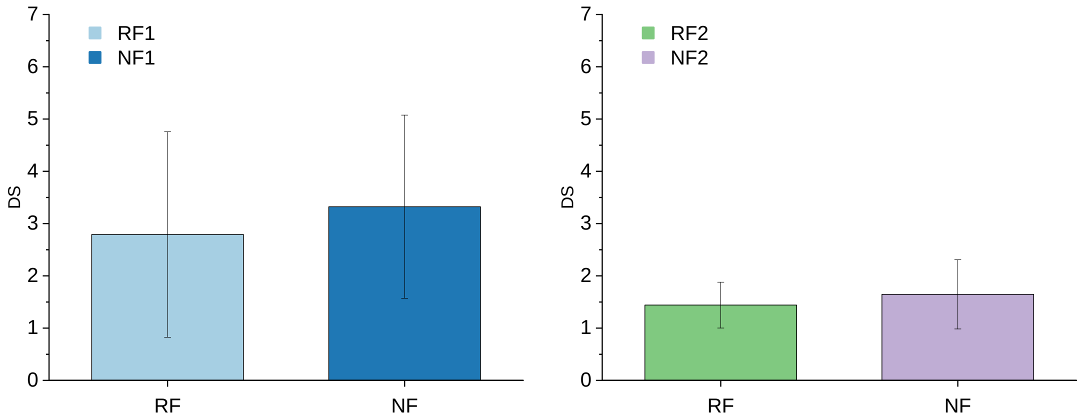
Table 4.1: Two-tailed t-test results of the first session between the *RF* and *NF* condition.

Figures 4.2 and 4.3 show the progression of individual (indicated by the dotted line) *DS* over all 20 waypoints. Additionally, the mean score for each waypoint is indicated by the continuous, thicker line in the same colour. The blue lines represent the condition *NF1*, the green lines *RF1*, the purple lines represent *NF2* and the red lines are the *RF2* values. Over the course of the experiment, only one participant terminated the experiment early when they reached a *DS* of 10. Similarly to Fernandes and Feiner [11] a value of 10 was assigned to the rest of the waypoints, even though the participant did not actually reach those.

	t	df	M_{RF2}	SD_{RF2}	M_{NF2}	SD_{NF2}	p
SSQ	-2.198	22	11.900	10.149	28.194	22.678	.039*
N	-1.371	22	13.876	12.338	24.217	22.243	.184
O	-1.604	22	10.336	10.323	23.323	25.037	.123
D	-3.183	22	5.062	9.385	26.769	20.850	.004**
DS	-.877	22	1.441	0.439	1.646	0.662	.390

* $p < .05$ ** $p < .01$

Table 4.2: Two-tailed t-test results of the second session between the *RF* and *NF* condition.



(a) *RF1* vs *NF1* **(b)** *RF2* vs. *NF2*

Figure 4.1: Comparison of *DS*. Error bars show standard errors. The *RF* condition is consistently lower compared to *NF* but the large standard deviation makes this difference insignificant.

4.1.1 Discomfort Scores

Although the Figures 4.2 and 4.3 show a difference in mean *DS* over nearly all waypoints, no actual significant effect could be measured. Neither *RF1* vs. *NF1*, nor *RF2* vs. *NF2* support (H1). Looking at Figures 4.1a and 4.1b, it is clear that even though *RF1* and *RF2* have visually noticeably lower mean values compared to *NF1* and *NF2* respectively, the high standard deviation indicates that a small difference in mean leads to insignificant results. Comparison of each waypoint showed that only W04 showed a significant result between RF and NF and this only in session 2 ($t(22) = -2.117, M_{RF2} = 1, SD_{RF2} = 0, M_{NF2} = 1.301, SD_{NF2} = 0.48, p = 0.04$).

4.1.2 Simulator Sickness Questionnaire

The difference in *SSQ* scores was significant in both sessions, as shown in Figures 4.4a and 4.4b. Comparing *RF1* and *NF1* shows, that the *RF* condition clearly has an impact on *SSQ* scores. When comparing the (N), (O) and (D) scores of the *SSQ* of the condition

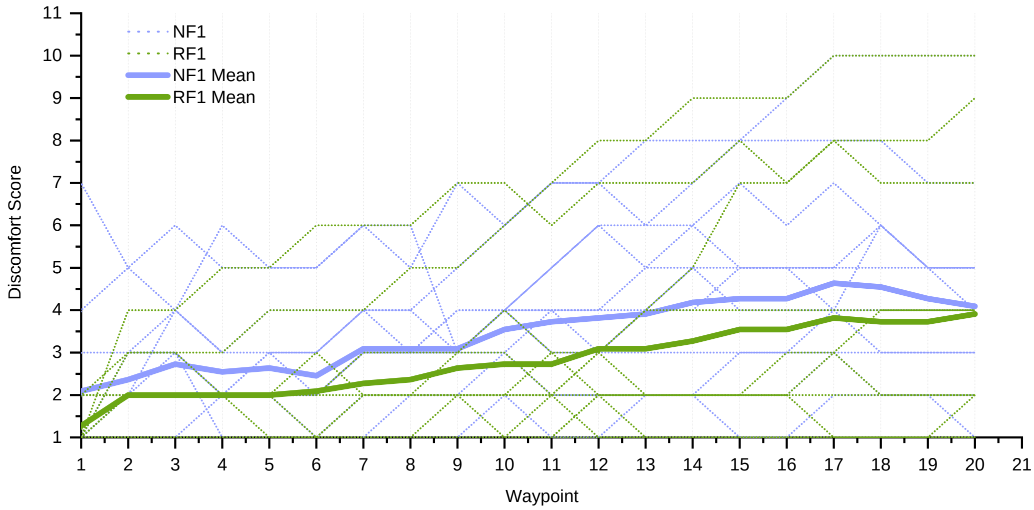


Figure 4.2: Comparison of the progression over the waypoints of the first session. The *RF* means are consistently lower across all waypoints but only insignificantly so.

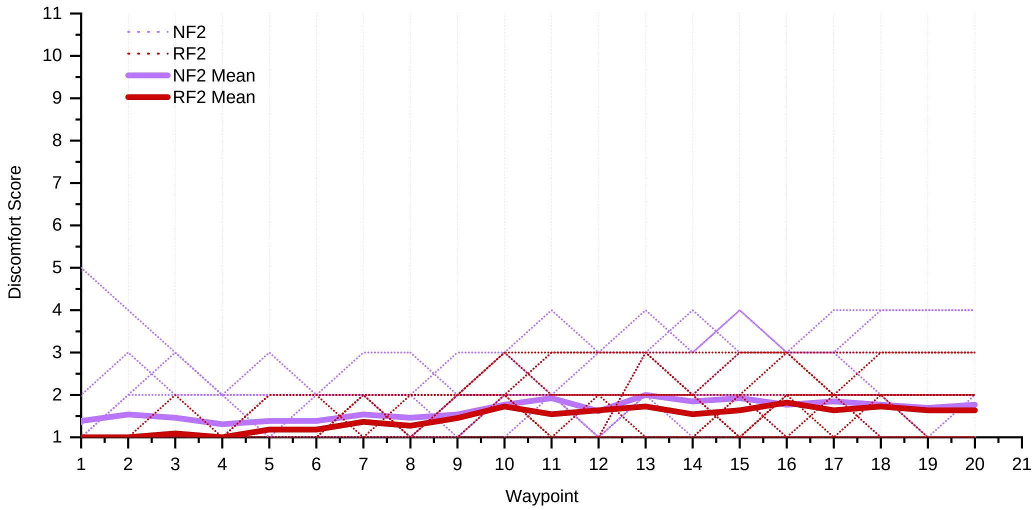
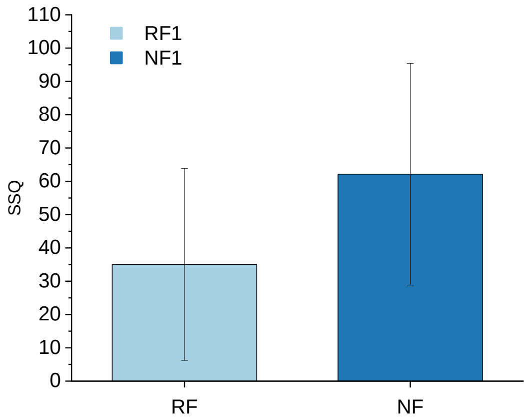


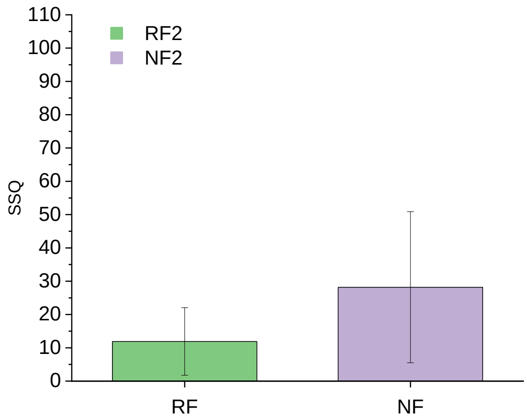
Figure 4.3: Comparison of the progression over the waypoints of the second session. The difference in scores is mostly small. In the first view waypoints the *RF* condition seems to have lower scores visually (not so statistically, however) but this difference narrows with later waypoints.

RF, as shown in Figure 4.5a, the scores are significantly lower in the categories oculomotor (O) and disorientation (D) categories, while nausea (N) showed no significant difference in mean values.

RF2 vs. *NF2* also results in a significant difference in means. However, in the second session only the (D) score was significantly higher in the *NF* condition, as opposed to (N) and (O).



(a) *RF1* vs *NF1*



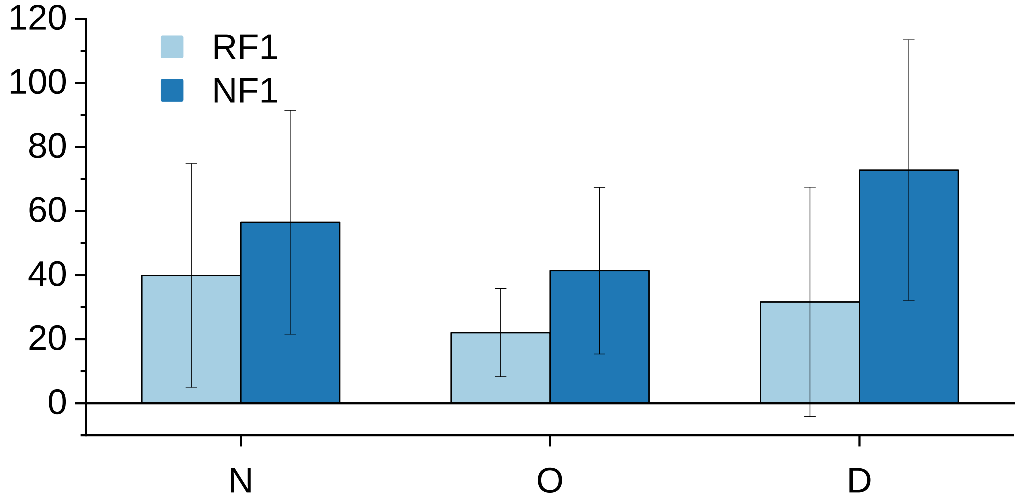
(b) *RF2* vs. *NF2*

Figure 4.4: Comparison of *SSQ* scores. Error bars show standard errors. The means are consistently lower of the *RF* condition visually and statistically, even though a large standard deviation is visible.

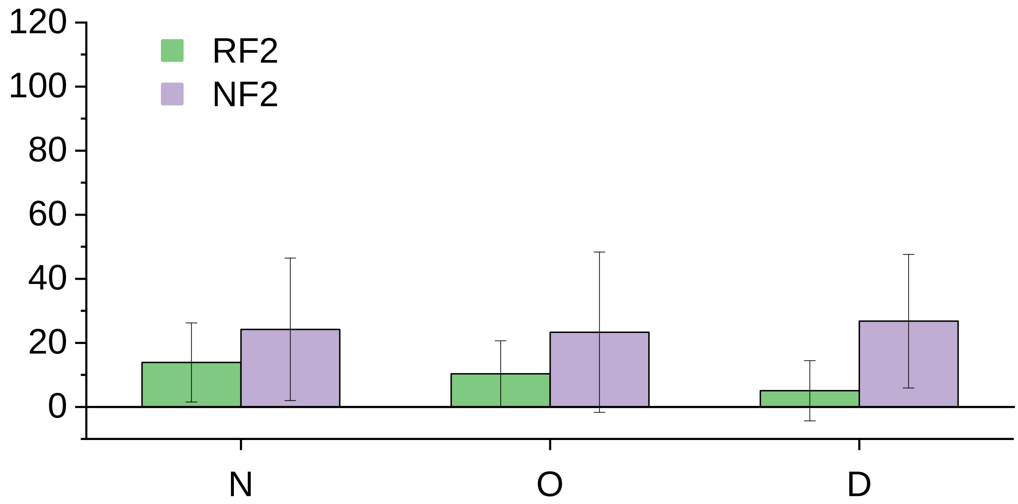
The *SSQ* and *DS* are in contrast to each other, as the *DS* show no significant results while the *SSQ* measurement does. As expressed in section 3.5, *DS* might not be a good indicator to measure symptoms as it is not accurately defined what kind of symptoms it measures. For example, one participant complained about a pressure on the nose that was caused by the *HMD* during the experiment, which may have been included in their estimation of the current level of discomfort. However, *DS* are a good tool to trace the progression of discomfort over the entire course, as they lets us discern at what points in the experience symptom scores and the general level of discomfort increase. On the other hand, the *SSQ* was filled out after the experience, which may distort the evaluation of the symptoms. For example, some symptoms may be short-lived in that they last only a few seconds. This means that the short time between taking off the *HMD* and filling out the questionnaire results in an alleviation of the symptoms. Conversely, two participants said that after approximately 10 minutes after filling out the *SSQ*, their symptoms didn't decline but rather increase to the point where one person threw up. Young et al. [65] showed that there is a significant difference of *SSQ* scores whether a pre-*SSQ* was filled out or not with people reporting an 80% increase in scores, when such a pre-test was applied.

4.2 Hypothesis 2: Session 1 vs. Session 2

In order to test this hypothesis, the results of the first session were compared to the ones of the second session using a paired samples t-test. The second session had lower scores over all categories with few exceptions. The results of the *NF* condition can be found in table 4.4 and the *RF* in table 4.3 and will be discussed in this section.



(a) *RF1* vs *NF1*



(b) *RF2* vs. *NF2*

Figure 4.5: Comparison of (N), (O) and (D) values of the *SSQ*. Here *RF* shows lower scores across the board with varying statistical results.

4.2.1 Discomfort Scores

Figures 4.6 and 4.7 show *RF1* vs. *RF2* and *NF1* vs. *NF2* respectively. Comparing both sessions of the *RF* condition, the hypothesis can be accepted given that the mean discomfort scores are significantly lower in the second session. Looking at each waypoint individually, the result is largely the same in that the second session shows significantly lower scores. Only *W1*, *W6*, *W7* and *W10* show next to no differences. Due to the large amount of t-tests, the results can be viewed in appendix C. However, these outliers show a nearly significant (<0.1%) difference.

The results of the comparison *NF1* vs. *NF2* are generally greater compared to the

	t	df	M_{RF2}	SD_{RF2}	M_{NF2}	SD_{NF2}	p
SSQ	2.707	10	35.0200	28.78939	11.9000	10.14887	.022*
N	2.725	10	39.8945	34.87472	13.8764	12.33846	.021*
O	2.540	10	22.0509	13.75077	10.3364	10.32257	.029*
D	2.199	10	31.6364	35.81035	5.0618	9.38486	.053
DS	2.756	10	2.7909	1.9653	1.4409	0.43864	0.02*

* $p < .05$ ** $p < .01$

Table 4.3: Two-tailed t-test results of the comparison of the *RF* condition between sessions.

	t	df	M_{NF1}	SD_{NF1}	M_{NF2}	SD_{NF2}	p
SSQ	6.740	12	62.1415	33.29575	28.1938	22.67848	.000**
N	6.161	12	56.5062	34.93550	24.2169	22.24252	.000**
O	4.013	12	41.3985	26.00418	23.3231	25.03725	.002**
D	5.389	12	72.8123	40.64459	26.7692	20.85024	.000**
DS	4.088	12	3.3231	1.75150	1.6462	.66221	0.002**

* $p < .05$ ** $p < .01$

Table 4.4: Two-tailed t-test results of the comparison of the *NF* condition between sessions.

RF conditions. Mean scores of both sessions show a sharp decline. Apart from *W1*, all waypoints of the *NF* condition show a significant drop in *DS* mean values over the two sessions. The t-tests can again be found in the appendix section (Tables C.2 and C.3).

4.2.2 Simulator Sickness Questionnaire

Comparing *RF1* with *RF2* and *NF1* with *NF2*, the *SSQ* scores show a significant decrease in mean value. Thus the hypothesis can be accepted. The *SSQ* score of *RF1* vs. *RF2* has a p-value of 0.022. Similarly, the (N), (O) and (D) values are significantly lower as well. This means that in all measured factors of the *SSQ* the second session has lower scores than the first. All this confirms the hypothesis.

Looking at *NF1* vs. *NF2*, the results are mostly the same. The main *SSQ* score of *NF1* vs. *NF2*. shows a significant decline in the second session. The (N), (D) and (O) scores show a considerable, significant drop. The hypothesis can be accepted given these results.

4.3 Hypothesis 3: Presence

The hypothesis was tested using a two-tailed t-test to compare scores between the conditions. Further, a two-factor analysis of variance was conducted to find out whether the conditions changed across the two sessions. The descriptive statistic can be found

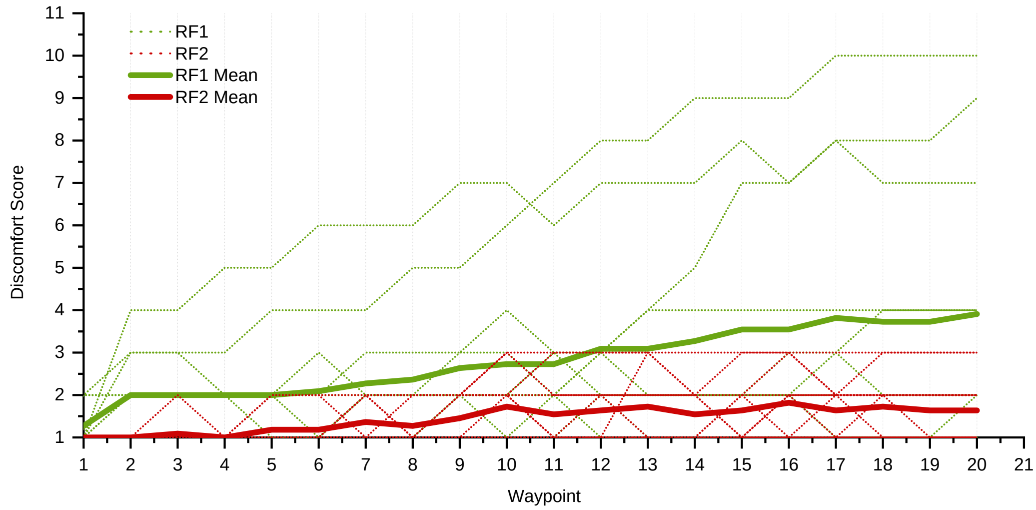


Figure 4.6: Comparing the progression over the waypoints of the *RF* condition over two sessions. The first session shows considerably higher scores over all waypoints.

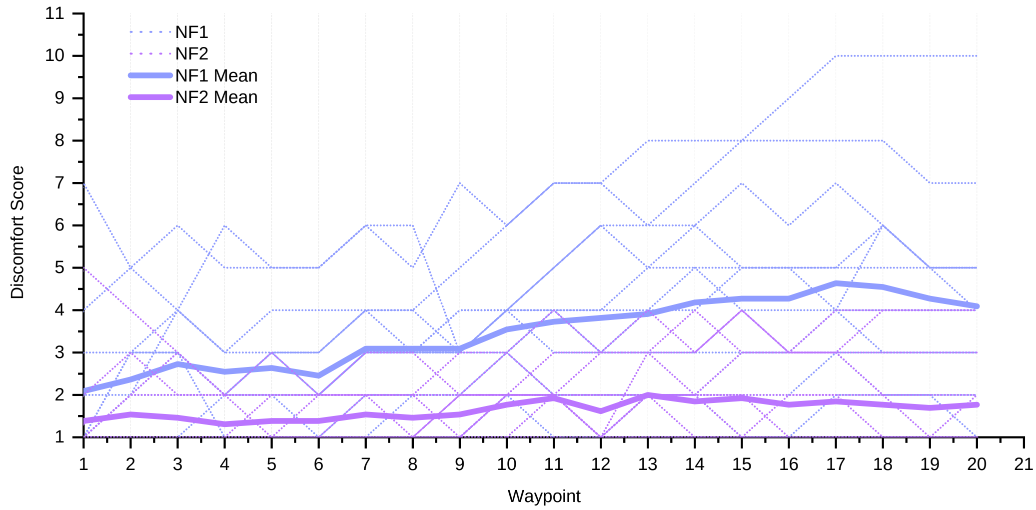


Figure 4.7: Comparing the progression over the waypoints of the *NF* condition over two sessions. The first session shows considerably higher scores over all waypoints. This difference is visibly larger compared to the *RF* condition.

in table 4.5 and the results in table 4.6.

While the levels of presence measured by the *SUS* [52] indicated generally higher levels of presence in the *NF* conditions but the results were insignificant. When comparing the presence score (*SUS* mean, see 4) of *RF1* vs. *NF1* and *RF2* vs. *NF2*, we can see that p is not statistically significant. Using the *SUS* count as the measurement, the results stay consistent with the score measurement. Hence the hypothesis will be rejected. It was further calculated whether the presence score changed when exposed to the *VE* a second time. This is not the case as the difference in both *RF1* vs. *RF2* and *NF1* vs. *NF2* is insignificant. It seems that adding the kind of frame that was applied here does not significantly change the feeling of immersion for the participants.

	M_{Score}	SD_{Score}	M_{Count}	SD_{Count}
Rest frame Session 1	2.667	0.943	1.636	1.120
No rest frame session 1	3.269	0.807	1.154	1.144
Rest frame session 2	2.667	0.980	1.273	1.555
No rest frame session 2	3.218	1.121	1.077	1.256

Table 4.5: Presence *SUS*-scores and -counts across both sessions and conditions.

	t	df	p
RF vs. NF session 1	-1.688	22	.105
RF vs. NF session 2	-1.270	22	.217
RF1 vs. RF2	.000	20	1.000
NF1 vs. NF2	.134	24	.895

* $p < .05$ ** $p < .01$

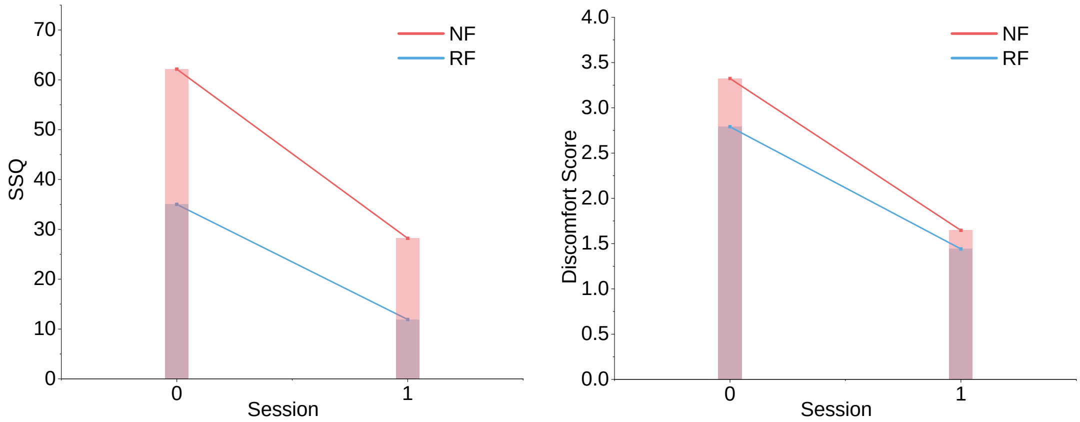
Table 4.6: Two-tailed t-test (*RF* vs. *NF*) and ANOVA (*RF1* vs. *RF2* and *NF1* vs. *NF2*) results of the presence comparison across both sessions. No result is significant.

4.4 Hypothesis 4: Habituation

To calculate the acclimation rate, a two-factor ANOVA was applied using the means of the *SSQ* and the *DS* means at every single waypoint. As described above, the between-subjects factor was the condition (*RF* vs. *NF*) and the within-subject factor was session. In general no significant difference in acclimation could be measured. Comparing the *SSQ* ($F(1, 22) = 1.283, p = 0.27$) and *DS* means ($F(1, 22) = 0.266, p = 0.611$) both result in a statistically insignificant difference. The same can be measured for each individual waypoint. The results of these waypoint measurements can be found in appendix C in table C.4. Figures 4.8a and 4.8b show the acclimation rate visually. The rate seems to be a bit steeper in the *NF* condition, but only insignificantly so. A larger sample size could possibly detect a clearer difference. Considering these results, the hypothesis will be rejected.

4.5 Further Measurements

In the preliminary questionnaire several demographic data was collected which can be used to find predictors of *CS*. The goal of this is to see, whether some data can be used as a predictor for symptoms. This was tested using two-tailed independent t-tests and with *ANOVA*. Gender differences were not measured as only one woman participated in the *RF* group. However, this should not change the outcome of this study as comparing



(a) Acclimation of *SSQ* scores

(b) Acclimation of discomfort scores

Figure 4.8: These graphs show the acclimation rate of *RF* vs. *NF* with the *SSQ* discomfort scores. The lines are drawn such that the steepness of the acclimation is visible. Although the lines indicate a faster acclimation rate in the *NF* condition, this is still statistically insignificant.

women and men in the *NF* condition yielded no significant differences (see Table C.1 in the Appendix).

Chapter 5

Discussion

The experiment partially confirmed several hypotheses which will further be discussed in-depth here. A short summary can be found in table 5.1.

5.1 Hypothesis 1

The hypothesis was stated as follows:

> Hypothesis 1 (H1): Conditions with rest frames will show significantly lower *CS* scores then without them.

As already mentioned in the summary, the results were inconclusive. The experiment was constructed to measure the symptoms of *CS* with the help of two different measurements. The *SSQ* by Kennedy et al. [19] and a discomfort score inspired by Fernandes and Feiner [11]. The results of the *SSQ* were clear. In both sessions the main scores of this questionnaire were significantly lower in the condition with a *RF*. This can be seen in Figures 4.4a and 4.4b. The *SSQ* is constructed from three main

	Summary
H1	The results were inconclusive. *SSQ* scores confirmed the hypothesis while the comparison of discomfort scores rejected it.
H2	The hypothesis was accepted. While some waypoints showed only near significant differences, most results accepted the hypothesis.
H3	The hypothesis was rejected. Although the condition without rest frames shows generally higher levels of presence, the difference is insignificant.
H4	The hypothesis war rejected. The acclimation rate of the non-rest frame condition is only insignificantly better.

Table 5.1: The results of the experiment summarised.

symptom-categories: Nausea (D), Oculomotor (O) and Disorientation (D). In the first session which is shown in 4.5a, only the nausea score was not significantly different. In the second session shown in Figure 4.5b, only the disorientation score was significantly higher in *NF*. Generally the *RF* condition had lower means on average but the rather high standard deviation—caused likely by the small amount of participants— often resulted in an imprecise measurement. Considering this trend though, it may be possible that larger test groups would have resulted in clearer differences. Interestingly nausea seems to be hardly impacted by *RF*s, while disorientation clearly is. This difference in the (D) score may be explained by the fact that *RF*s have previously shown to impact spatial orientation positively [34]. It has to be stated that average completion time of the experiment was significantly lower in the second session. This means that symptoms that accumulate over time couldn't have reached the levels they had in the first session. However, it is still unlikely that disorientation scores are unaffected by *RF*s. The time difference may explain the inconclusive results of the oculomotor measurements though. Further, it stands to reason that factors such as eye-strain and blurred vision—which are considered oculomotoric variables by Kennedy et al. [19]—are ultimately caused by limits in technology. A few participants complained about a somewhat blurry screen which could results in exactly those symptoms. Considering that neither the discomfort score nor the *SSQ*—when considering only the nausea component—confirm the hypothesis may indicate that these factors correlate in some way. This would have to be tested in a separate experiment, however.

In the previous chapter the *DS* were measured at 20 waypoints. However, considering that time may impact levels of discomfort throughout the experiment, the Figures 4.2 and 4.3 in that chapter may not accurately represent the progression of *CS* symptoms. With this in mind, Figures 5.1 and 5.2 were plotted to accurately represent the *DS* over time. The position of the waypoints in the graph were calculated using the average time it took participants to reach that waypoint. At this x-value the average score for the waypoint was used as the y-value. Here we can see that the differences in scores are much more negligible compared to the aforementioned figures. This may explain why comparing *RF1* vs. *NF1* and *RF2* vs. *NF2* with the *DS* results in only an insignificant difference. It has to be noted that due to a bug in the recording program, only the time for 19 waypoints was recorded. However, this should not affect the results.

5.2 Hypothesis 2

The hypothesis was defined as follows:

> Hypothesis 2 (H2): Participants will in general have higher *CS* scores in the first session than in the second one.

The second hypothesis was tested using a paired samples t-test and clearly resulted in the experiment confirming it. Both *RF1* vs. *RF2* and *NF1* vs. *NF2* indicate a clearly statistical difference in *SSQ* and *DS*. All *SSQ* scores, including the sub-components (N), (O) and (D), show a significant drop in value in both *RF1* vs. *RF2* and *NF1* vs. *NF2*. This can be viewed in Figures 4.6 and 4.7. Similarly to the time-dependent graphs in the section above, Figures 5.3 and 5.4 show the differences in *DS* over time with the mean values calculated using the average time it took the participants to reach a waypoint as

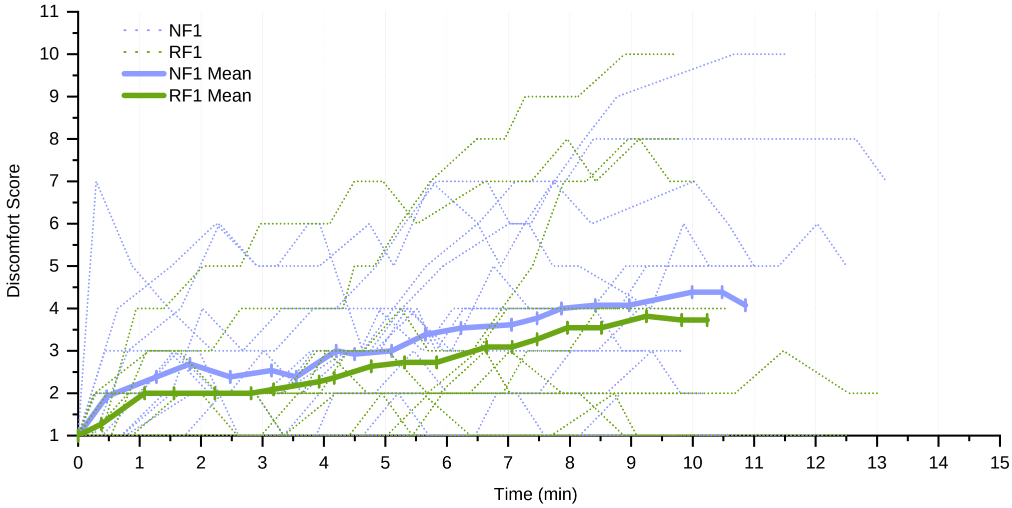


Figure 5.1: Progression of discomfort scores over time with mean values from the first session. Waypoints are indicated by vertical lines starting from 0 to 19.

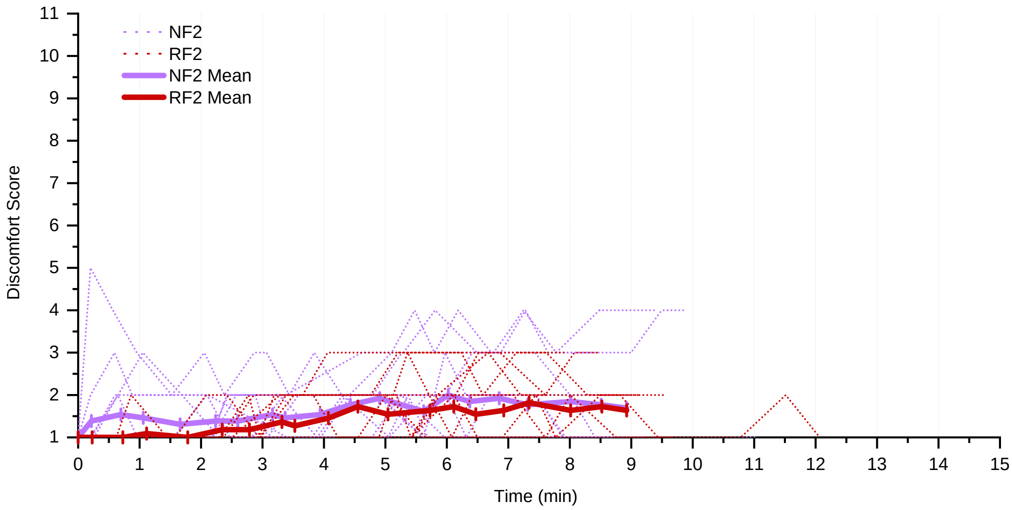


Figure 5.2: Progression of discomfort scores over time with mean values from the second session. Waypoints are indicated by vertical lines starting from 0 to 19.

the x-component and the average DS at the waypoint as the y-component. However, in all four of those plots the difference seems clear in that the second session results in significantly lower scores in all measurements. Considering these results, the hypothesis was accepted.

The reason for this significant drop in scores is not quite clear, however. Despite the short exposure to a VE of less than 15 minutes, participants acclimated themselves to the VR to a large degree. The most likely reason for this is the fact that the exposure to the VE itself seems to be a large contributor in the acclimation process. Time has repeatedly been shown to be a major factor for this [10, 18] although it is inconclusive to what extent. Further, it may be possible that demand characteristics were a contributor the the decline in scores. Some people may have guessed that the purpose of the experiment was to measure the effects of *CS* in *VR* given that participants generally were students with a similar major as the author. This expectation may have resulted in lower scores in the second session.

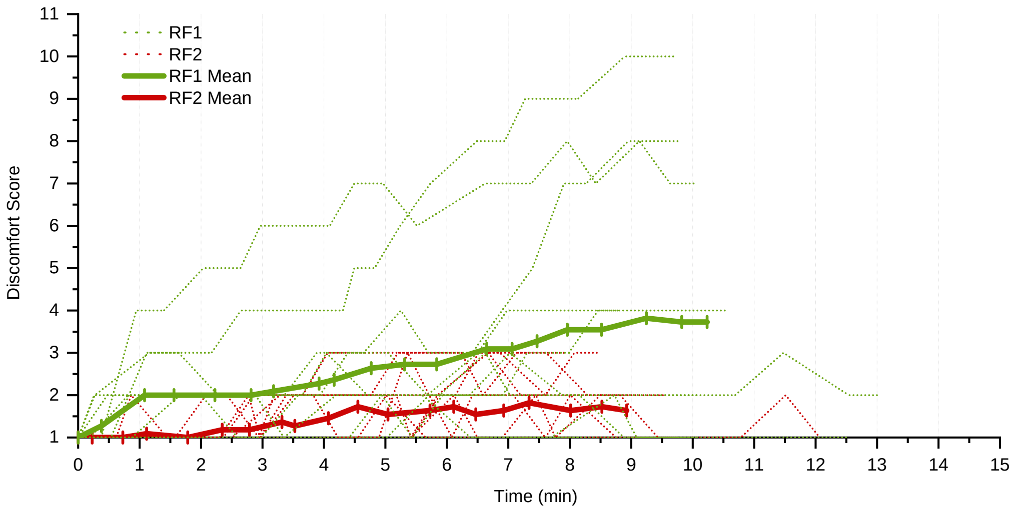


Figure 5.3: Comparing the *DS* progression of the *RF* condition over two sessions. Waypoints are indicated by vertical lines starting from 0 to 19.

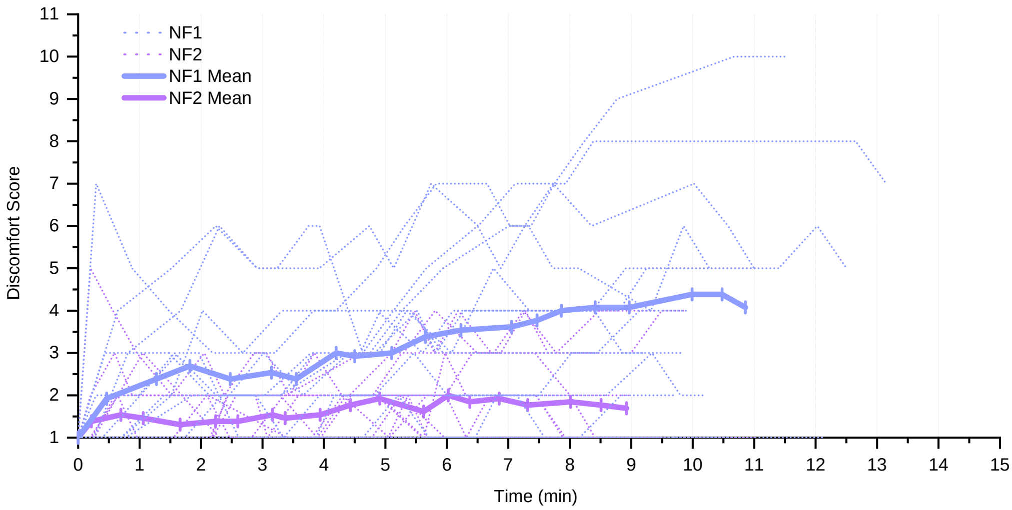


Figure 5.4: Comparing the *DS* progression of the *NF* condition over two sessions. Waypoints are indicated by vertical lines starting from 0 to 19.

5.3 Hypothesis 3

Hypothesis 3 was defined as:

> Hypothesis 3 (H3): Rest frames will worsen presence scores significantly for most participants.

This was measured using the *SUS* [52] by comparing presence scores between conditions and across sessions. Contrary to the expectations, the *RF* condition resulted in only insignificantly lower presence scores in both sessions compared to *NF*. Hence the hypothesis was rejected. The reason may be the fact that the *RF* is not as imposing as was expected, thus resulting in barely any change in immersion (see Figure 3.5). It has to be mentioned that the exact reason for this result is not known. Considering that visual realism may only be one factor contributing to presence [35], the impact it has on the overall experience may be minor. The frame is a constant factor and does not change during the experience, so individuals reported not noticing the rest frame all too much. Despite the exposure to the same experience twice, the presence score did not significantly change in the second session, even reaching p-values of 1 for the *RF* condition and 0.888 for *NF*.

5.4 Hypothesis 4

The hypothesis was given as:

> Hypothesis 4 (H4): Rest frames will accelerate acclimation to the virtual environment for most people.

This was measured using a two-factor *ANOVA* using the condition of *RF* vs. *NF* as a between-subject factor and the two sessions as the within-subject factor. It was applied to the *SSQ*, to the mean of the *DS* and to the score that users reported at each waypoint. In all measurements no significant difference could be found. Thus the hypothesis was rejected.

The acclimation rate of the *SSQ* and the mean *DS* can be seen in Figures 4.8a and 4.8b where the lines represent the acclimation over time. They would have the same acclimation rate if the lines would be parallel to each other. In this case, they are very close to being parallel. Although the slope of the *NF* condition seems to be a bit steeper in both cases the difference is insignificant. However, in both cases the *RF* condition has generally lower mean values across all measurements. Although the rate in which participants adapt to the symptoms of *CS* seems to be constant, the base value is—at least when measured with the *SSQ*—correlated to the *RF*. According to this, *RF*s have a positive impact for people susceptible to symptoms of cybersickness.

This experiment seems to confirm the fact that habituation happens even with relatively short-term exposure to *VR* experiences. Is currently unknown how long that habituation effects lasts, however. The fact that habituation seems to occur is consistent with other studies [15, 18, 44, 47].

5.5 Impacts of the Environment on Discomfort Scores

As stated in section 3.5 the progression of the *DS* over the waypoints provides an opportunity to find what characteristics of the *VE* cause abrupt changes in the scores. While no differences were measured at specific waypoint-pairs using a two-tailed t-test—possibly because of the high standard deviation—some visually protruding points were analysed. This was done only in the first session (Figures 4.2 and 5.1) as *DS* were generally low in the second experiment and no differences were obvious. When looking at both graphs, jumps can be seen from waypoint 1 *(W1)* to *W2*, *W6* to *W7*, *W9* to *W10* and *W11* to *W12*. Further, after peaking at *W17* both conditions somewhat declined in score until the end. The criterion for choosing those points was when a significant protrusion was visible on both graphs. For example, Figure 4.2 shows a jump at *W16* but this can be explained by the fact that the distance between *W16* and *W17* is large, thus leading to a clinched slope.

The sudden jump between the first and second waypoint may be easy to explain. Participants were suddenly exposed to a new environment and this sudden change resulted in their vestibular system reacting negatively. After *W2* and *W3* scores on average do not change much, so it is possible that the brain adapted to the new situation quickly. The sudden jump at beginning at W6 may be explained by the fact that the environment contained a lot of visual noise such as grass and wooden objects which have been shown to impact symptom levels [17, 54]. Further, some individuals reported a strange, uncomfortable feeling when walking through the tall grass located at this point which may have been caused by the lack of haptic feedback when contact with the grass was made. The jump at *W9* is likely due to the sudden change in elevation level. Between *W9* and *W10* there is a valley with an elevation span of about 8 metres. Some participants reported that a change in altitude was uncanny and caused increased levels of nausea and discomfort. The area between *W11* and *W12* is the same as between *W5* and *W7*, so the reason for the jump here is likely the same. The only difference is the direction in which participants were going. Lastly, starting from *W17* a slight decline in discomfort score is visible. This is likely due to the fact that, especially starting from *W18*, the environment changes into a more tranquil area with less visual noise. The far-away horizon becomes visible, thus adding another frame of reference. Further, the ground is level and has no objects. Observing Figure 3.2, the space leading up to the last waypoint which is located at the hole on the norther side of the map looks somewhat like a tunnel. So maybe a lack of head-movement caused by a clear goal in front of the participants mitigated symptom-causing factors. Head-movement has been shown to cause symptoms [43].

It has to be stated that this analysis is only an estimation on what specifically caused the change in scores. An in-depth research looking at the specific symptom-causing factors has to be done to find significant conclusions.

5.6 Limitations

For starters, the most obvious limitation is the rather small amount of participants in the study. Precise conclusions are difficult to make and only when the significance is high, which was mostly not the case and stayed in the range of 95 percent. Further, considering the fact that women tend to have higher susceptibility to *CS* [23, 25] due to hormonal differences and a larger field of view and the fact that the *RF* group contained only one woman the results may be skewed towards said condition. Although a two-tailed t-test between male and female did not find a significant effect of gender on the results of the *NF* condition it still has to be considered within the analysis of the results. The candidates of this study were recruited at the related university and thus somewhat selectively. Age has been shown to affect susceptibility and the rather small standard deviation and generally low age of the participants ($M = 25.5, SD = 7.03$) may have changed the outcome of this study. However, the target audience for *VR* seems to be mostly younger people [68] up to about 40 [48]. From the standpoint of producers of *VR* applications this result is still important. The acclimation rate was tested by comparing two separate control conditions with one another which resulted in no statistical significance. It may be necessary to research whether a third session without *RF*s for all participants would have shown a difference in *CS* scores. A goal of this study was to find if *RF*s could alleviate symptoms in the long-term and additional sessions may have been required to find whether that was the case or not. However, due to time and resource constraints this was not possible. The movement that was used in this study was rather slow and consistent. It is not clear if an experience with abrupt and inconsistent actions would result in the same findings. The type of movement seems to impact how much symptoms can be felt [23]. It is, however, difficult to test how much the type of movement affects susceptibility. A multitude of experiments would be necessary to find reasonable conclusions.

5.7 Comparison to other works

While the results of the *SSQ* are similar to those of Cao's study [4], the *DS* are not. Cao was able to find a significant difference in both conditions in what can be considered a relatively similar setup compared to this experiment (see chapter 3). It is reasonable to assume that the way *RF*s and the *VE* are implemented significantly impact the extent of *CS* in an individual, so it is not entirely clear where this difference in experimental results originated. Although it is likely that these differences can be attributed to the technical implementation, the fact that the *DS* in this experiment are clearly trending towards confirming hypothesis 1 indicate that *RF*s reduce *CS* symptoms at least to some degree. As the causes of these differences in results are not quite clear and the exact impact the environment has on *CS*, further studies are warranted.

Chapter 6

Conclusion and Future Work

This study attempted to find whether a *RF*, hypothesised by Prothero in 1998 [41], has a positive impact on the symptoms of *CS* in *VR* applications over short and long-term period. The experiment contained two groups, one with such a frame and one without, that over the course of two separate sessions measured statistically significant differences. The results indicate a partial success. The virtual environment was created and adapted from Unity's free asset package of their short film *The Blacksmith* [67]. Participants moved through the environment using an Oculus Rift and Rift Touch controllers with the goal of walking through 20 waypoints that were spread across the map.

Through two different core measurements, the *SSQ* [19] and *DS* inspired by Fernandes and Feiner [11], two different results were obtained. The *SSQ* score indicated a significant difference while the *DS* did not. However, it is likely that the real results lean toward the *SSQ* score, considering it is a much more precise measurement. The *SSQ* uses 16 questions on a four-point scale while the *DS* measure one factor on a ten-point scale. Further the *SSQ* has been the standard measurement tool for several years now [1] even though it has been criticised by some [60]. Considering this, *RF*s seem to be a successful method of reducing symptoms. This also confirms other studies with the same or similar goal [4, 5]. It was further measured whether the average scores for both conditions were lower in the second session. This was the case with some measurements showing a highly significant difference ($p < 0.001$).

It was further tested whether a constantly visible frame reduces immersion for individuals. This was tested measured using the *SUS* [52] as a post-survey which is commonly used to measure presence levels. The results showed no significant effect on the levels of immersion. However, considering that the *RF* condition generally showed lower average presence scores, albeit small, a study with a larger amount of participants will potentially find a difference.

The last measurement made was the acclimation rate of the two conditions with the goal of determining whether the adaption to symptoms of simulator sickness can be sped up. Using a two-factor ANOVA it was found that the condition has no impact on the habituation process.

Some aspects have to be further researched, however. For example, it is not clear if this effect is measurable for every type of movement. Although a habituation process was visible in the experiment it is not clear for how long this effect lasts. For example, if a person plays a *VR* game for the first time and then plays it again the day after an effect may be noticeable. If, however, this individual returns to the game several weeks after experiencing the game the same effect might not be there. Another possible research could be how effective different types of *RF*s are. Is the effect more noticeable with a thicker or perhaps a more tightly spaced frame? Considering the effect *RF*s have—especially during the first exposure to *VR*—a further look into how this can be maximised to alleviate *CS* for users is useful. As already mentioned in section 5.7 it is necessary to find how exactly an environment impacts the emergence of *CS*. While some research on this topic has been done already, figuring out in what ways a *VE* can be created that least affect the users well-being is imperative.

Considering these results, *RF*s seem to offer a valid and cost-effective method of alleviating *CS* symptoms, especially when using a *VR* headset for the first time. This means that creators could potentially add such frames to the tutorial and beginning phases of the experiences and gradually remove them whenever necessary. This makes it easier for people to overcome the problems of *VR* and reduces the barriers that some have when deciding whether they want to invest in this technology.

Appendix A

CD-ROM Contents

The companion CD includes the following files:

- A PDF version of this thesis
- A compressed folder containing the *VR* application used for the experiment

Appendix B

Questionnaires

Personal Information:

Gender:
☐ Female
☐ Male
☐ Other

Age:

Employment Status:			
☐ Working	☐ School/ University	☐ Retired	☐ job-seeking
☐ Other: ……………………………………………………………………………………..			

How often do you play (computer) games?			
☐ Daily	☐ Several times a week	☐ Sometimes	☐ Never

How often are you confronted with virtual reality applications and games?			
☐ Daily	☐ Several times a week	☐ Sometimes	☐ Never

If you have played VR-games before, what kind of genre were those?

Do you own a VR-headset (HTC Vive, Oculus Rift, Gear VR,…)?		
☐ Yes	If yes, what kind? _______________	☐ No

D		
☐ Yes	If yes, what exactly? _______________	☐ No

Do you take medication that possibly inhibits performance or your general wellbeing?		
☐ Yes	If yes, what exactly? _______________	☐ No

In the last 10 years how often did you travel with the following modes of transportation?

	Never	1 to 4 times	5 to 10 times	11 or more
Car				
Bus				
Train				
Plane				
Boat				
Ship				

How often did you feel discomfort or nausea during those travels?					
	Never	Rarely	Sometimes	Frequently	Always
Car					
Bus					
Train					
Plane					
Boat					
Ship					

How do you rate your past experiences with motion mickness (Travel sickness, VR-sickness, seasickness)?						
1 - Susceptible	2	3	4	5	6	7 - Immune

How many hours did you roughly spend in VR?

Do you have past experiences with motion sickness in VR and if yes, in what games with what headsets?

POST-Survey

1. Do you feel you are in the same state of health as when you started the experiment?

   O Yes O No

2. If you answered no please explain briefly in the space provided below:

3. If you expressed slight, moderate, or severe on any of the questions above, please state if you felt that way before playing the game, and if so, explain how you felt worse after playing the game.

4. If you felt any of these symptoms and you remember what in the game caused them, please list those events.

5. What part(s) of the experience made you feel like you were in the virtual world?

6. What part(s) of the experience caused you to realize you were not in the virtual world?

7. (Reference Frame) Did the reference frame impact your experience in any way? (Orientation, Motion Sickness)

8. What did you like best about the experience?

9. What did you like worst about the experience?

10. Do you have anything to add?

SSQ

For each of the following conditions, please circle how you are feeling right now, on the scale of “none” through “severe”.

1.	General discomfort	***none***	***slight***	***moderate***	***severe***
2.	Fatigue (weariness or exhaustion of the body)	***none***	***slight***	***moderate***	***severe***
3.	Headache	***none***	***slight***	***moderate***	***severe***
4.	Eye strain (weariness or soreness of the eyes)	***none***	***slight***	***moderate***	***severe***
5.	Difficulty focusing	***none***	***slight***	***moderate***	***severe***
6.	Increased salivation	***none***	***slight***	***moderate***	***severe***
7.	Sweating	***none***	***slight***	***moderate***	***severe***
8.	Nausea (stomach distress)	***none***	***slight***	***moderate***	***severe***
9.	Difficulty concentrating	***none***	***slight***	***moderate***	***severe***
10.	Fullness of head (sinus pressure)	***none***	***slight***	***moderate***	***severe***
11.	Blurred vision	***none***	***slight***	***moderate***	***severe***
12.	Dizzy (with eyes open)	***none***	***slight***	***moderate***	***severe***
13.	Dizzy (with eyes closed)	***none***	***slight***	***moderate***	***severe***
14.	Vertigo (surroundings seem to swirl)	***none***	***slight***	***moderate***	***severe***
15.	Stomach awareness (just a short feeling of nausea)	***none***	***slight***	***moderate***	***severe***
16.	Burping	***none***	***slight***	***moderate***	***severe***

Presence Questionnaire

1. Please rate your sense of being in the virtual environment, on the following scale from 1 to 7, where 7 represents your normal experience of being in a place.I had a sense of “being there” in the virtual environment:

1 Not at all	2	3	4	5	6	7 Very Much

2. To what extent were there times during the experience when the virtual environment was the reality for you? There were times during the experience when the virtual environment was the reality for me...

1 At no time	2	3	4	5	6	7 Almost all the time

3. When you think back about your experience, do you think of the virtual environment more as images that you saw, or more as somewhere that you visited? The virtual environment seems to me to be more like...

1 Images I saw	2	3	4	5	6	7 Somwhere I visited

4. During the time of the experience, which was strongest on the whole, your sense of being in the virtual environment, or of being elsewhere? I had a stronger sense of...

1 Being elsewhere	2	3	4	5	6	7 Being in the Virtual Environment

5. Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By ‘structure of the memory’ consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.I think of the virtual environment as a place in a way similar to other places that I've been today...

1 Not at all	2	3	4	5	6	7 Very Much So

6. 6.During the time of the experience, did you often think to yourself that you were actually in the virtual environment?

1 Not very often	2	3	4	5	6	7 All the time

Appendix C

Statistics

	t	df	p
SSQ S1	-.101	11	.921
SSQ S2	.068	11	.947
N S1	.213	11	.835
O S1	-.276	11	.788
D S1	-.253	11	.805
N S2	-.053	11	.959
O S2	.413	11	.688
D S2	-.555	11	.590
DS Mean S1	-1.885	11	.086
DS Mean S2	-.386	11	.707
Completion Time S1	-1.359	11	.201
Completion Time S2	-.180	11	.860
Presence S1	.593	11	.565
Presence S2	.012	11	.990

* $p < .05$ ** $p < .01$

Table C.1: Gender differences in the *NF* condition, the p-value is generally high, with the *DS* of the first session as an exception

Waypoint	***t***	***df***	***p***
1	1.936	10	.082
2	3.317	10	.008*
3	3.194	10	.010*
4	2.803	10	.019*
5	2.324	10	.042*
6	2.193	10	.053
7	1.992	10	.074
8	2.631	10	.025*
9	2.550	10	.029*
10	1.982	10	.076
11	2.358	10	.040*
12	2.451	10	.034*
13	2.366	10	.040*
14	2.610	10	.026*
15	2.313	10	.043*
16	2.557	10	.029*
17	2.564	10	.028*
18	2.345	10	.041*
19	2.501	10	.031*
20	2.598	10	.027*

* $p < .05$ ** $p < .01$

Table C.2: Paired samples t-test of hypothesis 2. Comparison of discomfort scores of the *RF* condition between the two sessions.

Waypoint	***t***	***df***	***p***
1	2.007	12	.068
2	2.513	12	.027*
3	2.792	12	.016*
4	2.344	12	.037*
5	2.645	12	.021*
6	2.449	12	.031*
7	3.376	12	.006**
8	3.787	12	.003**
9	3.376	12	.006**
10	4.395	12	.001**
11	3.228	12	.007**
12	3.280	12	.007**
13	3.055	12	.010*
14	3.816	12	.002**
15	3.425	12	.005**
16	3.895	12	.002**
17	4.191	12	.001**
18	4.180	12	.001**
19	4.167	12	.001**
20	3.605	12	.004**

* $p < .05$ ** $p < .01$

Table C.3: Paired samples t-test of hypothesis 2. Comparison of discomfort scores of the *NF* condition between the two sessions.

Waypoint	M_{NF1}	SD_{NF1}	M_{NF2}	SD_{NF2}	F	p
1	1.273	0.467	1.923	1.801	0.690	0.415
2	2.000	1.000	2.385	1.387	0.112	0.741
3	2.000	1.000	2.692	1.548	0.346	0.562
4	2.000	1.183	2.385	1.557	0.017	0.899
5	2.000	1.342	2.538	1.450	0.341	0.565
6	2.091	1.640	2.385	1.502	0.024	0.878
7	2.273	1.555	3.000	1.780	0.767	0.391
8	2.364	1.690	2.923	1.553	0.427	0.520
9	2.636	1.859	3.000	1.732	0.194	0.664
10	2.727	2.102	3.385	1.609	1.011	0.325
11	2.727	2.005	3.538	2.106	0.369	0.550
12	3.091	2.300	3.615	2.256	0.403	0.532
13	3.091	2.427	3.769	2.166	0.243	0.627
14	3.273	2.687	4.000	2.345	0.244	0.626
15	3.545	3.012	4.077	2.532	0.057	0.813
16	3.545	2.841	4.077	2.597	0.421	0.523
17	3.818	3.311	4.385	2.663	0.122	0.730
18	3.727	3.228	4.385	2.755	0.352	0.559
19	3.727	3.228	4.077	2.532	0.088	0.769
20	3.909	3.300	3.923	2.597	0.013	0.909

* $p < .05$ ** $p < .01$

Table C.4: *ANOVA* results of each waypoint. No difference in habituation rate is discernible.

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