Redirected Rotation Affected by Particle Based Weather Conditions

Mikkel Rasch Nielsen

May 2014

This page is intentionally left blank.

Preface

A CD should be included with this report. It contains a copy of the product used for the study of Rotational gain with a particle system implemented to simulate a snow storm. A digital version of this report and the raw data from the results and the build used in the study. The CD is not a necessity and the report can still be read without the CD.
This project is a master thesis in the field of computer science with a focus on computer graphics and virtual reality. It is expected that the reader has a background or understanding of computer science at a university level or higher.

I would like to thank Evan A. Suma for feedback in the early stages of the idea face and Niels C. Nilsson for feedback and sparring throughout the project.

Contents

This page is intentionally left blank.

Chapter 1

Introduction

Natural walking in Virtual Reality (VR) is often limited by the size of the physical space and affects VR applications, as it requires large tracking areas that many labs would have an increased cost finding the physical space, for this type of experiments. The Virtual Environments (VEs) can spread over an endless area limited only by the designers restriction and computational power. But the physical tracking area provides restrictions for the movement of the user. Because of these physical restrictions there have been a lot of research contains walking in place and redirected walking techniques. The three most commonly known techniques for redirected walking is *Translation gain, Curvature gain* and *Rotation gain.*

The motivation behind investigating redirection techniques is tied together with the increase in technology with both gaming and other fields. Sony has recently announced their Project Morpheus (Sony Computer Entertainment Inc. [2014]) and Facebook has purchased OculusVR for 2 billion dollars *(http://www.businessinsider.com/facebook-to-buy-oculus-rift-for-2-billion-2014-3).* The technology advances have made the technology attempts from the 90's into a new hype of gaming and experience technology therefore it is important to find new ways to utilize these advances in the technology and find matching interaction methods.

Based on this and the fact that redirected walking for outdoor scenarios is still to be further explored, compared to indoor scenarios where a few additional techniques that can help redirect the user e.g. change blindness and impossible spaces, but outdoors these illusions are restricted or impossible to use. Therefore we investigate if we can find alternative methods to modify the limitations for non-noticeable gain values for Translation, Rotation and Curvature gain. This paper researches on if the Rotation gain values can be modified with the use of directional distraction effects e.g. would snow coming from the side have an effect on the amount of Rotation gain applied before the the participant can notice a change in rotation speed.

This paper looks into redirected rotation using other means of expression (e.g. weather conditions) to create a larger distraction for the fact that the world is moving in relation to the user by the use of optical flow. The optical flow created for this study is snow which is a particle based weather effect and Haringer and Beckhaus [2012] already showed an improvement of the sense of presence using naturally occurring weather phenomena like particle/fluid based weather effects (e.g. snow, rain and fog). Therefore we look at other beneficial effects this can have on the virtual experience and manipulation of the users senses, by investigating if particle effects like snow can be used to reduce the sense of being redirected in VR with a focus on Rotational redirection.

Chapter 2

Background Work

Various methods to support walking in VR will be described in this chapter. These include using real walking, adding illusions or utilizing the noise in the perceptual system. Some utilizes treadmills for one directional walking or larger and more expensive treadmills for omni-directional walking. Other techniques focuses on walking in place and some that uses low friction surfaces, where the user is sliding as a walking method. With focus on finding a method that both feels natural and works in VR. This chapter will summarise some of the previous work done in this area.

2.1 Redirection

There are three common methods used when talking about redirection, Translation gain, Rotation gain and Curvature gain. At times, distractors are also mentioned in this category but as a fail-safe for when the user is about to exit the physical tracking space, the distractors have will be described in a separate section.

Suma et al. [2012a] wrote a taxonomy for deploying redirection techniques in VEs, describing the five most common methods used for natural walking in VR; Translation gain, Rotation gain, Curvature gain, levitating blindness and distractor redirection with the last of them to be the only true intrusive method resulting in Break-In-Presence (BIP) and levitating blindness increasing the chance of a BIP. How the three methods are working and what they are doing will be described below.

2.1.1 Translation gain

The purpose of translation gain is to alter the perceived distance traveled in the virtual world compared to the physical environment. There are two general methods for implementing Translation gain; either alter the user's movement speed or move the world in relation to the user. For large complex environments it can be rather costly to move all the elements and some might be affected by the move e.g. with the use of physics on the objects. Figure 2.1 shows an example of translation gain with a gain value of more than one, resulting in a shorter actual movement in the physical space compared to the movement in the virtual environment. The effect is reversed if the value for translation gain is below one; in that case the user will be moving further in the physical space than in the virtual environment. Translation gain is calculated by the following equation;

$$g_t = \frac{T_{Virtual}}{T_{Physical}} \tag{2.1}$$

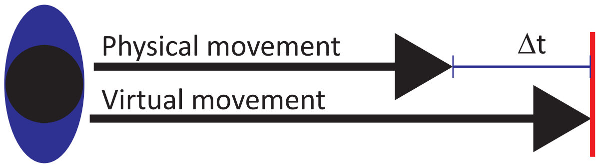


Figure 2.1: Displaying the mechanics of Translation gain, Δt is the differnce in length between the real and virtual movement.

2.1.2 Rotation gain

The purpose of Rotation gain is like with transaction gain to manipulate the user's movement, but for this method it is the manipulation of the users rotation, and like before there are several methods of implementation. As before there is the rotation of the environment or the rotation of the user as the user is moving but, as mentioned by Peck et al. [2009] some have also tried applying a small rotation to the visuals while the user is standing still. This effect seams a lot easier for the user to perceive resulting in a lower threshold for the Rotation gain value. Figure 2.2 shows how the Rotation gain is applied for the condition where the user is moving. Like translation gain, Rotation gain is calculated by the following equation;

$$g_r = \frac{R_{Virtual}}{R_{Physical}} \tag{2.2}$$

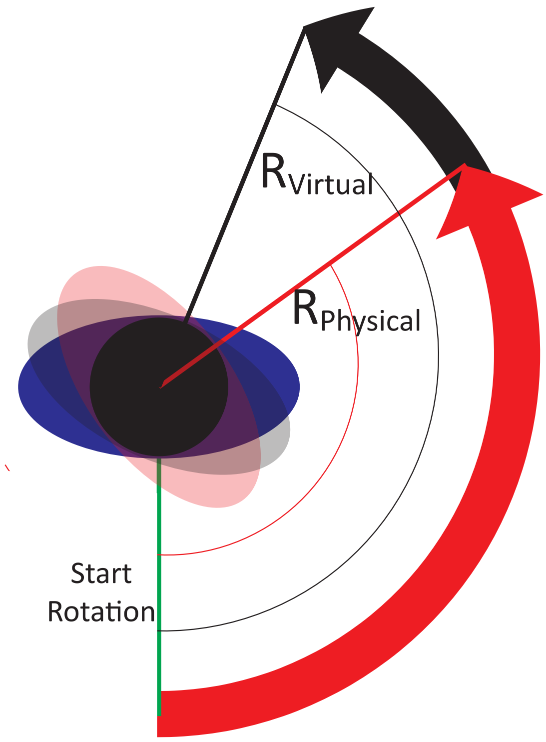


Figure 2.2: Displaying the difference in rotation from the physical space (red curve) to the rotation in the physical space(black). The starting position is marked by the green line.

2.1.3 Curvature gain

The method of curvature gain works as a manipulation of the user's walk. By adding a small rotation to the visuals with the intention of making the user unnoticeably correct the direction while walking (the method is displayed in Figure 2.3. The illusion utilizes the static, the perceptual system gets from the proprioceptive and vestibular system and the sense of what is straight gathered from the visual system. The thresholds are determined by the amount of added rotation, that can be applied before the user perceives the effect. The advantage of curvature gain is that it enables the user to walk in circles while perceiving to be walking in a straight line. Threshold for curvature gain is given by the radius (r) of the circle is calculated by the following equation:

$$g_c = \frac{1}{r} \tag{2.3}$$

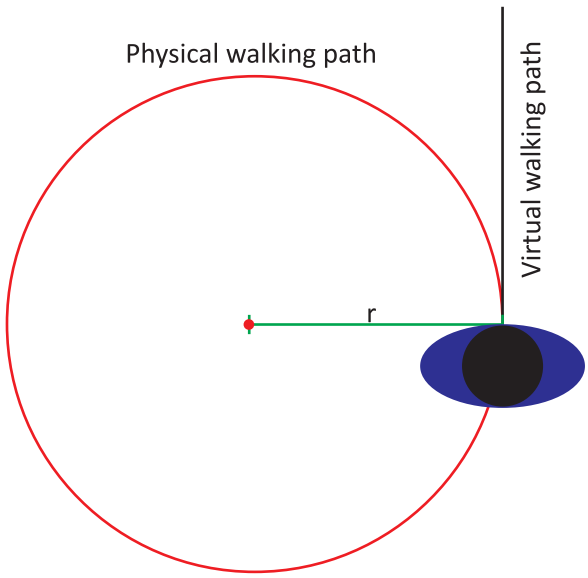


Figure 2.3: Displaying the users percieved direction (the black line) and motion in the virtual space, while the users physical walking path follow round a circle (red) with the radius r.

The objective in redirection research is often to find the threshold values for when a user can be manipulated by these effects without perceiving any of the three redirection methods. For this, Steinicke et al. [2010] found the following thresholds based on a study performed on 13 participants (nine male and four female aged 19-50, Ø 25:54) using a '3DVisor Z800' HMD, running a $800x600$ resolution at $60Hz$ with 40 degrees diagonal field of view (FoV). Steinicke et al. [2010] tested three methods for redirected walking; Translation gain, Rotation gain and Curvature gain). Based on their study they found the following thresholds for the three methods.

$$-14\% >= \text{Translation gain } (g_t) >= 26\%$$
$$-20\% >= \text{Rotation gain } (g_r) >= 49\%$$
$$\text{Curvature gain } (g_c) \text{ minimum circular radius } 22m$$

Neth et al. [2012] states that you can reduce the minimum radius if the participants are walking at a slower speed (sounds like a combination of curvature and translation gain/decrease) the study was performed on 12 participants walking at three different speeds with the following Translation gains: 0.75, 1.0 and 1.25. The paper found that using a reduced walking speed the radius of the circle could be reduced to 10 meters Neth et al. [2012] and with an increased walking speed the circle radius for unnoticed curvature gain was found to be 27 meters (which is larger than the thresholds found by Steinicke et al. [2010]). Neth et al. [2012] also looked into if using avatars as distractors and as a method to influence the participant's walking speed where they, with the use of static gain found a radius of 15 meters to provide unnoticed repositioning for curvature gain.

Most of the experiments using Curvature gain uses a straight path, however this might not be the optimal usage of the walking method. Suma et al. [2012b] performed a study with two focuses, impossible architecture and curvature gain but instead of using a straight path as seen by Steinicke et al. [2010] they used an S curved path. This effect was used on users novice to the manipulation. The test was setup as a think out loud test and the participants were told to comment on anything they found to be unnatural. Curvature gain was set to redirect the users by a dynamic curvature gain with an average of 22.52° pr. meter, where Steinicke et al. [2010] resulted in a rotation of 13° pr. 5 meter (or 2.6° pr meter). Seven of the 14 participants noticed a manipulation of their movement, so if the intention is to make this value unnoticed for all participants the gain value should be lowered and possibly set closer to the one used by Steinicke et al. [2010]. However, it should be noticed that they reduced the physical space needed from a VE of 22 x 44 meter to a Physical Environment of 9 x 9 meter.

2.2 Distractors

Distractors are often used as a last resort to stop the users before leaving the physical space. Peck et al. [2009] tested several methods of using distractors over the course of three studies. The first study investigated four different methods of using distractors; *"Turn without instructions"*, *"Turn with audio instructions"*, *"Head turn with audio instructions"* and *"Head turn with a Visual distractor"*. The visual distractor for the first test was a large red ball moving on a horizontal arc until the VE had turned 180°. The participant then had to reorientate him/her self 180° before continuing. The study was performed on 24 participants that where asked to walk down a 200m path, with a stop for every 5 meter. During the stop the participant were then exposed to one of the four methods for distractors. Their results suggested to continue with the head turning methods. Several of their participants stated that they found the big red ball unnatural and that it broke their sense of being in the environment. For the second study, based on the feedback from the first study; Peck et al. [2009] added a new type of distractor based on the feedback regarding the naturalness of a big red ball. They created a visual distractor that fitted the environment. The new distractor design was of a butterfly flying in to the scene and out when the user had been redirected implemented with the same values and speeds as the red ball. Peck et al. [2009] found that, of the new methods the butterfly distractor was an improvement, for the naturalness and sense of presence. Some of their participants had mentioned that the sound and flapping of the butterfly wings were annoying. Peck et al. [2009]'s third study replaced the model of a butterfly with a high detailed improved model of a hummingbird. This experiment then investigated three different versions with the new model and matching sound. The three methods used for this experiment was; *Distractor visual*, *Distractor audio & visual* and *Distractor audio* only. The study was performed on 12 participants, all naive to the purpose of the study as as was the case with the previous studies. Peck et al. [2009] found that a visual distractor produced a better sence of presence to an audio only distractor, but found a significant difference between the visual only and the audio-visual distractor in the sense of naturalness or presence. The participants stated that they preferred the audio-visual distractor.

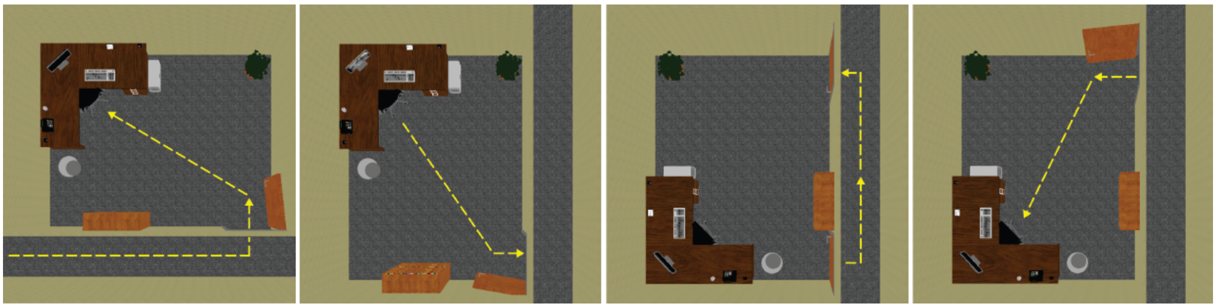


Figure 2.4: Change blindness experiment setup the figure is showing the 90° rotation of the door to the adjacent wall [Suma et al., 2011]

2.3 Architectural Manipulation

Two of the interesting methods for architectural illusions are change blindness and impossible spaces. In the case of change blindness one utilizes small changes to the environment that most users would not notice, and unlike other redirection techniques change blindness does not introduce any visual-vestibular conflicts from the manipulation between physical and virtual motions, as the change is only applied to the virtual architecture. Suma et al. [2011] tested this technique on 77 participants over two studies, only one of these 77 participants noticed the change (see figure 2.4). While this is an amazing find it requires a lot of the level designer to allow for such an architectural manipulation, to dynamically change the architecture on the fly and an AI to determine when it is beneficial to utilize. Change blindness would be a strong tool for indoor scenarios with a lot of small spaces, where it would suffer at larger spaces because it's only changing the architecture and not manipulating the user's transformation.

Suma et al. [2012b] presented a method of architecture that is bigger on the inside, motivated by the users spacial awareness in virtual environments. They showed that the spaces could overlap with up to 56% for small spaces and 31% for a space of 9.14m x 9.14m. The test was performed on 17 participants all primed of the manipulations they would be experiencing. Suma et al. [2012b] did an additional study where the users were novice to the manipulation where 12 of the 14 participants were unable to notice the manipulation, in a think out loud test. The 12 participants admitted that they did not notice the manipulation of the overlapping spaces after they were informed about it. The two that noticed the manipulation, explained that the rooms size would not be possible with the first room located next to it. Suma et al. [2012b] suggest that the effect of overlapping spaces would have a more compelling effect for users that are unaware of the manipulation.

2.4 Walking in place

There are three commonly used methods for walking in place Marching, Tapping and Wiping. Nilsson et al. [2013] investigated the difference and advantages between these three methods of walking in place. Trackers were placed on the angles of the user to calculate the direct movement of the feet. Marching is when the user lifts his knees up while walking. Wiping is when the user moves his feet backwards to simulate walking. Tapping is when the user keeps the toes on the floor at all times while only lifting the heels continuously. Nilson et at. 2013 found no significant difference in presence between the three techniques. Tapping was found to be the most natural technique with a significant difference compared to Wiping. Regarding strain, Tapping was also found to be significantly less strenuous compared to Marching and Wiping and produced the lowest amount of positional drift from the center. However, Marching compared to the Tapping method, allows the users to lift their feet while walking, and the action may become more natural when the user can lift his feet. Wiping generally received the lowest score for naturalness and the highest score for fatigue [Nilsson et al., 2013].

2.5 Low Friction Walking

Low friction walking is a lot like walking in place, using a slippery surface and utilizing it's low friction for the user to slide in pleace as a method for walking. Two of the devices used for this method is the 'WizDish' [Wizdish Ltd., 2014] and the 'Virtuix Omni' [Virtuix, 2014]. In a previous project (spring semester 2013) at Aalborg University Copenhagen my semester group tested the naturalness of sliding on the 'WizDish' compared to Marching, as a walking-in-place method. It was concluded that neither of the two methods felt natural to our users and several of the users had problems keeping their balance, while using the 'WizDish' was uncomfortable. The Virtuix Omni is using some of the same techniques but is also equipped with a support ring to help users keep their balance while walking, which would have been an improvement to the WizDish. The Virtuix Omni is designed for home usage, and is still in development and will not be shipped until later this summer (2014). According to the Virtuix Omni videos and website the users are allowed to lift their feet while walking, where on the WizDish the user was to slide his/her feet back and fourth without lifting the feet [Toft et al., 2013].

2.6 Other Alternatives

Bruder et al. [2012] presents an alternative for moving over long distances by testing walking vs. driving in VEs, providing an interesting point for movement over large distances using alternatives to walking. Using an automatic wheelchair with a joystick control, a more physical interaction could be preferable as this would closely relate to traditional joystick or controller-based movement, known from more traditional computer games. A more physical interaction could provide the user with a better sense of movement perhaps by using a non-automatic wheelchair possibly with dynamic resistance on the wheel movement.

2.7 Presence for virtual environments

Suma et al. [2012a] looked at a taxonomy of redirection techniques for VR to determine the thresholds for unnoticed manipulation as it resulted in a low BIP. Therefore, if a technique should be found to increase these thresholds it would be beneficial to find a method that already improved or aided the feeling of presence in VEs. Haringer and Beckhaus [2012] found that weather conditions showed an indication for an increased sense of presence found for their participants. Haringer and Beckhaus [2012] also found that using weather conditions helped relax stressful users in training situations or give bored users a more challenging experiences and states *"..., we want to open up the field of emotionally enhanced VEs or emotional VEs."[Haringer and Beckhaus, 2012]*. Haringer and Beckhaus [2012] presented a new method for creating means of expression used to generate mood and emotion in the user. They mention that nature have an emotional impact on all of us, good or bad, and that weather conditions are partly responsible for. This way, natural phenomena such as time of day, seasons and weather conditions have a rather predictable influence on our mood [Haringer and Beckhaus, 2012]. The application was tested on 30 participants (12 females and 18 males) thirty means of expression were used in the test including different weather conditions (sunny, cloudy, fog, thunderstorm, winter, sunset and night environments) [Haringer and Beckhaus, 2012]. Their application of means of expression was evaluated consistently for 70% of all the test participants and statistically, three of four means of expressions could stimulate the intended emotion [Haringer and Beckhaus, 2012]. The participants were mounted with physiological measurements recording skin conductivity, breathing and heart rate.

Chapter 3

Problem Definition

There has already been put a lot of effort in the field of Redirected Walking for VR. Though I have found that there are several of these methods that only seem to work in indoor environments, e.g the architectural manipulations and I have yet to find research using elements like weather effects to impact redirection techniques. The reason I chose to focus on outdoor scenery is; indoor scenes are often limited in size with corridors and turns. A house/building can often be designed to be optimized for using the three redirection methods combined with levitating doors and impossible spaces, traversing indoor environments already has an extensive set of tools, where outdoor environments has some difficulty utilizing some of the architectural techniques. So what I wish to do is see if weather conditions can affect the already found values of redirection gains found in previous research. I have chosen to focus on Rotational redirection for two reasons; first, if this technique works for rotational redirection and can increase the existing threshold values for unnoticed rotation gain, and secondly as the lab at our disposal is of a limited size and do not provide the space needed to test translational or curvature gain. Based on this the focus of this thesis is;

How is Rotation gains for redirection affected by the use of
particle based weather conditions, creating an element of optical flow?

Chapter 4

Analysis

Based on the problem posed in this project looking on redirection, the previous work in this field, the naturalness of the walking method and other advantages with real or natural walking techniques, this chapter will look into some of the benefits and definitions of naturalness and presence together with the possibility of using particles for the implementation purpose of creating the effect of weather conditions.

4.1 Naturalness

Mapping natural human actions to VR is translating the physical actions from an interactive controller to the VR. For Redirection, the users' own natural proprioceptive movement is mapped to the VR with the added gain. Skalski et al. [2011] created four methods of natural mapping that increases naturalness:

- Directional natural mapping is a correspondence between the directionality of the controller (e.g. a joystick) and the VR.
- Kinesic natural mapping is a correspondence between the users real-life body movements and actions that do not require a physical controller (e.g. the Air Guitar game).
- Incomplete tangible natural mapping is replicating user's real-life actions by using a tangible controller (e.g. PlayStation Move controller or Wii controller).
- Realistic tangible natural mapping is replicating users real-life actions by using a realistic tangible controller (e.g. a gun or steering wheel).

Redirection is a kinesic methods utilizing the users own body as a controller with a one to one mapping. On top of that there is the added gains. According to Skalski et al. [2011], players could more easily access mental models of real human behavior using naturally mapped controllers if the mental models are present for the player. The mental models are human tools which forms the understanding of how to interact with the VE through a natural mapped interaction. The more natural an action is to execute it, the faster a player will understand how to interact in the VE.
Steinicke et al. [2010] also write that *"Traveling through immersive virtual environments by means of real walking is an important activity to increase naturalness of virtual reality (VR)-based interaction."* combined with **?** stating that naturalness affects spatial presence, i.e. *"The feeling of being in the environment"*, essentially being transported to another place [Lombard and Ditton, 1997, Steuer, 1992] makes finding the thresholds for when this sense of being redirected is perceived by the user essential for designing VE and interaction that has a higher chance of providing the sense of presence for users.

4.2 Presence

Several articles emphasize that a matching proprioceptive movement to the virtual movement provides a higher sensation of presence when experiencing a VE [Engel et al., 2008, Feasel et al., 2008, Field and Vamplew, 2004, Nilsson et al., 2013, Whitton et al., 2005]. Therefore it make sense to include presence when trying to determine naturalness of a walking method. Presence has been subject to several different definitions but most consider it a "state of being there" [Sas and O'Hare, 2003]. According to Lombard and Ditton [1997] presence is a state of mind, and therefore something personal, it is not one sided, and can be caused from different stimuli, which in turn suggest that there are different kinds of presence.

Lombard and Ditton [1997] talk about "presence as immersion", which can be divided into two types of immersion: Perceptual immersion and psychological immersion. Perceptual immersion; is immersion of the senses defined by how many of the human senses the system is 'locking out' of the person's natural senses. For example, the HMD replaces the visuals of the real world with the virtual world, and thereby adds visual perceptual immersion. Psychological immersion is defined by the user being *"[...] involved, absorbed, engaged, engrossed"*[Brown and Cairns, 2004]. The first faces of immersion is according to Brown and Cairns [2004] explained by engagement and engrossment. This is when a user accepts the interaction and starts to lose the sense of time and surroundings no longer matter. Psychological immersion can happen when the senses are not blocked but the user does not perceive the work around him/her e.g. while reading a book.

There have been issues measuring presence and according to Youngblut and Huie [2003] who used the SUS questionnaire, writes that it is difficult to find factors that indicate a strong effect on presence. Slater, Usoh and Steed who made the SUS questionnaire used a VAS scale (from 1 to 7) and validated the questionnaire by testing a a VE against a PE. However, it was stated that it seemed strange that participants could answer less than 7 in the sense of being there; for a participant who was physically in the environment. Usoh et al. [2000] ends up by showing a small significant difference between the physical environment and the VE as expected [Usoh et al., 2000]. As mentioned in chapter 2.7, Haringer and Beckhaus [2012] found a tendency of improvement for presence when using weather effects more specificly using fog, snow and rain. Their participants showed an increase in valance, arousal and dominance for all participants, all related to do with emotional responses thereby suggesting a higher sense of being in the environment or presence.

4.3 Particles

According to Puig-Centelles et al. [2009], to create the sensation of a particle based weather condition, like rain or snow, there are a couple of options. First, one could produce a small particle field around the users visuals and use wind direction to simulate the movement of the given weather effect, but this method would produce an visual noticeable inconsistency in the continuous movement of the particles when the particles are re-spawned. According to Luna [2013]; to create a more realistic weather condition like snow one would need a larger field to influence the movement of the particles or snow grains to move in a realistic pattern. This would then also require a higher number of particles to fill this space. In order to produce a high number of particles and maintaining a high frame rate for the system, it would be an advantage to implement the particles calculated using the Graphical Processing Unit (GPU)[Luna, 2013]. This way one could implement a million particles to run at a frame rate of 60 fps and thereby create a realistic sensation of the snow movement. As Unity 3D supports DirectX11 shader programming [Unity3D, 2014] it could produce one million particles to be rendered in real time [Luna, 2013], this would most likely be the best approach to generating the particle based weather effect.

4.4 Delimitation & Focus

The focus for the testing of this theory will for this project be focused on the possible expansion of the threshold values as a way to improve the implementation of free movement for larger VEs in smaller physical spaces.

This project will focus on snow as the implemented weather condition for the initial test, as snow has a more visual impact compared to rain and by the assumption that fast moving particles causes a distraction that could impact the perception of the users movement speed while rotating.

Chapter 5

Method/Approach

The theory is based on the fact that the human perceptual system has some static in the perceived movement resulting in complications determining precise movement when the visual feedback sends other information, making determining how much we actually have moved while rotating harder. As our eyes detect changes in light and the snow will flicker before the user's eyes creating additional movement in the environment the effect of the Rotation gain might be less notable. So if the particles moving in the scene, either with or against the user's movement (the snow is moving at an almost horizontal angle), will this added effect of moving particles change the perception of the users rotation speed? According to Peck et al. [2009], while using moving distractors fitting the environment their users had a harder time noticing the redirection at two times the movement speed (about twice the effect that was found by Steinicke et al. [2010]).

Before defining the final test setup, lets look at the setup used by Steinicke et al. [2010] and their way of measuring step size and the thresholds they move between. Steinicke et al. [2010] found the following threshold for redirected rotation, they tested from 0.5 to 1.5 as gain values using a step size of 0.1 and found the threshold for Rotation gains to be

$$0.80 >= \text{Rotation gain } (g_r) >= 1.49$$

But when testing the Rotation gain values between 0.5 and 1.5 using a step size of 0.1 the value of 1.49 would not have been tested but would be an estimated value given from the average of recolonized values between the two segments. Not to mention this value is only 0.01 from the highest tested gain value, therefore it would only be logical to redo the test wiht a larger span and a smaller increment between the gain values.

Evaluating the thresholds of rotation gain with the user knowing about the effect versus being naive to the purpose of the test. Suma et al. [2012b] found that they could expand on the thresholds of overlapping spaces when users were novice to the experiment. As mentioned in section 2, when using curvature gain on a S curved path again with users novice to the manipulation the users ended walking in an 8 shape with a smaller radius than Steinicke et al. [2010] found.

Though there are data that provide bases for the point that while users are novice to the purpose of the experiment there is still reason to test the thresholds for users that are primed for the manipulation to find the minimal threshold of unnoticed Rotation gain.

Chapter 6

Implementation

6.1 Environment

The environment was designed as a simple scene where the user would be surrounded by trees with variations in height, placement, with fallen trees, hills to create variations in the landscape and a hole in the ice a little away (see Figure 6.1). The variation in the background is kept realistic and simple while keeping noticeable variations for the user to notice their rotation, to reduce the chance that a too simple background would cause a higher difficulty in recognizing the rotational manipulation and keep the environment as a close to something that could be used in games or virtual explorations.

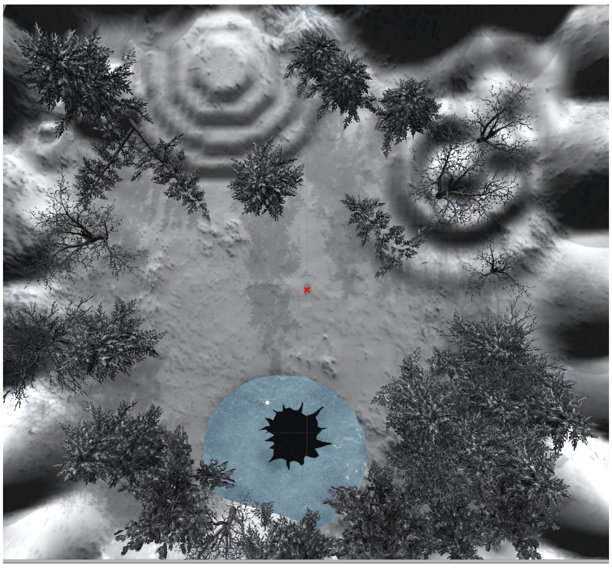


Figure 6.1: An overview of the Environment

The environment was modeled in Autodesk Maya as unity3D's terrain editor has some limitations regarding differencing the specular of the different textures, which would reduce the effects of the ice and snow on the ground. This way the environment could easily be manipulated and optimized to the scene and instead of calculating with a complex mesh for colliders with the trackers, the space was fixed so the only places the participant could reach before being stopped would be a flat plane. The trees are standard unity assets and the water in the hole of the ice was a unity pro water asset.

6.2 Particles

The particle effect is made out of four essential components

- A modified shader *"GPU Particle.shader"*
- A script to calculate the particles and communicate with unity *"GPUParticles.cs"*
  - A script showing these calculations to cameras *"GPUParticlesCam2.cs"*
- A compute shader script to apply and handle the particles *"UpdateParticles.compute"*
  - A script handling the movement *"noice.hlsl"*
- The materials

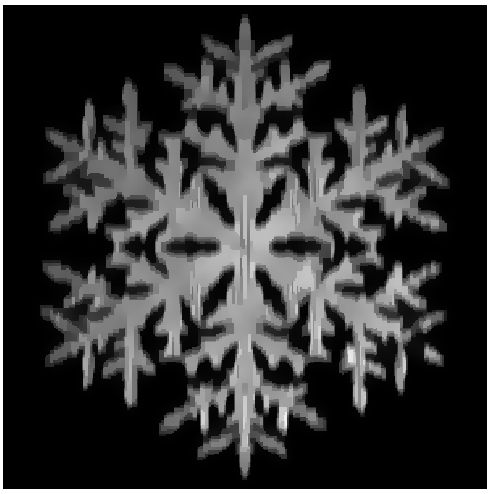


Figure 6.2: The snowflake texture.

The particle size is varied randomly up to one fifteenth of the given shader's scale value, this effect provides some variations and give the effect to the snowflakes that help make them more individual and realistic.

The particle effects were GPU programmed as a prove of concept, to show that these effects can now be used as area effects and can use a million particles on a standard laptop computer with access to DirectX11, while not limited small particle emitters with a small area of effects.
This makes it possible to make individual areas with the effect which the user can walk into an area of effects, with little cost to the frame rate. Where the old CPU generated particles cost easily could be seen to reduce the frame rate. This way of calculating the particles is a post rendering effect and because it works as a post rendering effect, has little cost to the performance.

To make sure that the application can be used on different levels of computational power, I made a spread area (a bounding box) to define an area where the particles will be generated. I also made the spread area and number of particles easily adjustable so it can be controlled from Unity3D's inspector and altered dependent on the environmental situation and the computational power.
I had two additional reasons to make the spread area. First to make alterations in the density of the snow particles when working on a slower computer where it wouldn't be possible to increase the number of particles due to the computational limitation. Secondly, to be able to fit the snow area around an

object so the player can walk into an area with snow. The snow is programmed to follow and surround a game object in the scene, in this case it follows the player object but could be centered around any static or moving object in the scene. Currently the spread area is controlled by a conditional check (an *if* statement) which one should try to avoid when working on the GPU, though with the [flatten] modifier this conditional statement is less of a bottleneck (as the GPU isn't optimized for conditional statements), and the centered position is sent for each frame. One small optimization could be to only send the change in position, as one of the most common delays and pitfalls in GPU programming is communication between the CPU and the GPU [Luna, 2013].

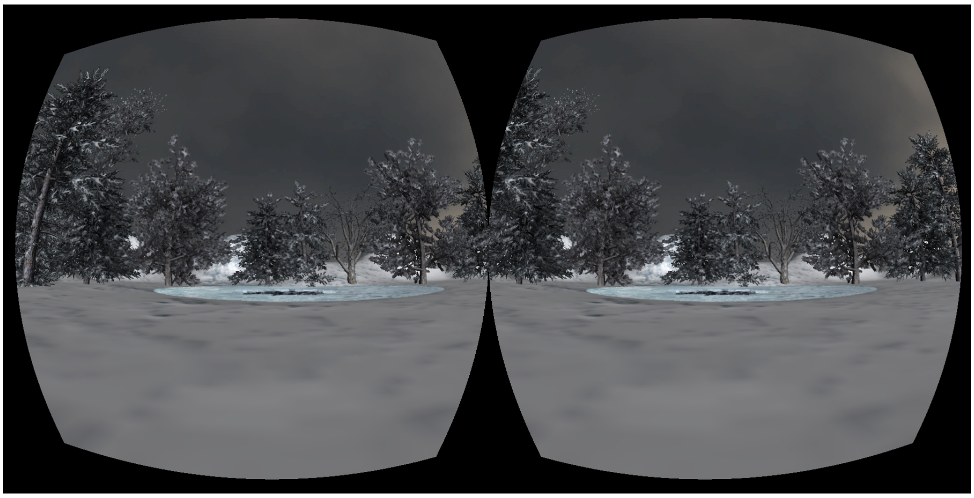


Figure 6.3: Environment without snow (*no* particles)

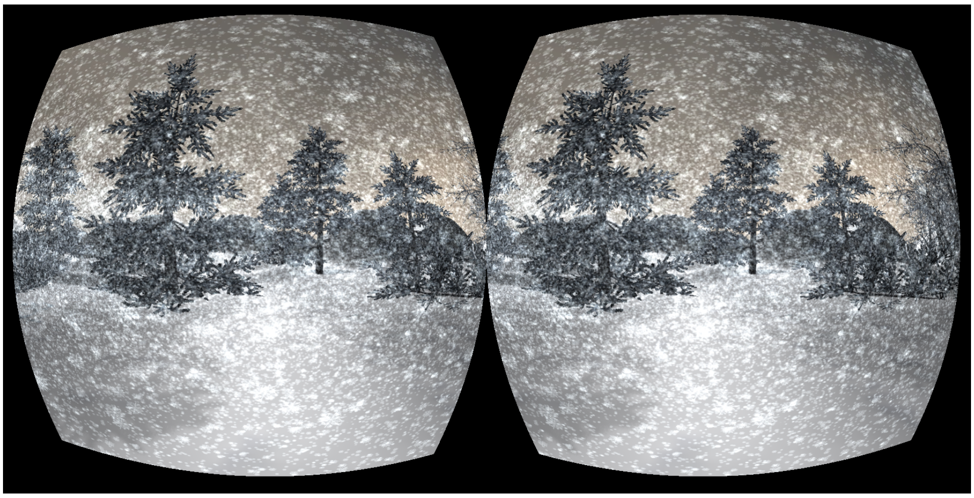


Figure 6.4: Environment with snow, *1.000.000* particles 50x15x50 spread area

The snow movement is generated from a High Level Shading Language (HLSL) script. I have added some turbulence as snow often dances in the air, with this addition the snow seam more natural. The script is generating a curling noise to give the turbulence sensation you find with falling snow. The y-axis has been scaled so it has almost no influence on the movement to make the direction on the y-axis towards the ground *(see the script below)*. In the script controlling the compute shader (a new feature in Unity3D and in DirectX11) the particles are given a gravitational force fitting the type of distribution.

Snow movement *"noise.hlsl"*

```
//Snow movement
float3 curlNoise3f(float3 p){
  float e = 0.1;
  float3 dx = float3(e, 0, 0);
  float3 dy = float3(0, e, 0);
  float3 dz = float3(0, 0, e);
  float3 r;
  r.x = (noise3f(p + dy).z - noise3f(p - dy).z) -
    (noise3f(p + dz).y - noise3f(p - dz).y) * 0.000001;

  r.y = (noise3f(p + dz).x - noise3f(p - dz).x) -
    (noise3f(p + dx).z - noise3f(p - dx).z) * 0.000000001;

  r.z = (noise3f(p + dx).y - noise3f(p - dx).y) -
    (noise3f(p + dy).x - noise3f(p - dy).x) * 0.000001;

  return r / (2.0*e);
}
```

The curlNoise3f function is then utilized together with additional noise factors and multiplied with delta time to keep the speed stable and independent of variations in the frame rate. The speed is added a downwards directed force to simulate gravity and keep the snow falling down.

```
//Containing the snow within a bounding box
UpdateParticles.compute
  vel.xyz += curlNoise3f(pos.xyz*noiseFreq)*noiseAmp*dt;
  pos.y += -0.5*dt;

  halfSpreadArea = spreadArea/2;
  [flatten]if (pos.x > spreadArea+objPos.x ||
    pos.x < objPos.x-spreadArea){ pos.x =
      (frand(spreadArea)-halfSpreadArea) + objPos.x; vel.xyz = 0; }

  [flatten]if (pos.y > 15 + objPos.y ||
    pos.y < -0.5){ pos.y=6+(frand(dt*100)); vel.xyz = -0.03;}

  [flatten]if (pos.z > spreadArea+objPos.z ||
    pos.z < objPos.z-spreadArea){ pos.z =
      (frand(spreadArea)-halfSpreadArea) + objPos.z; vel.xyz = 0;}
```

This implementation of the prototype is made to generate the particles on the GPU, using a *Compute Shader*, making a *static* buffer for the position and velocity for the particles. The buffers are then shared between the cameras (in case of multiple cameras e.g. for VR applications) and because the particles are calculated as a position in space, instead of a position of the camera image, the position of each particle is then the same independent of where the camera is placed. The advantage of this is that when rendering the view of the two cameras on a Head Mounted Display (HMD), the offset of the individual camera gives the correct stereoscopic view of the individual particle (so it fits the position of each eye) and the vector buffer makes the motion of the particles fluent and natural (all code can be found on the accompanying CD in the folder *"Implementation/Code"*).

To make sure that the order of the trials were not influencing the results the trials were randomized by shuffling the list 90,0000 times. This assures that the order of the individual trials were always truly random.

Experiment manager

```
for (float gain = minGain; gain < maxGain; gain += stepSize){
  for (int snow = SNOW_FLEE; snow <= SNOW_NONE; snow++){
    for (int repititions = 0; repititions < 2; repititions++){
      gain = (Mathf.Round(gain*100.0f))*0.01f;
      trials.Add(new Trial(DIRECTION_LEFT, snow, gain));
      trials.Add(new Trial(DIRECTION_RIGHT, snow, gain));
    }
  }
}
shuffle();

...

void shuffle(){
  object temp;
  int index1, index2;
  for(int i=0; i < 90000; i++){
    index1 = Random.Range(0, trials.Count-1);
        index2 = Random.Range(0, trials.Count-1);
    temp = trials[index1];
        trials[index1] = trials[index2];
        trials[index2] = temp;
  }
}
```

6.2.1 Data logging

There are three different sources of feedback for this study (see Experiment setup): Two questionnaires and the feedback given doing the test. To ensure that the userøs feedback is logged instantly as the participant experiences a gain value and to log the forced feedback mentioned in the method chapter *(See chapter 5)* two keys were mapped to the two options; page up for increased rotation speed and page down for decreased movement speed. the experimenter then pressed the button and the system then wrote the trial number, gain value, trial condition, direction, the response and the time the given trial took (trial time). All this was done in the load time between trials.

```
void stopTrial(int response){
  currentState = STATE_WAITING;
  trialStopTime = Time.timeSinceLevelLoad;
  target.renderer.enabled = false;
  arrow.renderer.enabled = false;

  redirectionController.rotationGain = 1.0f;
  float trialTime = trialStopTime - trialStartTime;
```

```
    Trial trial = (Trial)trials[currentTrial];
    if(!Settings.training){
        float tempGain = Mathf.Round(trial.gain * 100.0f) * 0.01f;
        logFile.WriteLine(currentTrial + "\t " + tempGain + "\t " +
            trial.snowCondition + "\t " + trial.direction + "\t " +
            response + "\t " + trialTime);
    }
}
```

Resulting in a feedback that looks like this,

Trial#	Gain	Condition	Direction	Response	Time
0	1.5	2	-1	1	8.583551

The example is taken from user1

The reason for using the Oculus Rift Development Kit 1, was its availability and that a limited FoW has previously provided a perception of walking slower for translation. If the hypothesis is correct for this project it would be prudent also to test if this effect would be beneficial to the other two commonly used methods for redirection; Rotation and Curvature gain. to utilize the the Oculus Rift their SDK version 0.2.5 downloaded from the Oculus Developer center (the SDK can be found here: "https://developer.oculusvr.com/?action=dl&v=8") was used. But instead of using the Oculus Rift gyroscope and accelerometer trackers it was chosen to use an OptiTrack system, as the positional tracking would be an improvement, because the exact position in the physical space would be mapped directly to the Virtual space. To assure the tracking data from the Oculus Rift HMD was not used the SDK was modified by removing all methods of their tracking data and implemented our own tracking script (the modified SDK and the rest of the implementation can be found on the DVD attached to this project).

Chapter 7

Experiment setup

The test was performed with user self reporting during the test using a two options forced choice recording of each trial. The user gives feedback to whether the conditions movement were smaller or greater than the physical movement? Each gain value was run twice for all three conditions in a randomized order to reduce randomness influencing the results. This method was selected to be able to compare the results with previous work in redirection techniques.

This experiment was made using a NaturalPoint OptiTrack system with 11 cameras and an Oculus Rift Developer's Kit 1. There was some concerns using the Oculus Rift Developers kit 1, because of its screen door effect and some motion blur given the quality of the screen and its pixel release time. Even though this could be an issue the display still have a decent resolution and a diagonal field of view of 110 degrees [OculusVR, 2014]. Figure 7.1 and 7.4 demonstrates the setup of the study.

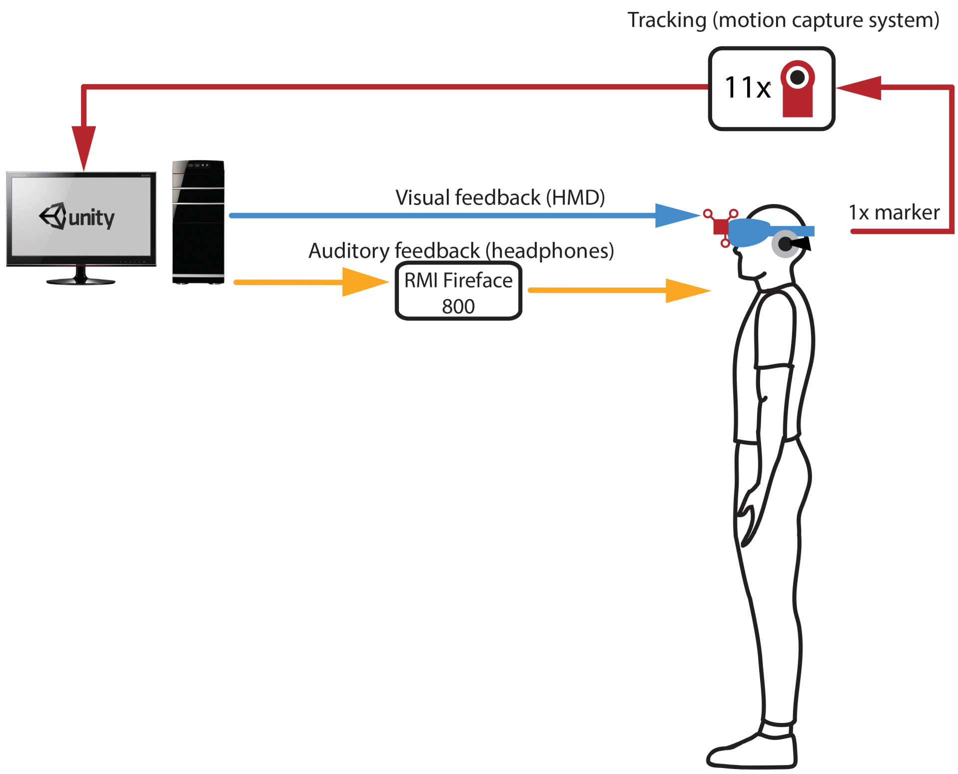


Figure 7.1: Equipment overview and usage.

Each gain was to be tested two times for both rotating left and right for each condition. This study looks at three conditions:
NoSnow: The base condition without any snow.
SnowFlee: Snow flying from a fixed angle of 90° from the user "fleeing as he/she rotates"
SnowFollow: Snow flying from a fixed angle of 90° from the user, following his/her rotation.
See Figure 7.2 for more details.

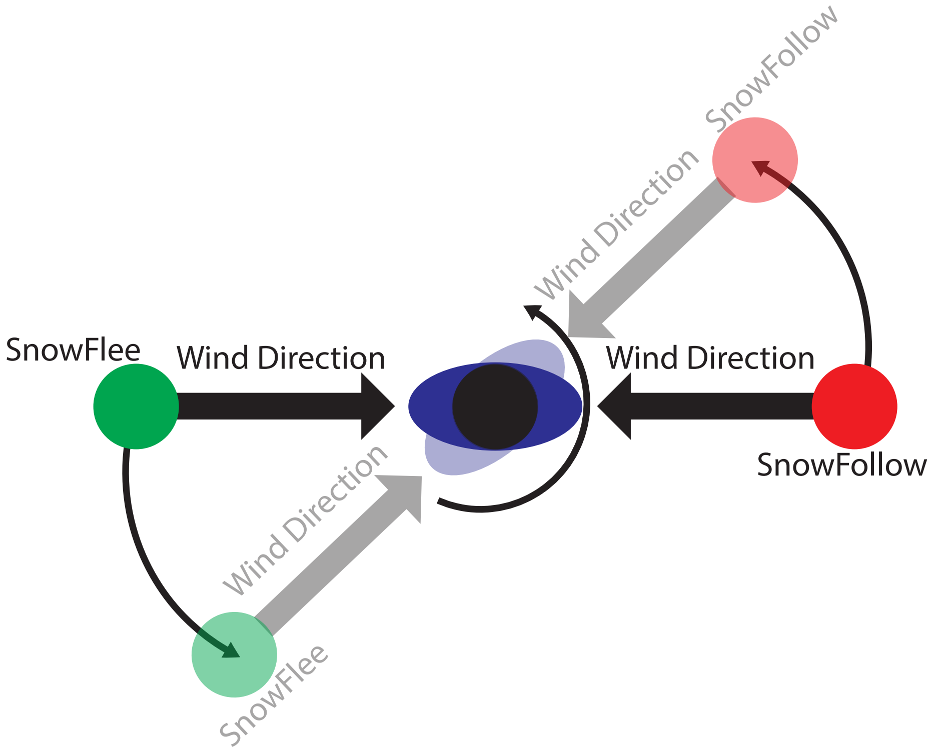


Figure 7.2: Displaying the mechanics of the two snow conditions.

7.1 Gain values

Initial considerations for this study were to test for the same thresholds found by Steinicke et al. [2010], however as the objective of this project is to find a method that can increase the threshold values for Rotation gain. Steinicke et al. [2010] found their threshold so close to their upper testing value, therefore it would be an intensive to test for higher gain values. Also based on the moving animated distractors from Peck et al. [2009], who is stateing that they could rotate their users with twice the rotational speed (a Rotation gain of 2.0) without the user noticing the Rotation gain, where Steinicke et al. [2010] found it to be a max of 1.49, but as we are to test both reduced and increased rotational speeds it might be and wise to investigate a value that is found between these two studies. Most of the studies from the background work (Chapter 2) and one test carried out in our own lab. Were asking the participants to rotate 90 degrees, and as a test participant in said test I quickly found a way, to make sure I always rotated close to the 90 degrees, by angling my foot out what felt like 90 degrees and turning. As an attempt to avoid this, the degree of rotation will be increased as a redirection might give the user too little time to notice any rotation and this way give a closer to free rotation, it was speculated that the stop marker should have a variation for the rotational angle randomly but out of concerns of this variation might increase the chance of the user feeling a slower rotational speed because the angle to the stop marker has increased.

If this study were to test the within the same values, as Steinicke et al. [2010] used for their test, g_c values from 0.5 to 1.5. Step size 0.1 giving 120 trials. A consideration could be to use a step size of 0.05 instead giving 252 trials.

Taking into consideration that an angle of 90 is a movement many people could be accustomed to for everyday walking, an angle 135 degrees was determined. Instead of the 90 degree used by Steinicke et al. [2010]. Because of the concern that the participants could rotated their feet first as a way to cheat the test. There were two solutions in mind to solve this problem 1^{th} solution, alter the fixed angle to a more uncommon angle e.g. 135 degrees, or 2^{nd} solution were to alternate between several fixed angles e.g. three sets of angles 90. 135 and 180 degrees. As a way to reduce the required number of trials needed per participant. A fixed angle of 135 degrees were chosen for the rotations for two reasons, 1^{th}; to reduce the number of trials and thereby fatigue for the participants, and 2^{nd}; to reduce possible issues occurred by users evaluate the physical rotation without knowing who much the user should be rotating this should not prove to be as big of an issue for a fixed rotation.

Starting to look at different border values for the test setup a high number of trials were found e.g. a threshold from 0.7 to 1.6. This is 0.11 further than what Steinicke et al. [2010] provided as unnoticeable gain values with half the there was used in the original experiment giving a step size of 0.05 resulting in 228 trials, or a threshold between 0.5 and 2.0 with a step size of 0.1 resulting in 180 trials. Given considerations of fatigue for the participants a maximum were set to approximately 150 trials. With this guideline of trials the following border values were under consideration

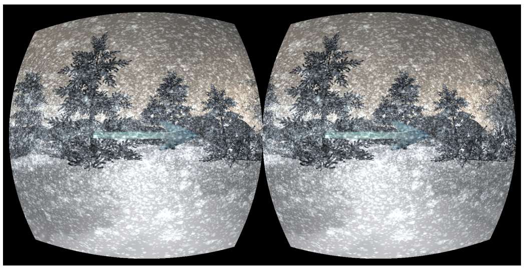
0.7 - 1.6 step 0.1 = 120 trials
0.6 - 1.7 step 0.1 = 144 trials
0.6 - 1.8 step 0.1 = 156 trials
0.7 - 1.9 step 0.1 = 156 trials

The threshold between 0.6 and 1.7 with a step size of 0.1 was chosen resulting in 144 trials. As an extra measure to reduce simulator sickness during the test, two forced breaks were implemented, the first after 50 trials and the second after 100 trials. The scheduled breaks was set to approximately 2 minutes. In case a participant felt dizzy or nauseous they could take a break or stop the test at any time. Due to this consideration while finding participants there there recommended that people with strong tendencies of motion sickness should not apply for the experiment.

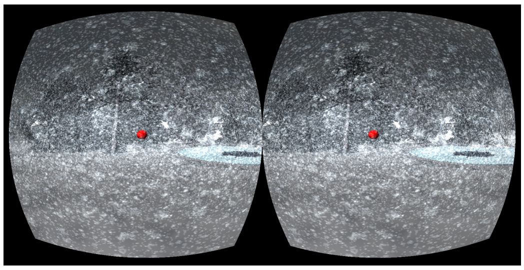
7.2 The test instruction

The participant was informed that they were to stand in the middle of the tracking stage, wearing an Oculus Rift Developers Kit 1, An arrow appeared (see Figure 7.3a) and the participant was instructed to turn in that direction until they saw a red ball (see Figure 7.3b). The participants were informed that the study consisted of 144 trials with two breaks, one after 50 trials and another after 100, and that if they at any point if needed could take a break or stop the test completely at any time. The test was scheduled to take approximately one hour based on a small pretest performed on people affiliated with the Lab. As a reward the participants were offered soda and treats after the study. This means that all participants were primed for the test and were told that they always had to choose either faster or slower, regarding their perception of the current rotational speed. The participants started by filling out the SSQ before starting the experiment, the experiment took approximately 30 minutes including the two short breaks.

After the experiment the participant filled out the SSQ again, to measure possible change in motion sickness and then the Feedback and Demographics Questionnaire. The entire study took approximately



(a) The arrow pointing in the direction the user should turn (snow condition).



(b) The red ball indicating that the user should stop his/her rotation, and report if the movement felt faster or slower compared to a normal rotation (snow condition).

Figure 7.3: Displaying the two visual guides used in the test, the direction of turning and the stopping point.

45 minutes giving air for aditional breaks and time to answer any questions the participants might have after completion of the test. Figure 7.4 shows the setup used while one of the participants is performing the test.

7.3 Questionnaire design

For this study two questionnaires have been used, the Simulator Sickness Questionnaire (SSQ) and a specific questionnaire designed to gather feedback regarding the experience and demographic data in case of outliers in the data that potentially could be prone to a select group.

The SSQ, designed by Kennedy et al. [1993], was used to determine whether the experiment and the particle based weather effect have a negative effect on the participants and provide a higher sense of motion sickness. As mentioned in the implementation section the Oculus Rift Developers Kit 1, may have an effect on Simulator Sickness, and the fact that the participant are rotating 144 times could also increase the sense of simulator sickness. Based on these conserns the results of the SSQ should increase to a general discomfort for the participant before excluding this effect from future studies.

The Feedback and Demographics Questionnaire was designed to directly gather feedback regarding the experience of the particle effect, environment as a subjective feedback to support or elaborate the data gathered during the test itself. The following section will expand on some of the questions posed in the questionnaire, for a complete version of the two questionnaires can be found in Appendix A.

7.3.1 Feedback and Demographics Questionnaire

Participant number: (Filled by the experimenter, to link the participant to the data gathered during the experiment)

What methods did you use to figure out whether a virtual rotation was smaller or larger than the rotation of your physical body?
Text response to determine whether the participants used their intuition, number of steps or other methods of determining the rotation speed.

Please compare the difficulty of the task when having the snow effect compared to no snow
the participants were to indicate their answer on a 7 point vas scale

Figure 7.4: The figure depicts a test participant during the experiment.

Please describe how you felt when the snow rotated around you. If you didn't notice this, please say so. text to determine how the participants perceived the snow for a more subjective take on the method

The task of determining if your rotation was faster or slower were easier when? The response if give as a multiple choice with the following four options: *"It was easier when it flew in the same direction as my rotation"*, *"It was easier when the snow flew against my rotation"*, *"The snows direction didn't affect the difficulty of the task"* and *"I didn't notice the snows direction change"*

Was there anything that contributed to or took away from your experience of the virtual world? If so, please describe them.
Text response, to get feedback regarding the participants sense of the environment and the effect, and to determine if any possible issues would be the result of the VE, particles or equipment.

Do you have any suggestions for improvement or anything else you'd like to tell?
Text response for general feedback.

The following questions are to determine the demographics of the participants in case some element would affect the data. Questions about age, gender, ethnicity, educational background and occupation is only to determine what kind of sample group the data would represent and to exclude or provide evidence of its effect on a specific groups perception of redirectional gain.
The following questions are to determine the participants experience playing video games and especially in 3D environments these users could have another response to the method of redirection, this is only a speculation and I have yet to find any research supporting this.

How long have you been playing video games?
Multiple choice divided into six categories: *"I don't play video games"*, *"6 months"*, *"1 year"*, *"2-5 years"*, *"5-10 years"* and *"10 or more years"*.

During an average week, how many hours do spend playing video games?
Multiple choice also divided into six categories: *"0-3"*, *"4-7"*, *"8-11"*, *"12-15"*, *"16-19"* and *"20 or more"*.

Do you consider yourself a... Multiple choice divided into four categories: *"Hardcore gamer"*, *"Casual gamer"*, *"Not a gamer"* and *"Don't know"*

Think about the the times you've played games that take place in a 3D environment. How experienced are you at playing these types of games? Multiple choice also divided into four categories: *"Not experienced at all"*, *"A little experienced"*, *"Experienced"* and *"Very experienced"*.

Chapter 8

Results

The test was performed in the Multisensory Experience Laboratory (MELab) at Aalborg University Copenhagen using an OptiTrack system with 11 cameras. The experiment was performed on 36 (32 male and 4 female) participants were aged between 19 and 42 years with an average age of 23.4 and a standard deviation of 4.49. All except two PhD fellows were students, most with a background in computer science.

The result chapter will be divided into three sections. The first section will go through the SSQ feedback, the second section will list the results of the data gathered during the test and the third section will cover the Feedback and Demographics Questionnaire.

8.1 SSQ: Before and after

In order to calculate and evalueate the SSQ the following mappings used

- Nausea *(N; General discomfort, Nausea, Sweating, Increased salivation, Difficulty Concentrating, Stomach awareness, Burping)*9.54*
- Oculomotor *(O; General discomford, Fatigue, Eyestrain, Dificulty focusing, Difficulty Concentrating, Blurred vision, Headache)7.58*
- Disorientation *(D; Nausea, Fullness of head, Blurred vision, Dizzy Eyes Open; Dizzy Eyes Closed, Vertigo)*13.92*
- Total Score *(TS; Nausea, Oculomotor, Disorientation)*3.74*

(Kennedy et al. [1993])

Figure 8.1 is displaying the calculated values of the four categories to show the differences in the before and after responses for the SSQ.

There has been found a statistical significant difference between the before and after answers; for all four categories (N, O, D and TS). N before the test resulted in a mean of 15.11 and a confidence interval (95%) of ±5.00 where N after the test had a mean of 26.24 with a confidence interval of (95%) of ±7.21 resulting in a significant difference with a p value of 0.0024 ($p < 0.05$). O before the test resulted with a mean of 12.84 a confidence interval (95%) ±3.86 and O after the test resulted in a mean of 22.53 a confidence interval (95%) of ±6.74 giving a p value of 0.0006 ($p < 0.05$). D before the test had a mean of 14.69 with a confidence interval (95%) of ±5.87, D after the test with a mean of 33.25 with a confidence interval (95%) of ±12.14 resulting in a p value of 0.0026 ($p < 0.05$). The Total Score mean before the test

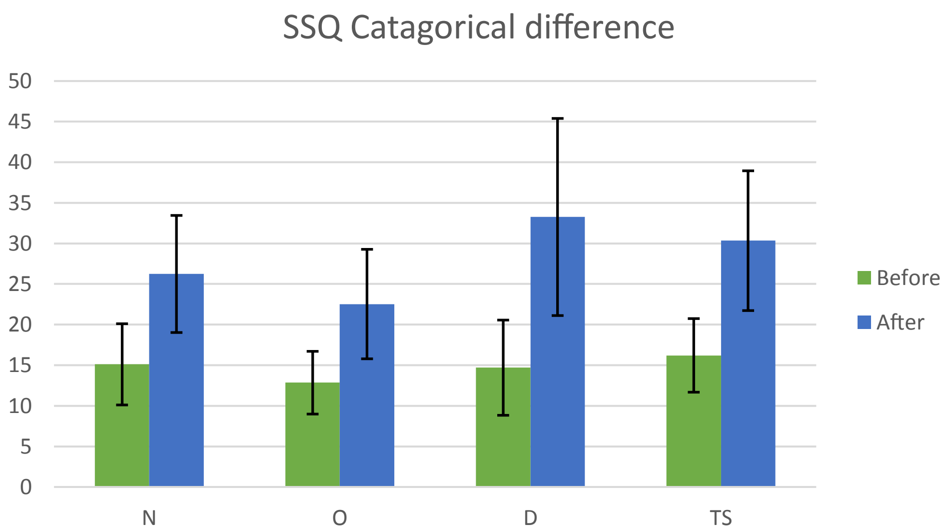


Figure 8.1: Graph showing the mean and error bars for the SSQ feedback before and after the test

was 16.21 with a confidence level of ±4.53 and after the test the TS mean was 30.34 with a confidence level (95%) of ±8.61 resulting in a p value of 0.0007 ($p < 0.05$).

8.2 Test feedback

The data gathered during the test has been sorted into the three different methods (NoSnow, SnowFlee and SnowFollow)

Figure 8.2 displays three curves one for each of the three tested methods (individual plots for the three conditions can be found in Appendix B). Looking at the graph it could indicate that there would be no significant difference between the two snow conditions (SnowFlee and SnowFollow) but there might be a significant difference on several of the gain values when comparing the snow methods against the NoSnow method (the zero condition). The approximation of min, mid and max values of the Rotation gain, can be found in table 8.1 where the thresholds is defined by the 25% and 75% bounderies.

	25%	50%	75%
NoSnow	1.03	1.22	1.41
SnowFlee	0.89	1.11	1.28
SnowFollow	0.92	1.08	1.30

Table 8.1: Approximated threshold values for the three conditions

Based on the data shown in the Figure 8.2 a Student T-Test has been performed on each of the gain values between the conditions pairwise, the results can be found in Table 8.2

The table show no significant difference between the SnowFlee and SnowFollow methods, but a significant difference was found between both of the snow methods and the NoSnow method for all of the gain values between 0.8 and 1.4. With the exception of 0.9 and 1.1 for the SnowFlee vs. NoSnow; and 1.2 for the SnowFollow vs. NoSnow, with a p value below 0.05.

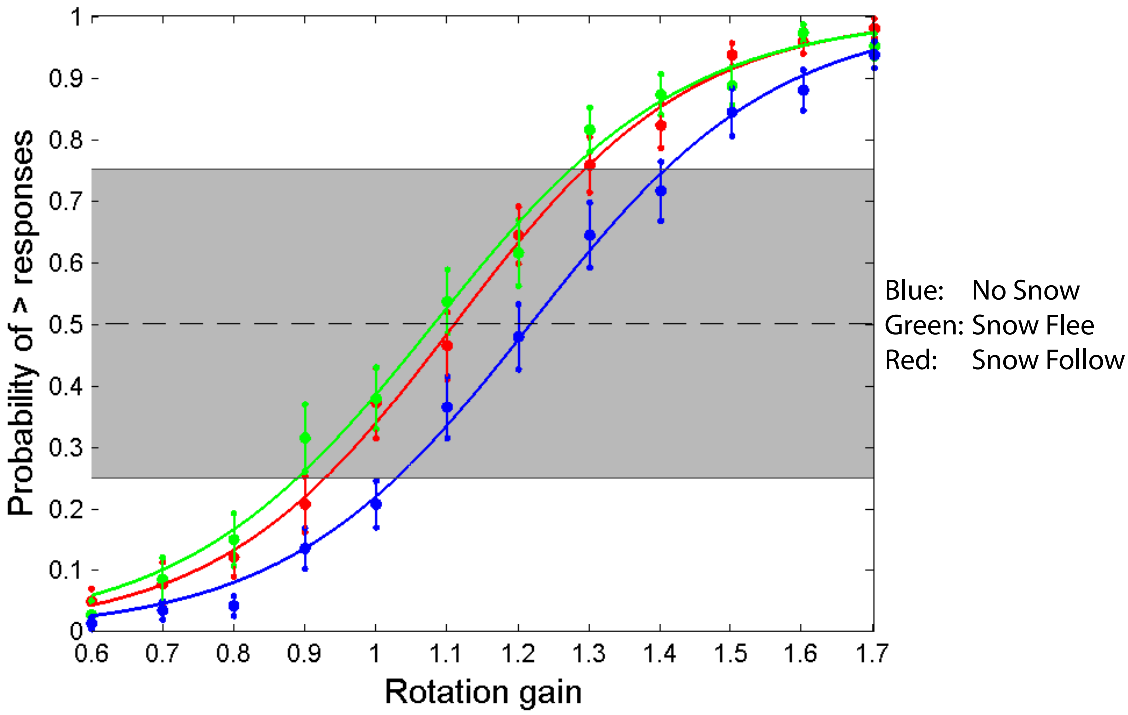


Figure 8.2: Comparison plot of the NoSnow, SnowFlee and SnowFollow methods

Gain	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
NoSnow Vs. SnowFlee	0.057	0.133	0.015	0.103	0.008	0.097	0.006	0.045	0.025	0.013	0.014	0.064
NoSnow Vs. SnowFollow	0.562	0.199	0.022	0.005	0.009	0.013	0.054	0.005	0.007	0.263	0.007	0.474
SnowFlee Vs. SnowFollow	0.478	0.887	0.592	0.112	1.000	0.263	0.616	0.274	0.389	0.251	0.546	0.418

Table 8.2: Listing the T-Test p values for each individual gain

8.3 Feedback and Demographics Questionnaire

For the question *"Please compare the difficulty of the task when having the snow effect compared to no snow"* with a feedback of a VAS scale from 1 (much easier) to 7 (much harder) the mean was found to be 4.5 with a standard deviation of 0.81. For the question *"The task of determining if your rotation was faster or slower were easier when?"* four categories ratio's were;
"It was easier when it flew in the same direction as my rotation" = 3
"It was easier when the snow flew against my rotation" = 5
"The snows direction didn't affect the difficulty of the task" = 9
"I didn't notice the snows direction change" = 19
Resulting in Chi-Square score of 16.889, giving a p-value of 0.00074488 (Yates' chi-square 14.778, Yates' p-value 0.00201654). These results are showing that more than half of the participants did not notice the change in direction resulting in a significant difference between the answers.

Of the 36 participants 32 had been playing computer games for more than 10 years, 3 had played for 5-10 years and 1 did not play at all. Regarding the question *"Do you consider yourself a... (Don't know, Not a gamer, Casual gamer, Hardcore gamer)"* 6 answered Hardcore gamer, 25 "Casual gamer", 4 answered "Not a gamer" and 1 answered "Don't know". The complete set of data (raw and prossed) can be found on the DVD accompanying this project in the folder "Results".

Chapter 9

Discussion

This project looked into, whether particle based weather conditions, in this case a snow storm, have an affect on the threshold values for unnoticed Rotation gain. The study showed; there was no significant difference between the two snow conditions SnowFlee and SnowFollow. This finding is also supported by the feedback from the Feedback and Demographics Questionnaire where 19 out of the 36 participants did not notice that the snow changed directions during the test. The Results showed a significant difference, between the two snow conditions when compared to the NoSnow condition, with the exception of two gains ($g_r = 0.9$ & 1.1) for the comparison the between SnowFlee and NoSnow and one gain value ($g_r = 1.2$) when comparing SnowFollow and NoSnow. When looking at the gain values from 0.8 to 1.4 (both included). It is of notice that all of these overlaps are close to the case where no gain is added ($g_r = 1.0$).

Reflecting on the setup of the test, trials and the insecurity the participants showed during the test each gain for the three conditions should have been tested more than the four times, that were the case for this experiment. Each of the gains was only tested twice for both rotational directions (two rotations to the left and two to the right) for each condition. Ideally the gains should have been tested the doubled amount of times for each direction and condition to reduce the chance of a random guess from the participants guess to have a high influence on the results. As the setup is now one insecure guess would reduce the count with 25%. If the gains had been tested four times for each side a chance response would only affect the results by 12.5%.

The reason not to use four trials per side, gain and condition in this study, were to reduce the time spend in the VE. This decision was made to reduce the chance of simulator sickness and as there was found a significant difference in the responses from the SSQ, though the SSQ scores were still low, a longer test could have produced an unwanted degree of simulator sickness for the participants. Regarding the significant difference and increase for all of the Simulator Sickness category values, it is not possible to determine if it is; the particle effect, the gains, the amount time in the VE, the number of rotations, to many consecutive rotations to the same side or the hardware when using the Oculus Rift Developers Kit 1.

The exact reason, would be an investigation for a separate experiment, that would be focused on simulator sickness. Two of the participants mentioned they experienced balance problems when exposed to the slowest gain value ($g_r = 0.6$) and one mentioned this issue for both the slowest and fastest gain values ($g_r = 0.6$ or 1.7). Still it is important to mention that none of the participants wished to stop or complained about motion sickness during or after the study. One of the participants had a lot of consecutive rotations in the same direction before switching direction. The participant suggested that there would be a max with only a few rotations to the same in a row before switching, as many rotations to the same side has a strong effect on motions sickness, in both the real and virtual world.

A few of the participant expressed after the test that they often, when in doubt tended to stick to either faster or slower as a response, which would affect the results, and that faster was often the most popular choice. This feedback provides some bias to the two answer forced choice method, and suggest that a middle interval could be beneficial though comparison to previous work and the evaluation method of the results should then me modified to take account for the additional option. Another option would be to add an assurance scale, but evaluating the extra data would again require a new way of calculating the data.

A few participants used their feet to help measure how long they moved, where other mentioned that they used the motion blur from the display, to help assess their movement speed. The participants using their feet had an unfair advantage in the assessment of the speed. But the large group should take account for the 1-3 participants that used this technique. The motion blur might have an effect on the data as the Oculus Rift Developers Kit 1, have some latency and ghosting problems (ghosting is when the pixel release time takes to long before updating to the new value). The ghosting could have seamed worse, or been worse for the slower movement speeds. The display also had a noticeable grid (the screen door effect) that several of the participants mentioned, during the test or in the improvement field of the Feedback and Demographics Questionnaire. This problem and a lot of the ghosting and delay is being resolved for the future versions of the Oculus Rift displays.

One participant was excluded from all evaluation as the system froze and crashed in the middle of the test without saving any of the responses from the user and due to time constrains and to avid bias the test was stopped at that point. The additional reasons for the exclusion was remove a possible learning effect to influence the test and the affect extra simulation time could have on the SSQ scores.

The threshold for unnoticed gain values, found in this test do not match the threshold values found by Steinicke et al. [2010]. Serafin et al. [2013] performed an experiment using acoustic based redirection, using an nVisor SX HMD and found their thresholds to be a 20% increase and a 12% decrease of the participants rotational movement speed. The results found in this project look to be somewhere between results of these two projects.

Comparing the values between this studies three conditions and the thresholds found by Steinicke et al. [2010] and Serafin et al. [2013], see Table 9.1 for an overview and comparison between the different studies.

Steinicke et al. [2010]:	0.80 >= Rotation gain (g_r) >= 1.49
Serafin et al. [2013]:	0.88 >= Rotation gain (g_r) >= 1.20
NoSnow:	1.03 >= Rotation gain (g_r) >= 1.41
SnowFlee:	0.89 >= Rotation gain (g_r) >= 1.28
SnowFollow:	0.92 >= Rotation gain (g_r) >= 1.30

Table 9.1: Listing and comparing the threshold values from this study and to the ones found by Steinicke et al. [2010] and Serafin et al. [2013]

It should be noted that this study used a rotation of 135 degrees where both Steinicke et al. [2010] and Serafin et al. [2013] used a 90 degree rotation for their trials. This could have an effect as the users have a longer movement to determine their rotation speed. This consideration of course important to remember, but as this method of redirection should be applicable to any given amount of rotation for virtual experiences, it should be considered less important.

The sound used in this experiment was a prerecorded wind sound created to fit a snow storm. For the implementation there were a direct direction but the spatialization of the audio was to strong for the ear directly in the line of the wind but to subtle for the opposite ear. This effect was the same for all cases and should therefore not influence the results.

As all three studies uses different HMD's it would be interesting to investigate how much the different HMD's affect the threshold values for unnoticed Rotation gain.

Chapter 10

Conclusion

This project has investigated the issue of natural walking in VEs. The previous work in this field has added methods for walking inside, but outdoor walking in large environment was still dependent on traditional redirection techniques. Therefore, this project investigated additions to the classic techniques by using a particle based weather condition, leading to the following statement *"How is Rotation gains for redirection affected by the use of particle based weather conditions, creating an element of optical flow?"*

The test was performed on 36 participants (32 male and 4 female, age of 23.4 standard deviation 4.49). The results show a significant difference between the NoSnow and the two used snow conditions (SnowFlee and SnowFollow) see Figure 10.1. When comparing the gains individually there were two gains not showing a significant difference in a T-Test comparison between NoSnow and SnowFlee (0.9 ($p = 0.103$) and 1.1 ($p = 0.097$)) and one for the T-Test between NoSnow and SnowFollow (1.2 ($p = 0.054$)) within a gain boundaries of 0.8 to 1.4 (both included).

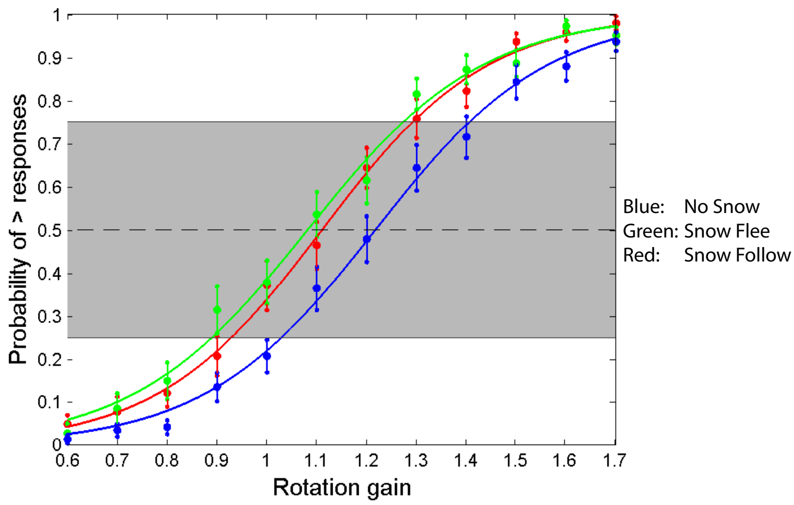


Figure 10.1: Comparison plot of the NoSnow, SnowFlee and SnowFollow methods

Steinicke et al. [2010] found in their study the thresholds for unnoticed Rotation gain to be 0.80 >= Rotation gain (g_r) >= 1.49. This project found the values to be as follows by the three conditions.

NoSnow:	1.03 >= Rotation gain (g_r) >= 1.41
SnowFlee:	0.89 >= Rotation gain (g_r) >= 1.28
SnowFollow:	0.92 >= Rotation gain (g_r) >= 1.30

The Feedback and Demographics Questionnaire showed that the majority of the participants did not notice the difference between the two snow conditions (SnowFlee and SnowFollow) which fit with the results from the values found during the test.

The Simulator Sickness Questionnaire (SSQ) was tested both before the test and immediately after the completion of the 144 trials. The results of the SSQ showed an increase in the four categories; Nausea, Oculomotor, Disorientation and Total Score.

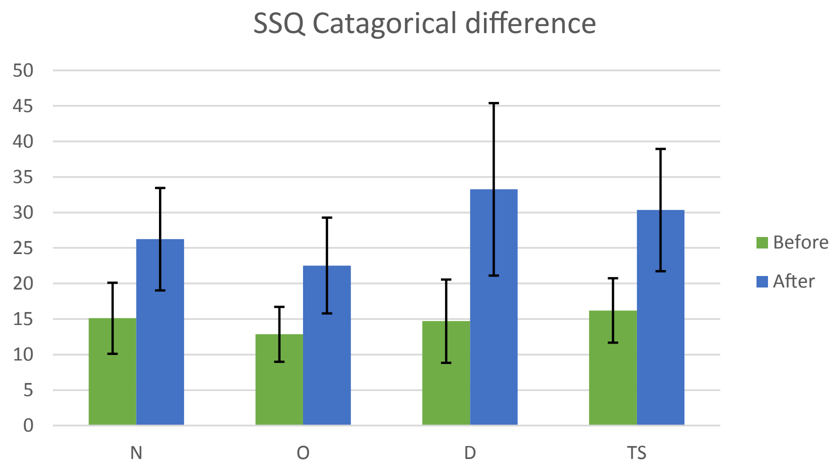


Figure 10.2: Graph showing the mean and error bars for the SSQ feedback before and after the test

The results of this project contribute to the development of future locomotion methods for VR, that can take advantage of weather or other visual effects. Yet, testing the setup with more repetitions for each gain will allow for better determination of the correct thresholds for the Rotation gains for each condition.

This project has focused on outdoor scenarios, as large open spaces would need redirection techniques for users to traverse these outdoor landscapes. Most buildings have restricted size (often larger that the physical tracking space) but if natural walking is to be utilized in laboratories or arcade setups for games, training, or virtual tourism, it is imperative that a solution is found for large outdoor spaces, where architectural methods are either impossible or difficult to install, as the user can see too much space and walls or rooms are not blocking the users view.

Chapter 11

Future Perspective

As the direction the snow was moving did not show any difference in this project it would be interesting to see what effect a more subtle falling snow would have on redirected rotation. This test placed the user in the middle of a blizzard but how would snow falling with little to no wind affect the redirectional gain values.

An other interesting test would be to look if other weather effects would influence the threshold values for unnoticed redirectional gains. For example how would rain work as a visual effect for redirection and would a more opaque effect as rain is affect the threshold values.

An obvious investigation would be to test these effects on the remaining two most commonly used redirectional techniques; curvature and translation gain. Would these effects only work for rotational techniques or would staight movement also be affected by the moving particles on the screen giving the weather effects.

Other interesting element to test for redirection would be how other moving elements in the scene would affect the users perception and when he/she can detect the gains applied to rotation. Or a testing method that used naive participants not aware of the modification to their movements.

This page is intentionally left blank.

Bibliography

Emily Brown and Paul Cairns. A grounded investigation of game immersion. In *CHI'04 extended abstracts on Human factors in computing systems*, pages 1297–1300. ACM, 2004.

Gerd Bruder, Frank Steinicke, Phil Wieland, and Markus Lappe. Tuning self-motion perception in virtual reality with visual illusions. *Visualization and Computer Graphics, IEEE Transactions on*, 18 (7):1068–1078, 2012.

David Engel, Cristóbal Curio, Lili Tcheang, Betty Mohler, and Heinrich H Bülthoff. A psychophysically calibrated controller for navigating through large environments in a limited free-walking space. In *Proceedings of the 2008 ACM symposium on Virtual reality software and technology*, pages 157–164. ACM, 2008.

Jeff Feasel, Mary C Whitton, and Jeremy D Wendt. Llcm-wip: Low-latency, continuous-motion walking-in-place. In *3D User Interfaces, 2008. 3DUI 2008. IEEE Symposium on*, pages 97–104. IEEE, 2008.

Tom Field and Peter Vamplew. *Generalised algorithms for redirected walking in virtual environments.* PhD thesis, University of Tasmania, 2004.

Matthias Haringer and Steffi Beckhaus. Adaptive generation of emotional impact using enhanced virtual environments. *Presence: Teleoperators and Virtual Environments*, 21(1):96–116, 2012.

Robert S Kennedy, Norman E Lane, Kevin S Berbaum, and Michael G Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology*, 3(3):203–220, 1993.

Matthew Lombard and Theresa Ditton. At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication*, 3(2):0–0, 1997.

Frank D. Luna. *Introduction to 3D Game Programming with DirectX 11.* Mercury Learning and Information, 2013.

Christian T Neth, Jan L Souman, David Engel, Uwe Kloos, Heinrich H Bulthoff, and Betty J Mohler. Velocity-dependent dynamic curvature gain for redirected walking. *Visualization and Computer Graphics, IEEE Transactions on*, 18(7):1041–1052, 2012.

Niels Christian Nilsson, Stefania Serafin, and Rolf Nordahl. Tapping-In-Place: Increasing the Naturalness of Immersive Walking-In-Place Locomotion Through Novel Gestural Input. *3D User Interfaces*, 2013.

OculusVR. Oculus rift weppage, May 2014. URL `http://www.oculusvr.com`.

Tabitha C Peck, Henry Fuchs, and Mary C Whitton. Evaluation of reorientation techniques and distractors for walking in large virtual environments. *Visualization and Computer Graphics, IEEE Transactions on*, 15(3):383–394, 2009.

Anna Puig-Centelles, Oscar Ripolles, and Miguel Chover. Creation and control of rain in virtual environments. *The Visual Computer*, 25(11):1037–1052, 2009.

Corina Sas and Gregory MP O'Hare. Presence equation: An investigation into cognitive factors underlying presence. *Presence: Teleoperators & Virtual Environments*, 12(5):523–537, 2003.

Stefania Serafin, Niels C Nilsson, Erik Sikstrom, Amalia De Goetzen, and Rolf Nordahl. Estimation of detection thresholds for acoustic based redirected walking techniques. In *Virtual Reality (VR), 2013 IEEE*, pages 161–162. IEEE, 2013.

Paul Skalski, Ron Tamborini, Ashleigh Shelton, Michael Buncher, and Pete Lindmark. Mapping the road to fun: Natural video game controllers, presence, and game enjoyment. *New Media & Society*, 13(2): 224–242, 2011.

Sony Computer Entertainment Inc. Sony Computer Entertainment Announces "Project Morpheus" - A Virtual Reality System That Expands The World Of Playstation©4 (PS™4), May 2014. URL `http://www.sony.com/SCA/company-news/press-releases/sony-computer-entertainment-america-inc/2014/sony-computer-entertainment-announces-project-morp.shtml`.

Frank Steinicke, Gerd Bruder, Jason Jerald, Harald Frenz, and Markus Lappe. Estimation of detection thresholds for redirected walking techniques. *Visualization and Computer Graphics, IEEE Transactions on*, 16(1):17–27, 2010.

Jonathan Steuer. Defining virtual reality: Dimensions determining telepresence. *Journal of communication*, 42(4):73–93, 1992.

Evan A Suma, Seth Clark, D Krum, S Finkelstein, M Bolas, and Z Warte. Leveraging change blindness for redirection in virtual environments. In *Virtual Reality Conference (VR), 2011 IEEE*, pages 159–166. IEEE, 2011.

Evan A Suma, Gerd Bruder, Frank Steinicke, David M Krum, and Mark Bolas. A taxonomy for deploying redirection techniques in immersive virtual environments. In *Virtual Reality Workshops (VR), 2012 IEEE*, pages 43–46. IEEE, 2012a.

Evan A Suma, Zachary Lipps, Samantha Finkelstein, David M Krum, and Mark Bolas. Impossible spaces: Maximizing natural walking in virtual environments with self-overlapping architecture. *Visualization and Computer Graphics, IEEE Transactions on*, 18(4):555–564, 2012b.

Christian Toft, Iben Schandel, Mikkel Rasch Nielsen, and Mohammed Arief. Walking in virtual reality. Medialogy 8th semester project, May 2013.

Unity3D. Using directx 11 in unity 4, May 2014. URL `https://docs.unity3d.com/Documentation/Manual/DirectX11.html`.

Martin Usoh, Ernest Catena, Sima Arman, and Mel Slater. Using presence questionnaires in reality. *Presence: Teleoperators & Virtual Environments*, 9(5):497–503, 2000.

Virtuix. Virtuix omni, May 2014. URL `http://www.virtuix.com`.

Mary C Whitton, Joseph V Cohn, Jeff Feasel, Paul Zimmons, Sharif Razzaque, Sarah J Poulton, Brandi McLeod, and Frederick P Brooks Jr. Comparing VE locomotion interfaces. In *Virtual Reality, 2005. Proceedings. VR 2005. IEEE*, pages 123–130. IEEE, 2005.

Wizdish Ltd. Wizdish ltd., May 2014. URL `http://www.wizdish.com`.

Christine Youngblut and Odette Huie. The relationship between presence and performance in virtual environments: Results of a VERTS study. In *Virtual Reality, 2003. Proceedings. IEEE*, pages 277–278. IEEE, 2003.

This page is intentionally left blank.

Appendix A

Questionnaires

The two questionnaires have been merged with the document and can be found on the following pages, first page is the Simulator Sickness Questionnaire and the following are the Feedback and Demographic Questionnaire.

Simulator Sickness Questionnaire

* Required

1. **Participant number: ***
   Only numbers may be entered in this field

Simulator Sickness

2. **Please indicate how you are feeling right now by selecting the degree to which you are currently experiencing the following symptoms.**
   Mark only one oval per row.

	None	Slight	Moderate	Severe
General Discomfort				
Fatigue				
Headache				
Eye Strain				
Difficulty Focusing				
Increased Salivation				
Sweating				
Nausea				
Difficulty Concentrating				
Fullness of Head				
Blurred Vision				
Dizzy (Eyes Open)				
Dizzy (Eyes Closed)				
Vertigo				
Stomach Awareness				
Burping				

Feedback and Demographic Questionnaire

There are 17 questions in this survey

* Required

1. **Participant number:** *

Feedback 1

2. **What methods did you use to figure out whether a virtual rotation was smaller or larger than the rotation of your physical body?** *
   Please write your answer here:

Feedback 2

3. **Please compare the difficulty of the task when having the snow effect compared to no snow** *
   When the snow effect was present, the task was...
   Mark only one oval.

	1	2	3	4	5	6	7	
Much easier	◯	◯	◯	◯	◯	◯	◯	Much harder

4. **Please describe how you felt when the snow rotated around you. If you didn't notice this, please say so.** *
   Please write your answer here:

5. **The task of determining if your rotation was faster or slower were easier when?** *
Mark only one oval.

- ◯ It was easier when it flew in the same direction as my rotation
- ◯ It was easier when the snow flew against my rotation
- ◯ The snows direction didn't affect the difficulty of the task
- ◯ I didn't notice the snows direction change

6. **Was there anything that contributed to or took away from your experience of the virtual world? If so, please describe them.**
Please write your answer here:

7. **Do you have any suggestions for improvement or anything else you'd like to tell?**

Personal Information

8. **Your age:** *
Please write your answer here:

9. **Your gender:** *
Please choose one of the following:
Mark only one oval.

- ◯ Female
- ◯ Male

10. **Are you left-handed or right-handed? If you are not sure, please choose the hand you write with.**
Please choose one of the following:
Mark only one oval.

- ◯ Left-Handed
- ◯ Right-Handed

11. **Ethnicity:** *
Please choose oe
Mark only one oval.

- American Indian or Alaska Native
- Asian
- Black or African American
- Hispanic or Latino
- Native Hawaiian or Other Pacific Islander
- Caucasian (White)
- Prefer not to specify
- Other: ____________________

12. **University status (current):** *
Please choose one
Mark only one oval.

- Bachelor/Undergraduate Student
- Master's Student
- Ph.D. Student
- University Staff
- Faculty
- Other
- Not affiliated with the university

13. **If you are a student, please indicate your program and semester:**
Please write your answer here:

____

14. **If you selected other please indicate your profession:**
Please write your answer here:

____

Video Game Experience

15. **How long have you been playing video games?** *
Please choose one of the following:
Mark only one oval.

- I don't play video games
- 6 months
- 1 year
- 2-5 years
- 5-10 years
- 10 or more years

16. **During an average week, how many hours do spend playing video games?** *
Please choose one of the following:
Mark only one oval.

- 0-3
- 4-7
- 8-11
- 12-15
- 16-19
- 20 or more

17. **Do you consider yourself a...** *
Please choose one of the following:
Mark only one oval.

- Hardcore gamer
- Casual gamer
- Not a gamer
- Don't know

18. **Think about the the times you've played games that take place in a 3D environment. How experienced are you at playing these types of games?** *
Please choose one of the following:
Mark only one oval.

- Not experienced at all
- A little experienced
- Experienced
- Very experienced

Appendix B

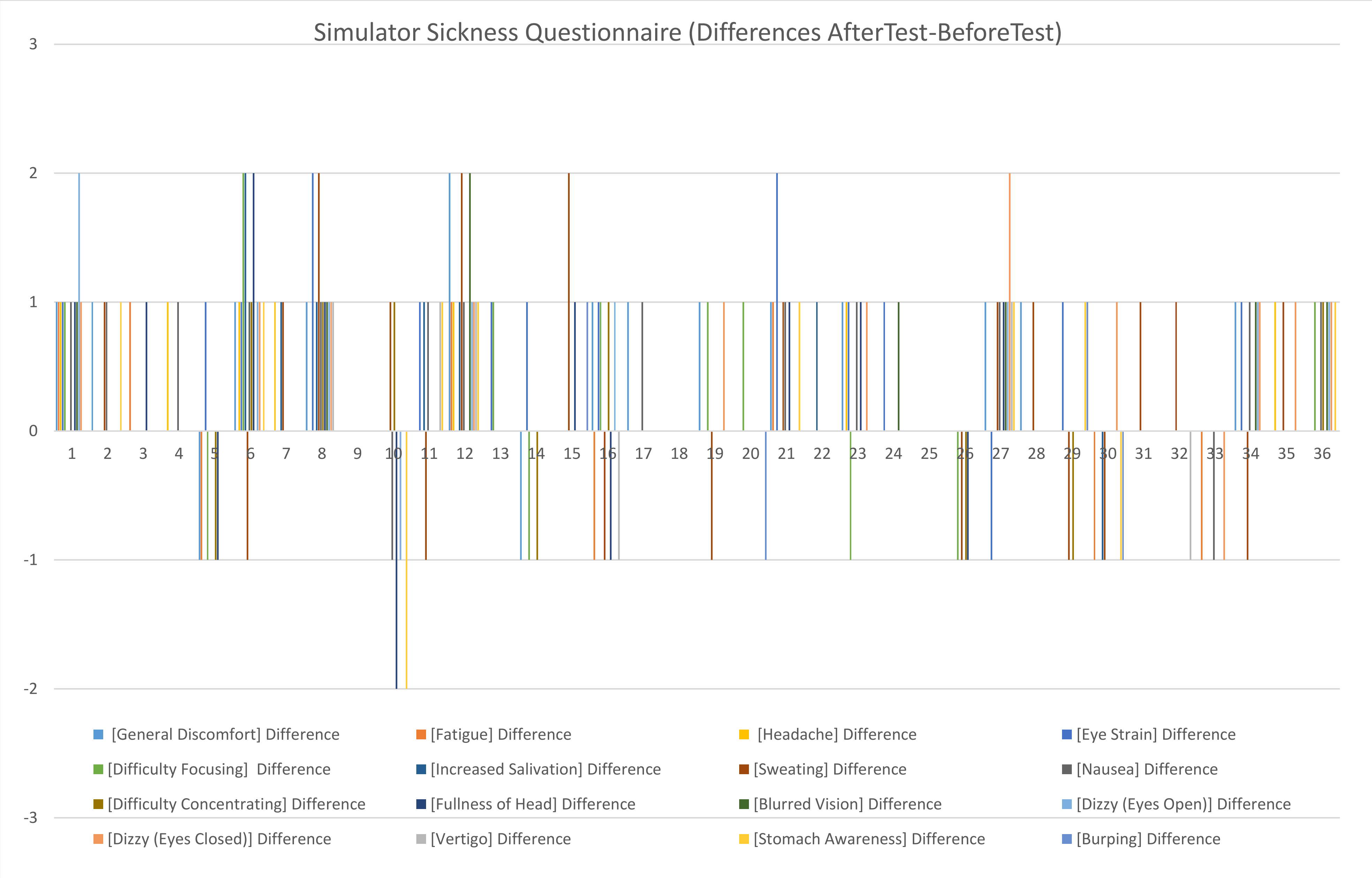
Graphs

The first the raw data and calculations from the three test conditions (NoSnow, SnowFlee and Snow-Follow) followed by a diagram of the differences in responses (after-before) from the Simulator Sickness Questionnaire, then three figures displaying the feedback for the three trial condition. After the three graphs the raw data and the calculations are listed for the following three pages.

0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	
0	0	1	1	2	4	3	4	3	3	4	4	No Snow
0	0	0	2	2	2	2	4	3	4	4	4	Snow Flee
0	0	0	0	1	1	2	4	4	4	4	4	Snow Follow
0	0	0	2	1	2	2	3	4	4	4	4	
0	0	0	0	0	1	0	2	3	2	4	3	
0	0	0	0	0	0	0	2	3	4	3	3	
0	0	0	0	0	0	0	0	1	3	1	4	
0	0	0	0	0	2	1	4	2	4	3	4	
1	0	0	0	0	2	2	3	3	3	4	4	
0	0	0	1	0	0	0	1	2	2	3	3	
0	1	0	0	0	0	3	4	0	3	2	4	
0	0	1	0	2	2	4	4	4	4	4	4	
0	0	0	0	1	1	0	2	2	2	4	4	
0	0	1	1	1	3	4	3	3	4	4	4	
0	0	0	0	0	0	1	0	1	2	3	4	
0	0	0	0	1	2	3	2	3	3	3	4	
0	0	0	0	0	0	1	2	1	3	3	4	
0	0	0	0	0	0	2	2	4	4	4	4	
0	0	0	1	1	2	2	3	4	3	4	4	
0	1	0	1	0	2	4	4	4	3	3	4	
0	0	0	0	0	0	0	0	3	2	2	3	
0	0	0	0	0	1	2	3	3	4	4	4	
0	0	0	2	2	2	3	2	4	4	4	3	
0	1	1	1	2	2	2	4	4	4	4	4	
0	0	0	0	0	1	0	1	3	3	3	2	
1	0	0	0	2	2	2	2	4	4	4	4	
0	0	0	1	2	2	2	2	2	4	4	4	
0	1	0	3	1	4	3	4	3	4	4	3	
0	0	0	0	1	0	1	2	3	3	4	4	
0	0	0	0	0	1	1	2	2	4	4	4	
0	1	0	1	0	1	1	1	3	0	2	3	
0	0	0	0	2	1	2	4	4	4	3	4	
0	0	1	1	1	3	4	3	4	4	4	4	
0	0	1	1	3	4	3	4	4	4	4	3	
0	0	0	1	1	1	3	2	1	4	4	4	
0	0	0	0	0	0	2	2	1	4	4	4	
0.05556	0.13889	0.16667	0.55556	0.80556	1.41667	1.86111	2.52778	2.83333	3.33333	3.5	3.72222	Mean
0.05247	0.1196	0.13889	0.58025	0.76775	1.40972	1.56404	1.52701	1.25	0.83333	0.58333	0.25617	Variance
0.22906	0.34583	0.37268	0.76174	0.87621	1.18732	1.25062	1.23572	1.11803	0.91287	0.76376	0.50614	Standart Deviation
0.07483	0.11297	0.12174	0.24883	0.28623	0.38786	0.40853	0.40367	0.36522	0.2982	0.2495	0.16534	Confidence interval (1.96

0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	
0	0	0	3	3	4	4	4	4	4	4	4	
0	1	0	1	4	1	3	4	3	4	4	4	
0	0	0	2	3	2	4	4	4	4	4	4	
0	1	1	1	1	3	1	1	3	4	4	4	
0	0	0	0	0	0	2	3	2	4	4	4	
0	0	0	1	0	2	3	4	4	4	4	4	
0	0	0	0	0	0	0	0	2	3	4	2	
0	0	0	1	0	1	3	3	4	4	4	4	
1	0	0	1	2	4	3	3	4	4	4	4	
0	0	0	1	1	0	3	2	4	3	4	3	
0	0	1	2	0	2	1	3	2	3	3	4	
1	0	1	2	2	2	3	3	4	4	4	4	
0	0	0	2	3	3	1	3	2	3	4	4	
0	0	0	1	2	2	3	4	4	4	4	4	
0	0	0	0	1	0	2	3	2	3	4	4	
1	0	0	1	0	0	3	3	4	4	4	3	
0	0	0	0	0	2	3	1	3	4	4	4	
0	0	0	0	2	1	4	3	4	4	4	4	
1	0	1	0	2	2	3	4	3	4	4	4	
0	2	2	2	3	4	4	4	4	4	4	4	
0	0	0	0	0	3	1	1	3	4	4	4	
0	0	1	0	1	2	2	3	4	4	4	4	
2	4	2	3	4	1	4	4	4	4	4	4	
0	0	3	1	3	3	3	4	4	4	4	4	
0	0	0	0	0	3	2	3	2	4	3	4	
0	0	0	0	0	0	1	2	3	3	2	4	
0	0	1	0	1	1	3	4	3	4	4	4	
0	0	1	1	1	3	3	4	4	4	4	4	
0	0	0	0	1	3	2	4	3	3	4	4	
0	0	0	0	0	0	2	3	1	3	4	4	
1	2	1	0	1	0	2	2	4	3	4	4	
0	0	0	0	1	1	1	2	4	4	3	4	
0	1	0	0	3	3	3	3	4	4	4	4	
0	0	1	4	4	3	4	4	4	4	4	4	
0	0	1	0	3	3	4	4	3	3	3	4	
0	0	0	0	1	1	3	2	3	4	4	4	
0.19444	0.30556	0.47222	0.83333	1.47222	1.80556	2.58333	3	3.30556	3.72222	3.83333	3.88889	Mean
0.21219	0.65664	0.52701	1.08333	1.74923	1.65664	1.13194	1.11111	0.71219	0.20062	0.19444	0.15432	Variance
0.46064	0.81033	0.72595	1.04083	1.32258	1.2871	1.06393	1.05409	0.84391	0.4479	0.44096	0.39284	Standart Deviation
0.15048	0.26471	0.23714	0.34001	0.43204	0.42045	0.34755	0.34434	0.27568	0.14632	0.14405	0.12833	Confidence interval (1.96
0.05736	0.13345	0.015	0.10342	0.00765	0.09659	0.00565	0.04492	0.025	0.01338	0.01427	0.06416	TTest: NoSnow vs SnowFlee

0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	
0	0	0	2	1	3	4	4	4	4	4	3	
0	0	0	0	2	4	3	4	3	4	4	4	
0	0	2	4	4	3	4	4	4	4	4	4	
0	0	0	2	2	3	4	3	4	4	4	4	
0	0	0	0	1	1	0	4	4	2	4	3	
0	0	0	1	1	3	3	4	4	4	4	4	
0	0	0	0	0	0	1	2	1	2	3	3	
0	0	0	1	1	0	3	4	4	4	4	4	
0	0	0	0	3	2	4	4	4	4	4	4	
0	0	0	2	0	2	2	3	3	4	4	4	
1	0	0	1	1	1	2	2	3	4	4	2	
0	0	1	0	2	2	2	3	4	4	4	4	
0	1	1	2	1	4	1	2	4	4	4	4	
0	1	0	0	3	3	2	2	4	4	4	4	
0	0	0	0	0	1	0	2	4	2	3	4	
0	0	0	0	1	2	2	3	2	4	4	4	
0	0	1	0	1	2	2	2	2	3	4	4	
0	0	0	2	1	0	2	3	4	4	4	4	
0	0	0	2	3	4	4	4	4	4	4	4	
0	0	2	3	3	3	4	4	3	4	4	4	
0	0	0	0	1	1	2	3	4	3	4	4	
0	0	1	2	1	2	3	4	4	4	4	4	
3	4	4	3	4	1	4	4	4	4	4	4	
0	1	3	4	3	4	2	4	4	4	4	4	
0	0	1	1	1	2	2	2	2	3	3	4	
0	0	0	1	0	2	1	2	4	2	4	4	
0	0	0	3	1	2	2	3	3	3	4	4	
0	1	0	1	2	4	4	4	3	4	4	4	
0	0	0	0	0	1	2	4	3	3	4	4	
0	0	0	0	0	1	1	4	3	3	4	4	
0	2	1	2	0	2	3	2	4	4	3	4	
0	0	0	0	0	2	0	3	3	4	4	3	
0	0	2	1	3	3	3	4	3	4	4	3	
0	2	2	4	3	4	4	4	4	4	4	4	
0	0	0	1	1	2	4	3	4	4	4	4	
0	0	0	1	2	1	2	4	4	2	4	4	
0.11111	0.33333	0.58333	1.27778	1.47222	2.13889	2.44444	3.25	3.47222	3.55556	3.88889	3.80556	Mean
0.26543	0.66667	0.96528	1.58951	1.4159	1.39738	1.52469	0.6875	0.58256	0.52469	0.09877	0.21219	Variance
0.5152	0.8165	0.98249	1.26076	1.18991	1.18211	1.23478	0.82916	0.76326	0.72436	0.31427	0.46064	Standart Deviation
0.1683	0.26672	0.32095	0.41185	0.38871	0.38615	0.40336	0.27086	0.24933	0.23662	0.10266	0.15048	Confidence interval (1.96
0.56181	0.19878	0.02182	0.00497	0.00945	0.01296	0.05355	0.00541	0.00675	0.26311	0.00687	0.47369	TTest: NoSnow vs SnowFollow
0.47799	0.88681	0.59221	0.11227	1	0.26299	0.61576	0.27388	0.38915	0.25089	0.54583	0.41821	TTest: SnowFlee vs SnowFollow


Simulator Sickness Questionnaire (Differences AfterTest-BeforeTest)
3
2
1
0
-1
-2
-3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
[General Discomfort] Difference
[Fatigue] Difference
[Headache] Difference
[Eye Strain] Difference
[Difficulty Focusing] Difference
[Increased Salivation] Difference
[Sweating] Difference
[Nausea] Difference
[Difficulty Concentrating] Difference
[Fullness of Head] Difference
[Blurred Vision] Difference
[Dizzy (Eyes Open)] Difference
[Dizzy (Eyes Closed)] Difference
[Vertigo] Difference
[Stomach Awareness] Difference
[Burping] Difference

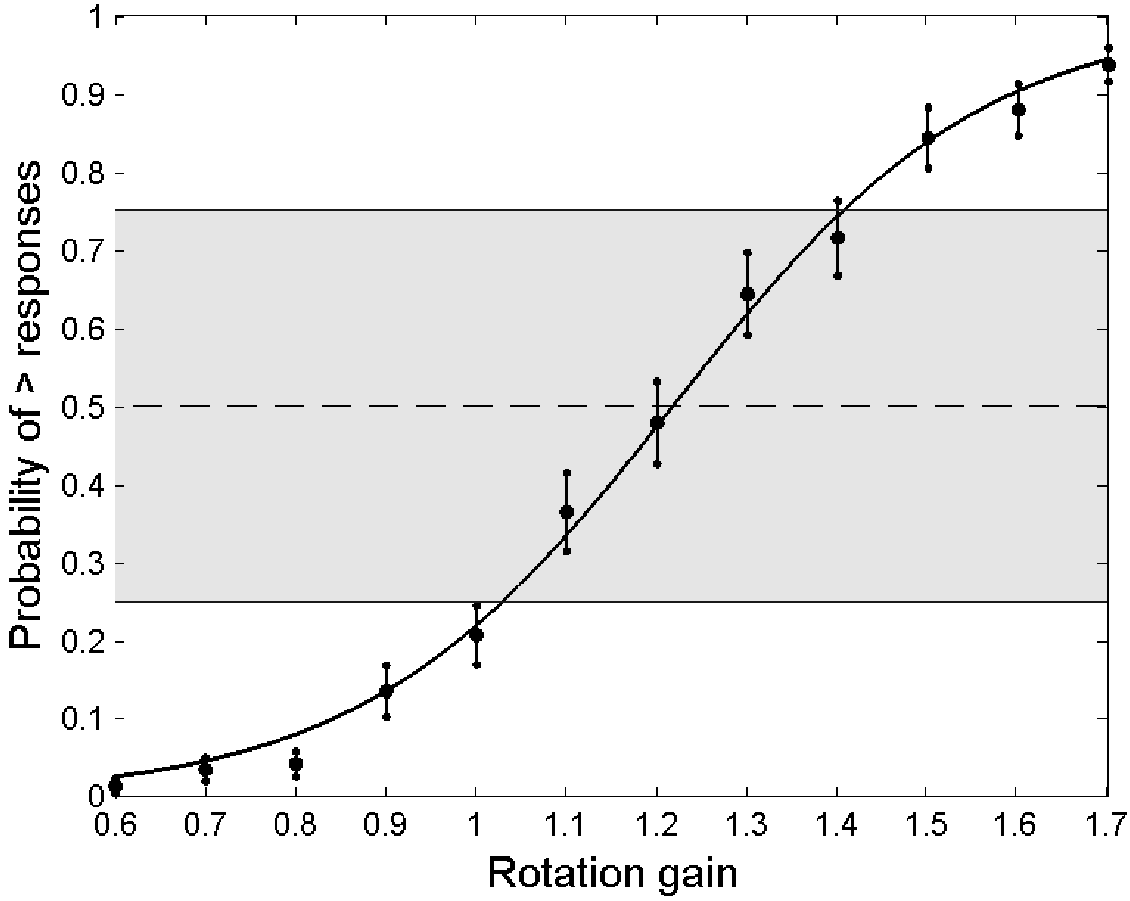


Figure B.01: NoSnow methods result graph

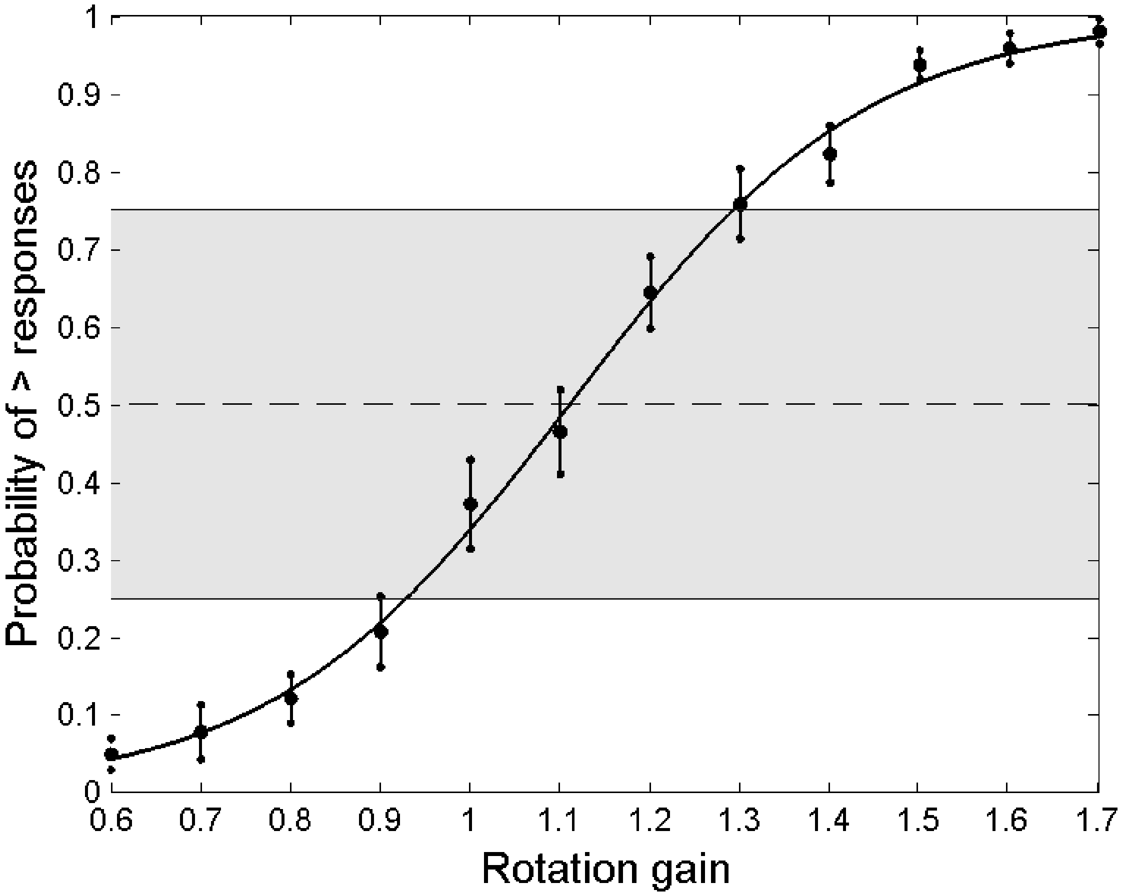


Figure B.02: SnowFlee methods result graph

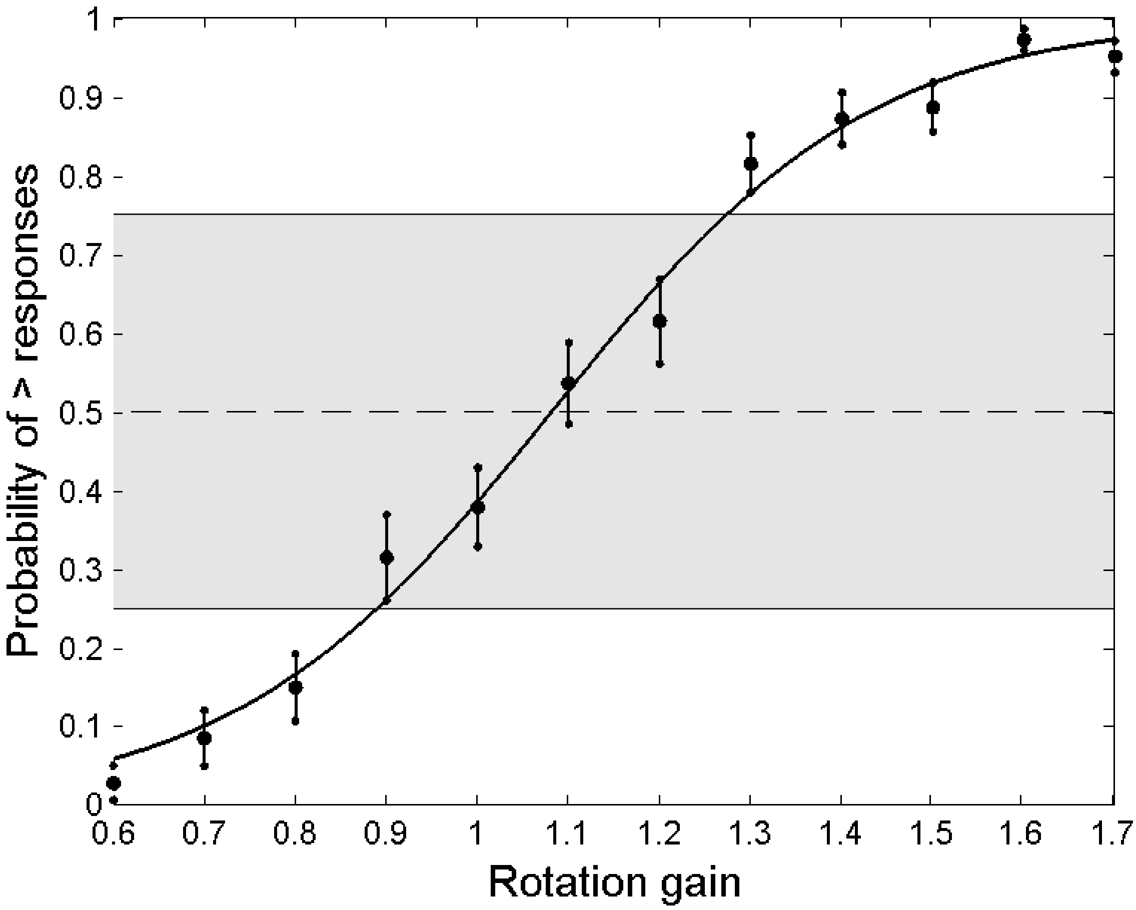


Figure B.03: SnowFollow methods result graph