

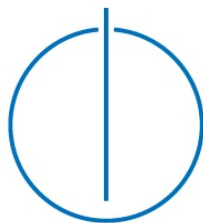
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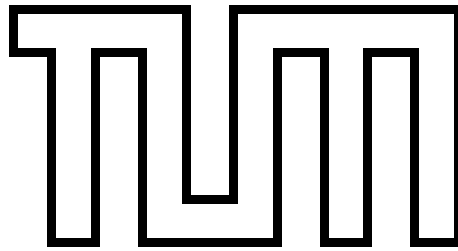
Fakultät für Informatik

Bachelors's Thesis in Informatik: Games Engineering

Virtual Embodiment: Dealing with Discrepancies between the
Virtual and the Real Body

Jonathan Haudenschild





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Virtual Embodiment: Umgang mit Diskrepanzen zwischen dem
virtuellen und dem realen Körper

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Submission: October 15, 2018

I confirm that this bachelor's thesis in 'Informatics: Games Engineering' is my own work and I have documented all sources and material used.

Munich, 10.10.2018

(Jonathan Haudenschild)

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Abstract

The aim of this thesis is to improve the virtual embodiment in immersive environments. This is achieved by detecting collisions and creating discrepancies whenever a virtual character collides with virtual objects in an immersive environment using the HTC Vive. In order to not to lose the sense of embodiment, discrepancies are handled in different ways depending on the body part. The thesis specifically focuses on discrepancies at the arms, hands and head. Discrepancies at the arms and hands are dealt with haptic feedback, audio feedback and visual indicators, whilst discrepancies at the head are dealt with visual effects. These different methods are then compared with the help of a user study in order to find an optimal way to handle discrepancies.

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1. Introduction

In this chapter we will discuss the motivation and background of this thesis. We will look at the importance of this thesis as a whole and also consider other related works which might have influenced this thesis.

1.1. Motivation and Background

1.1.1. Virtual Reality (VR)

Virtual Reality is a rapidly improving technology and revolves around creating a simulation where one can interact with its surroundings. VR has gotten very popular in areas such as gaming and natural sciences. Via virtual reality, we're able to create worlds with our own rules. It has become especially popular in the current pop culture, such as in books and movies. For example, the popular TV series Black Mirror demonstrates in some of their episodes the possibilities of Virtual Reality and the impact on our society. The best-seller "Ready Player One" even includes Virtual Reality as a major factor in a dystopian society. As VR develops we have to consider the advantages and downsides, and it will be interesting to see how virtual reality will evolve in the near future. Nevertheless, the technology is already mind-blowing for many users.

There are many decent VR technologies available on the market such as Oculus Rift and HTC Vive. As more and more companies are deciding to invest in virtual reality, we are looking at possibilities where VR is used in entertainment such as computer games and real-life activities such as water parks such as at the "Therme Erding".

1.1.2. Virtual Embodiment

The idea of a truly immersive experience has become possible with the progress of the VR technology. However, the immersive experience correlates strongly with how realistic

the environment and the embodiment of the user in this environment is. Hence, 'Virtual Embodiment' is one of the major aspects in Virtual Reality. The ultimate goal is to create a virtual environment, where a user is unable to distinguish themselves and the virtual environment from reality. Virtual Embodiment focuses on the ability of one to exactly feel, how one would feel in real life as well. This will be further explained in the chapter 'Virtual Embodiment'. With our current technology the perfect embodiment is not possible yet, however using the current technology, we will explore different methods and ideas of how to create a better sense of embodiment in virtual reality.

1.1.3. Effects of Not Handling Discrepancies

When mapping the real body directly and consistent onto a virtual body, the body would not usually experience any discrepancies and the only limitation of one's movement would be real life obstacles and the play area. However, what happens when one collides with a virtual object? If this situation is not handled, the user could freely move through walls or grab through objects, which has a big impact on the realism and immersion of the user. Whilst it is currently difficult to handle these collisions with our current technology, we could still apply the physics in the virtual worlds onto the body, which results in discrepancies. Not handling these discrepancies however, lead to lower immersion and realism. Apart from that users also often experience headaches, eye-strain, nausea, anxiety and sometimes motion sickness.

Experts say that these effects are due to the eye-brain connection.[LaM17] After all, the entire virtual reality experience is based on tricking the eye and the brain. The 3D depth that the users see, is actually just a screen in front of the eyes. Even small discrepancies over time is notable for the user especially when discrepancies occur due to collisions. Hence, handling these discrepancies would be important for the developer to consider.

1.1.4. Application

In what areas can Virtual Embodiment be applied?

One of the issues in Virtual Reality with our current technology is the inability to give the user a one-to-one haptic feedback when comparing it to real life. Sometimes users are not even able to notice a collision and are thus disorientated quickly. Handling discrepancies would solve many such issues and would enhance the virtual embodiment.

A proper virtual embodiment can be applied in video games and simulations to make games and would create more realistic environments. People who play games, can have a more immersive experience and collisions would be more noticeable for the users. For instance, people would recognize a physical collision in the virtual world, when picking up objects or walking through walls.

1.2. Related Work

1.2.1. Haptics for Virtual Reality and Teleoperation

The work is written by by Matjaz Mihelj and Janez Podobnik with a focus on haptic responses in virtual reality. The research explores how a human perceives forces and different ways of perceiving forces such as via gloves. According to them, interaction with virtual environment is divided into manipulation, navigation and communication. Manipulation and navigation will play a huge part in the following theses, as it is all about changing things in the surroundings, such as buttons, levers and moving objects which will lead to discrepancies and navigation will be a big factor, as the user will be limited in the virtual world where he is able to go, but not in the real world, thus creating discrepancies as well. Generally, the idea of using haptic responses to handle discrepancies is probably the most effective way, however we are limited with the provided equipment and will be pursuing other techniques as well. [Mat12]

1.2.2. Dynamic Collision Detection in Virtual Reality Applications

Jens Eckstein and Elmar Schömer did a research about dynamic collision detection in virtual reality. Although, the standard collision detection from Unity will be used in this thesis, it is an interesting work to read. The methods they have discovered can be used for all standard polygonal models, where algorithms for computation of bounding object hierarchies are modified and new ones are developed. [Jen99]

1.2.3. Virtual Embodiment In Other Papers

In order to write this thesis, other thesis have been read and studied as well. For example, one master thesis already approached some areas in this thesis. Okan Agca has written a thesis about the topic 'Implementation and Evaluation of a VR interaction concept with

HTC Vive and Leap Motion' in 2017. It deals with interaction in Virtual Reality between objects and hands. He pursued the idea of having a ghost hand and lines that would aid the users. However, his particular focus was specifically on grabbing objects.

Another thesis 'Controlling a Physics Based Mech Simulation in Room-Scale Virtual Reality', which has been written by Andreas Leitner, particularly deals with controlling a mech in virtual reality where the use of inverse-kinematic has been a big component in his thesis. The user would be able to move inside a virtual cockpit and control a robot, which arms could (using inverse kinematics) be controlled and be used to manipulate objects in the virtual world.

Additionally the paper's 'The Role of Interaction in Virtual Embodiment: Effects of the Virtual Hand Representation' written by Ferran Argelaguet et al., 'Embodiment, ownership and disownership' by Frédérique De Vignemont and 'The Sense of Embodiment in Virtual Reality' by Konstantina Kilteni et al. have been read and studied in order to gain an understanding about embodiment itself and what to take into account when handling discrepancies between the virtual and the real body. These works will be assessed in the chapter 'Virtual Embodiment'.

2. Fundamentals

Disclaimer: This chapter can be skipped if the necessary knowledge is already present.

This chapter will briefly describe the different resources which were used.

2.1. Hardware

HTC Vive

The hardware that we will use for this thesis is the HTC Vive. It is a virtual reality headset developed by Valve Corporation and HTC: It consists of two lighthouses, a headset, two controllers and the ability to add more trackers. [Viv18]”

2.2. Software

Unity

Ian Zamojc, a freelance game designer and developer who has created various Unity tutorials online, describes Unity as the following:

“Unity3D is a powerful cross-platform 3D engine and a user friendly development environment. Easy enough for the beginner and powerful enough for the expert; Unity should interest anybody who wants to easily create 3D games and applications for mobile, desktop, the web, and consoles. [Zam12]”

The game engine is free to download and will be used for the implementation. The character, the methods and the environment will be entirely build in the game engine

using C#. Unity also has an asset store which will assist in providing 3D models and other helpful tools during the development phase.

SteamVR

The popular online magazine 'PCGamer' has an article about SteamVR which is a plugin where we can integrate HTC Vive into Unity:

”SteamVR is a virtual reality system, with a headset built by Valve and partner HTC. The headset itself is called the HTC Vive. Like the Oculus Rift, the Vive is a VR device that contains two screens (1080x1200 resolution) streaming data at high refresh rates (90Hz) to create the sense of 3D virtual reality. Lenses sit between your eyes and the displays to create a rounded field of view and help your eyes focus on the LCDs. The headset will connect via a hardwire to a PC, which will run games and other VR software. [PCG15]”

We can thus use HTC Vive in Unity using the plugin SteamVR. The plugin also provides effects that can be integrated in our implementation.

Blender

The official site of Blender, describes the software as the following:

“Blender is the free and open source 3D creation suite. It supports the entirety of the 3D pipeline—modeling, rigging, animation, simulation, rendering, compositing and motion tracking, even video editing and game creation. Advanced users employ Blender’s API for Python scripting to customize the application and write specialized tools; often these are included in Blender’s future releases. Blender is well suited to individuals and small studios who benefit from its unified pipeline and responsive development process. [Ble18]”

Besides benefiting from existing models from the asset store, we will potentially work with self-made 3D models, especially when creating the 3D model of the upper body of the character. Blender also provides the ability to rig the character accordingly, which could help us when implementing inverse kinematics.

2.3. Algorithms

Inverse Kinematics

Inverse Kinematics is an algorithm that is used in robotics and simulations. Using the HTC Vive controllers, we know the positioning of the hands and the shoulders. Using the algorithm we can thus calculate how the upper arm and lower arm need to be rotated in order for the hand to be at the target position. For further insight and information please refer to following literature at mathworks.com/help/fuzzy/examples/modeling-inverse-kinematics-in-a-robotic-arm.html. Inverse kinematics is also explained in the bachelor thesis by Andreas Leitner which was mentioned in the 'Related Work' chapter.

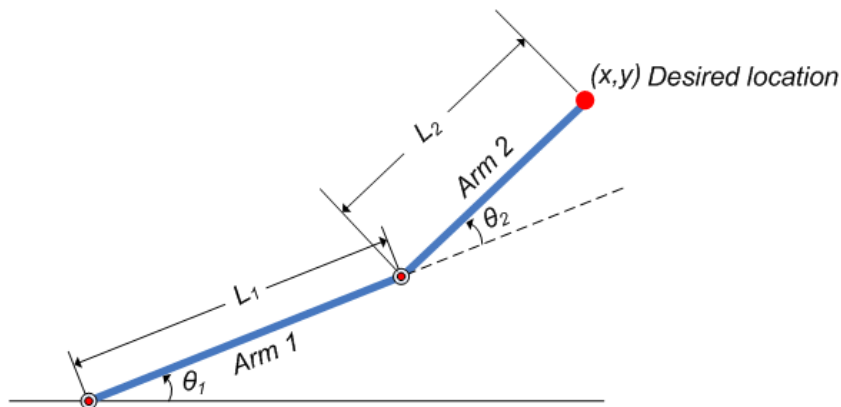


Figure 2.1.: Concept of Inverse Kinematics [18]

3. Virtual Embodiment

This chapter will look at the concepts of sense of embodiment, which were discussed in other papers.

There has been a lot of research done in psychology about the topic of embodiment. We have experiments such as 'the rubber hand illusion' [HP05], where we can trick the mind to believe that a rubber hand is actually the real hand. These experiments show that we can easily fool the mind. It's fascinating, because even without the sense of feeling, but merely relying on one's belief, we can make one think that a virtual avatar is one's own body. This sense of embodiment is the ultimate goal to achieve to create an immersive experience in virtual reality. Dealing with discrepancies that occur in virtual reality will hopefully increase the sense of embodiment. But, what is sense of embodiment?

Sense of embodiment is defined by Kilteni et al

as the sense that emerges when B's properties are processed as if they were the properties of one's own biological body. [Kon12]

The term 'embodiment' itself can be categorized into three concepts. The concepts of sense of self-location, the of sense of agency and the of sense of body ownership.

Sense of Self-Location (Spatial)

The sense of self-location is one's spatial experience of being inside a body, meaning the space in which one perceives one to be located at. If there is a body, self-location would be the feeling of one's self being inside that body. Self-location is also dependent on the visuospatial perspective, where first-person perspective gives one a greater sense of self-location than a third-person perspective.[HP05] This would suggest that to achieve a greater sense of self-location, we would have to focus on the first-person perspective of the user in virtual reality.

Sense of Agency (Motor)

The sense of agency refers to the control of one's body and the motor activity. Basically, when one is able to navigate the body according to his own will. We would have a high sense of agency, if the intention is close to the outcome of a movement, making the embodiment more realistic. Discrepancies have a negative impact on the sense of agency. [Kon12]

Sense of Body Ownership (Affective)

The sense of body ownership refers to one's self-attribution of a body, meaning if one believes that the body is his own. Basically if one is convinced by the illusion that anything which affects the body affects one as well, one would have a high sense of body ownership. This would mean that the virtual body, arms and hands would also need to visually resemble the real body parts and have morphological similarities .

Kilteni et al. created a table which has a proposed scale for sense of embodiment:

One experiences SoE toward a body B	if one feels self-located inside B at least in a minimal intensity if one feels to be an agent of B at least in a minimal intensity if one feels B as one's own body at least in a minimal intensity if and only if one experiences at least one of the three senses at least in a minimal intensity
One experiences full SoE toward a body B,	if one experiences all of the three senses at the maximum intensity (Biological body)

Table 3.1.: Table 1: Propositions for Sense of Embodiment Towards a Body B [HP05]

Depending on these three concepts and the definition we can make sure that the user has a sense of embodiment in virtual reality, by providing the user with a body and making one able to control the body according to one's will. The experience will be more immersive for the user, however it is probably impossible to have one experience a full sense of embodiment, where we view the virtual avatar like our biological body - At least not with our current technology. Additionally, we have to deal with situations which would not occur with one's biological body, but which could occur with one's virtual body. For

instance, we are unable to walk into walls with our real body or position our hands inside a physical, solid object, however it is possible in the virtual world.

The paper 'The role of interaction in virtual embodiment: Effects of the virtual hand representation' mentions that the virtual representation has an impact on the sense of ownership, however also highlights studies which show that users tolerate if the virtual arm has a different length compared to their biological arm.[16] This would allow us to use a standardized 3D body model, which all users are able to use.

4. Concept and Design

The chapter will briefly discuss the concept and the design of the thesis. It will quickly summarize what will be implemented in the following chapter and how the user study will be set up.

4.1. Idea

In order to increase the sense of embodiment, we would need to deal with discrepancies between the real and virtual body. Not handling these discrepancies is an issue that is not taken care of in many VR projects. Currently, in these projects the users can move freely through the world and not be impacted by any collision. Discrepancies only occur, when we allow virtual objects to have an impact on the virtual body, where we will be restricting the virtual body of it's can movement. Discrepancies occur as our real body is not impacted at all by these restrictions.

In the implementation phase, we will try to find solutions or ideas how to handle these discrepancies. In order to do so, we need to set a few criteria, taking the points (sense of self-location, a sense of agency and a sense of body ownership) mentioned in the previous chapter into account, which will be used as guidelines for each of the implementation. These criteria will also be important for the user study.

- **Orientation:** Does the user need to keep his or her orientation?
- **Immersion:** How much should it impact immersion/sense of embodiment?
- **Restriction of the view:** What are the consequences on ones view?
- **Discomfort:** How much discomfort should the user feel?
- **Nausea:** Does the implementation lead to nausea and motion sickness?

Keeping these criteria in mind, we will implement different methods how to handle these discrepancies and with the help of a user study we will be comparing the methods.

4.2. Process

The implementation and the user study will have the following outline:

1. Create a character which the user can control
2. Add different methods to handle discrepancies based on the criteria identified above
3. Make a sample environment for the user study
4. Invite several participants and carry out the user study
5. Analyze the result and potentially make improvements

We will mainly rely on the methods and software explained in the 'Fundamentals' chapter.

5. Implementation

In the following pages the implementation process will be explained in detail. The approach will be discussed, how ideas were implemented and what problems might have been an issue to deal with. Discrepancies which occur during collisions will be handled using different methods. First, the discrepancies at the head will be considered and then the discrepancies at the arms and hands. Both need to be approached with different methods to fully increase the embodiment of the user. After that a setting for test users will be established to test and analyze the methods.

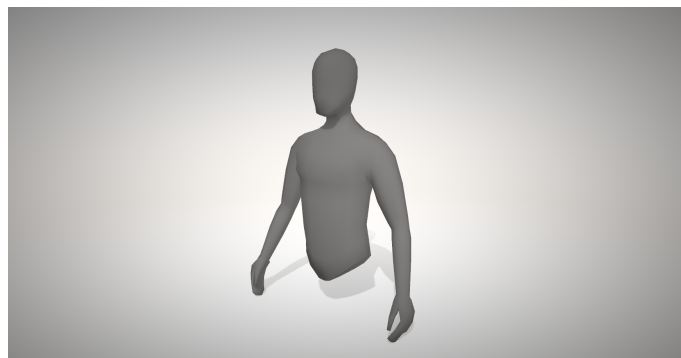


Figure 5.1.: Upper-body Character Model

5.1. Setting up the Character

When developing in Virtual Reality, a general issue that one has to deal with is the portrayal of the user. Considering that one is aiming for a realistic embodiment (see chapter 'Virtual Embodiment'), the choice might seem simple: We could simply creating a realistic 3D character model which the user is able to control. However, in order to do so, we would need full body tracking devices, such as the kinect, but most of them are not yet 100% practical and accurate. In the case of this thesis, we are purely depending on the HTC Vive which innately only tracks three points in the play area: The headset

and it's two controllers. The option of implementing additional tracking devices could be explored in future developments.

5.1.1. Creating and Controlling the Character

In order to deal with discrepancies and collisions, the user would need to be able to control a character. Thankfully there exists something such as 'Inverse Kinematics', which has been partly explained in the 'Fundamental Chapter'. Using 'Inverse Kinematics' we are able to create two virtual arms, which can be moved in a realistic way and can be controlled using the two controllers. In this case, the controllers define the positions of the hands, which then are connected to the body via the arms. The headset tracks the head and acts as the eye of the user, which is done by positioning the camera where the eyes of the character are. This achieves a sense of self-location and from the position of the headset, we can also define the rough position of the person's upper body and thus fulfilling everything which is needed to know in order to implement inverse kinematics (apart from the elbow positions). The elbow positions are set at a fixed position, so that the hand-head-elbow always creates a triangle. Due to the tracking restrictions, legs will not be considered for now, although they might be very interesting to regard in the future. Visually the legs are removed as well, in order to prevent disembodiment which may arise due to the feeling of uselessness and disownership about the leg [Vig10]. The final result of a character is a floating 3D model of an upper body, which the user can freely control. The user should be able to have a sense of self-location, by having the illusion that the one's self is inside the virtual body and some sort of sense of agency as he is able to move his arms and hands according to his will.

5.1.2. Moving the Character

Despite being able to control the arms of the character the user still lacks control over the movement of the character. The initial approach was to simply map the rotation and position of the camera onto the character, which however would result in a very unrealistic movement of the character and hurting a good sense of embodiment. Thus, the rotation of the camera is mapped onto the head only, whereas the entire rotation of the body needs to be calculated. By calculating the midpoint vector between the two hands and using this vector as key point, the character is able to face the direction in which his hands are facing. As a result, the character can then be steered more accurately. However, whenever both arms are moved behind the back whilst the user still faces the same way, a buggy

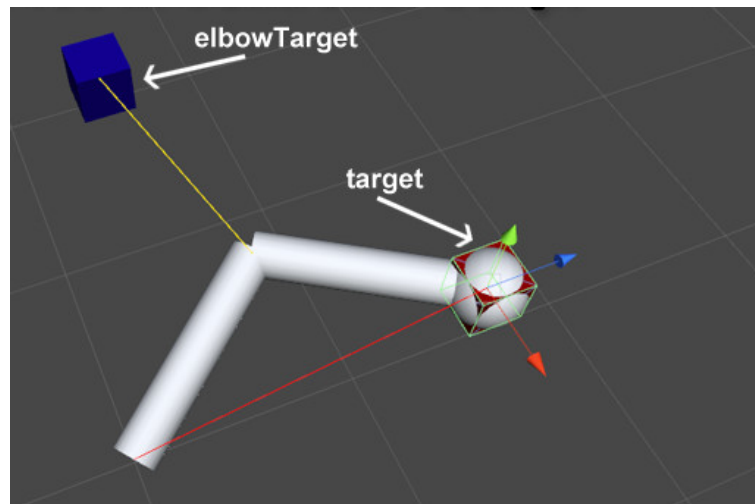


Figure 5.2.: Inverse Kinematic Model [Día17]

movement of the character occurs as well. Situations are created where the 3D model randomly flips. In order to solve this issue, we will still keep in mind which way the camera is facing, in addition to the direction of the hands. In the end, we have a user friendly control over the character with a high sense of agency, albeit it should be noted that there are still limits to this implementation, due to fact that we're restricted to three tracking points.

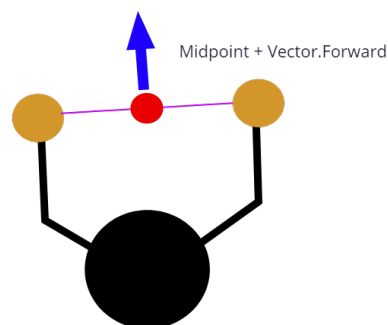


Figure 5.3.: Sketch of Direction

5.2. Collisions and Discrepancies

The user now has a functional character, which he or she can control freely. However, without handling any collisions, the user could move his character through any virtual objects, such as walls and obstacles. He or she would only be limited by actual physical

objects in the play area. This greatly affects immersion and realism of the virtual experience of a user. Thus, we will introduce discrepancies. Discrepancies occur, whenever the virtual body is being impacted by the physics of the virtual world, however the real, biological body in the real world is not. That could result in situations, where the user is standing inside a wall, his virtual avatar however, is still positioned outside the wall actively trying to get to the position of the player. The moment the user moves outside the virtual wall again, his virtual character moves to his current position. In order to implement this, we would need to make sure that the entire virtual body has colliders and is affected by the Unity physics engine. Since we only have to deal with the upper part of a character, we can ignore the collisions happening at the legs - because there are none. Thus only collisions with the head and arms have to be detected. Using the in Unity inbuilt “Ragdoll” function, we are able to add capsule colliders along the arms which are connected with joints. This method of collision detection is not very accurate, however Unity does not provide any efficient alternatives. Any collision will then be detected by the physics engine of unity.

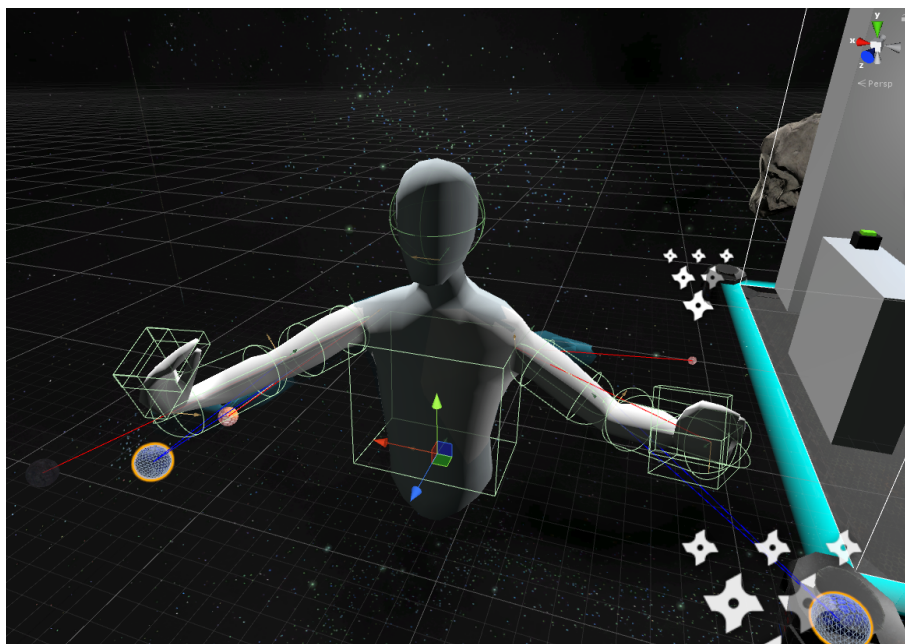


Figure 5.4.: Character Model with Ragdoll-Collider

The result is quite disappointing as the user does not always recognize every discrepancy happening and easily loses orientation or is unable to grasp what is happening with his virtual body. For instance, when the user moves into a virtual object, his virtual avatar might stop moving, yet the user would not even notice given the lack of feedback. Thus our goal is to give the user the ability to recognize and 'feel' discrepancies. But, unless

there is an actually way to fully reproduce a virtual object as a real physical object in the real world in that exact position, collisions will never feel 100% real. Although with the help of visual, haptic or audible indicators, we can at least show the user that something is not “right” when discrepancies are happening and keep the user in immersion by having more realistic interactions. The issue, which is mentioned in the ‘Virtual Embodiment’ chapter, is that discrepancies have a negative impact on the sense of agency, as the player is restricted where he or she can move his body and his or her virtual arms. When the body stays outside virtual objects, the user also loses some sense of self-location. Yet, for the sake of immersion, it is still important that one is not able to just pass through virtual objects without any consequences. In order to so solve this, we have to implement methods to increase the sense of embodiment.

5.2.1. Discrepancies at the Head

It’s difficult to imagine what happens when our head moves into an object, because it is physically impossible. What do we see? Do we see darkness? What way does one need to move in order to get outside of the wall again? What would be the most user friendly approach? These questions all concern with the sense of embodiment, where we have to deal with situations which are not possible to happen to our real body, but possible to our virtual body. Hence, the first step is to consider how to deal with the discrepancies at the head and given that discrepancies occurs at the head, the best way to handle discrepancies, would be via visual feedback, where ones view is altered. The different effects will then be shown to the test subjects who then have to provide feedback.

5.2.1.1. Visual Feedback

The issue with changing the view of the user is that there are a million different possibilities how to alter ones view. We have identified five criteria in the ”Concept and Design” Chapter:

- **Orientation:** The user still needs to keep his orientation whenever he/she is in a virtual object.
- **Immersion:** The user should keep the immersion as much as possible. The sense of embodiment should not be impacted much.
- **Restriction of the view:** The user should see less or nothing at all from the environment, as in reality we can’t see through objects

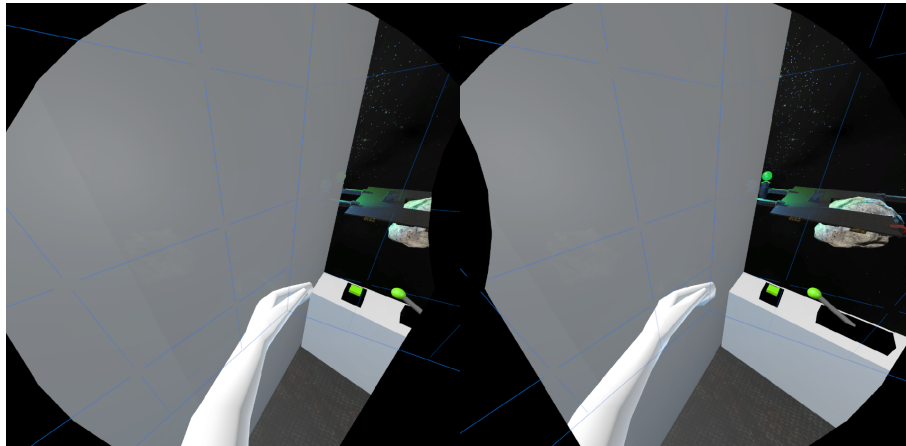


Figure 5.5.: User at a Position of a Virtual Wall (No Effect)

- **Discomfort:** The user should feel some sort of discomfort in order to encourage the user to go back to a valid position. Walking against a wall or object would hurt in real life, thus a little discomfort might increase the sense of body ownership
- **Nausea:** The implementation should best not cause nausea and any motion sickness

Considering these factors, five different effects have been identified:

- **Effect 1:** Adding a blur to the view of the user
- **Effect 2:** Adding a distortion to the view of the user
- **Effect 3:** Adding a color shader to the view of the user
- **Effect 4:** Adding the option of making the view complete black (Fade to Black)
- **Effect 5:** Adding a shader which highlights the outlines of virtual objects from the inside and adding surfaces to the insides of the objects

Adding Blur:

The idea behind adding a blur to the vision of a player, is to allow the player to still keep their orientation and find their way, however reducing their vision so they can't see everything clearly. The visual change should suggest that something is wrong such as that the player is currently in an invalid position. In general, the user should still be able to see the surrounding objects albeit very blurry. This effect was done by using the existing "post-image processing" plugin provided by Unity itself, where simply the settings of the camera is manipulated.

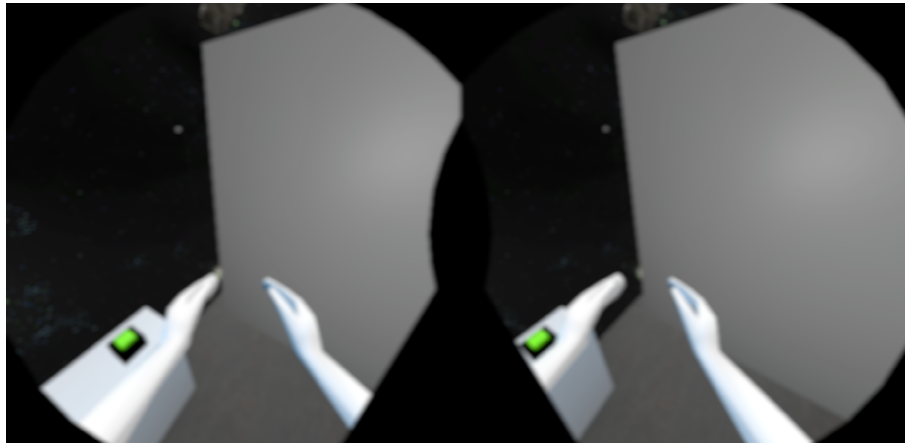


Figure 5.6.: User at a Position of a Virtual Wall (Blur Effect)

Adding Distortion:

The distortion effect shader should provide the user with an uncomfortable view, where the entire view sort of tilts and distorts. This could discourage the user from going into walls in the first place, who will try to abstain from even moving close the walls. This effect might cause discomfort and motion sickness, however the exact reaction will be carefully observed in the following study. Whenever the user moves into an virtual object with his head, a distortion shader is applied to the view of the user. The distortion shader was taken and adjusted by the shader 'Distortion Image Effect written by Jason Booth'. [Boo15]

Adding a Color Shader:

This shader basically creates a filter, which turns all existing colors into different colors without actually changing the individual materials. The colors that should be initially be seen by the player are passed through a function, which calculates the new color. The resulting color can be adjusted depending on one's desire. The shader is applied whenever the user's head moves into a virtual wall. The purpose of this shader to simply notify the user of a discrepancy without influencing any other parts of his vision. In other words, the user knows something is up with his positioning, but still keeps his orientation and everything else. The 'Change of Colors Effect' was done by implementing a shader which was inspired by the shader 'BWEffekt by Alan Zucconi.' [Zuc15]

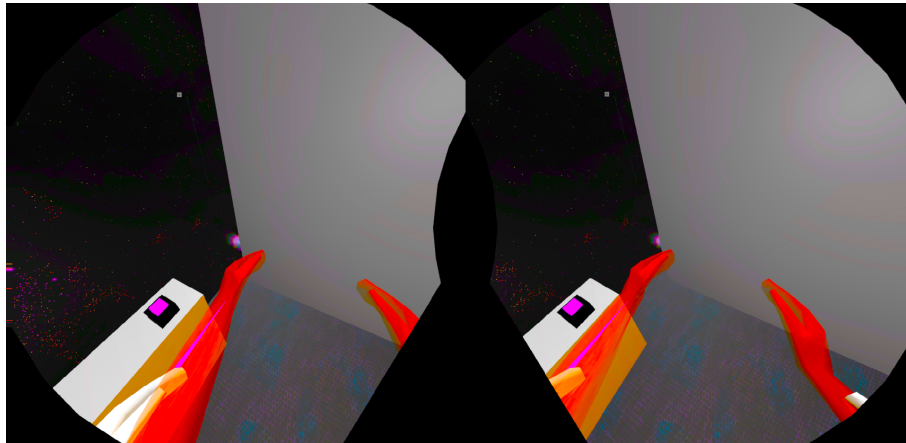


Figure 5.7.: User at a Position of a Virtual Wall (Change of Colors Effect)

Fade to Black:

This idea is nothing new in the industry and is used by many other developers already. In fact it is the “go-to” solutions for many VR simulations and games. When a user walks against the wall and his “head” is within the virtual wall, the field of view of the player turns black, thus giving the user a feedback that his head is stuck in the wall. This also prohibits the user from seeing “through” the wall, which could for example prevent players from cheating in games. A developer could even decide to restrict the movement of the entire environment when the user has collided against the virtual wall. “Fade-to-Black” would avoid motion sickness in such situations. This method will play a significant role during the study, where we would use this method as a reference point, when testing other options. The implementation was done using the pre-coded “Fade-to-Black” class which was provided by the SteamVR plugin and detecting a collision between the virtual head and the virtual wall.

Adding Interior/Surface Shader:

3D objects and their surfaces usually have only an one-sided surface depending on the surface normals, meaning that a surface can only be seen from one side. Hence, whenever the user is within a wall, he would not know how large the wall actually is and how far he would need to go in order to get out of the wall again. The surface shader thus adds surfaces on the insides of the wall, in addition to highlighting the outlines. The user can exactly see how large the virtual object is, in which he currently is. The shader was inspired and modified by the ‘Outlined Diffuse Shader’ by Luke Kabat. [Kab17]

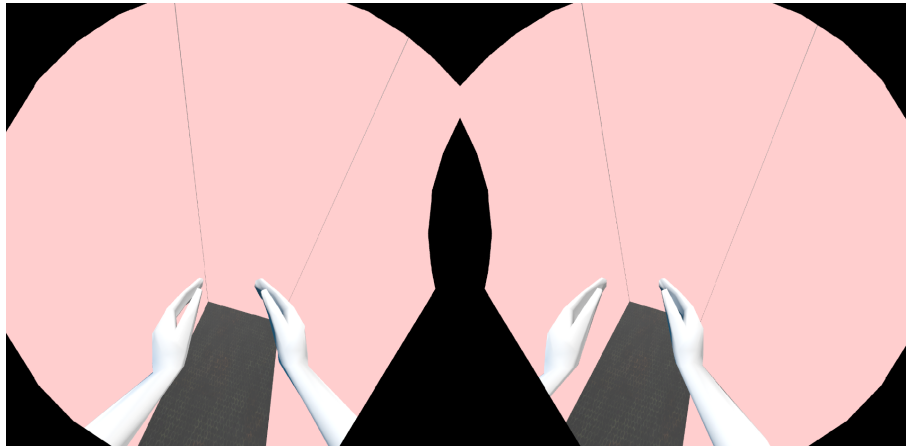


Figure 5.8.: User at a Position of a Virtual Wall (Interior Effect)

These different effects will be carefully analyzed in the user study, based on the five criteria, in order to identify the most effective and pleasant way for the user to experience a virtual collision.

5.2.2. Discrepancies at the Arms and Hands

Discrepancies at the arms and hands will be handled a little bit differently. We have to observe different scenarios: The user could move through walls and through objects with his hands by accident or one could purposely try to pick up and interact with objects, which could result in discrepancies.

In order to find different methods to implement we will look back at the 5 criteria for handling discrepancies at the arms and hands.

- **Orientation:** The user should always recognize easily where his real and his virtual arms and hands are.
- **Immersion:** The user should keep the immersion as much as possible and should keep a high sense of agency when interacting with the environment.
- **Restriction of the view:** The view does not needed to be restricted
- **Discomfort:** The user should not feel much discomfort
- **Nausea:** The implementation should not cause nausea and any motion sickness

In this case, we can basically focus on the orientation and immersion part.

5.2.2.1. Visual Feedback

Similar to the head, when colliding with the arm against an object, a ghost image of the body is created to indicate the discrepancies. So, every time discrepancies occur at at least one of the hands, a ghost image of the body is created which is then controlled by the user, whilst the “real” body, albeit still trying to match the correct position, is limited to the restrictions set by the physics engine. In order to show these discrepancies, there are two bright lines connecting each ghost hands with the virtual hands. This shows which ghost hand belongs to which hand, so the user can easier relocated his hands to the the “real” positions. The green lines have the shape of a cone, with one end being very small and the other end, which is at the ghost hand, being bigger. This effect should encourage the user to move his or her real, biological hand to the position of the virtual hand of his or her character. Every object turns a bit transparent, in order to see the ghost hands and lines when the arms collide with the walls, .

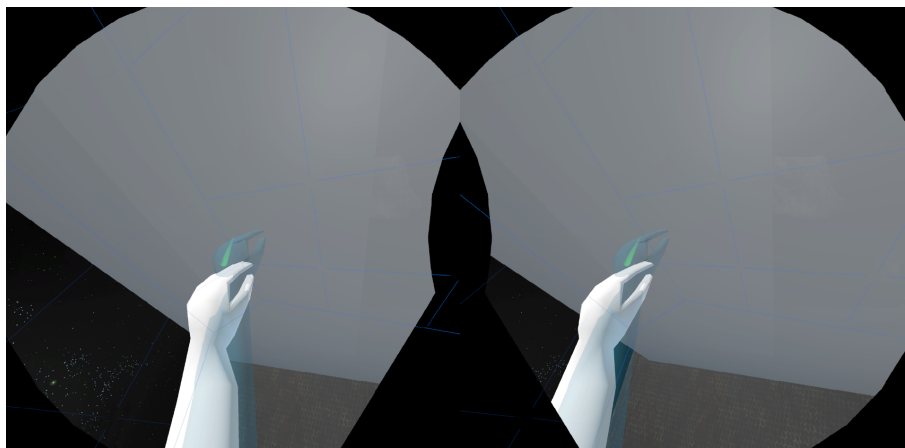


Figure 5.9.: Ghost Image Effect

5.2.2.2. Haptic feedback

We can create a rumble every time discrepancies occur using the HTC Vive controller inbuilt haptic function in the controllers. The haptic feedback happens on the controller whichever controls the hand that experiences the collision. So, when either the right or the left arm and their respective hands collide with a virtual object, the user will be notified of a collision by a rumble. This will give the user an idea which of his hands is experiencing a collision and can adjust his hands positioning accordingly. Haptic feedback might be the most immerse effect, as the user is actually able to feel collisions and the user would have a proper idea which hand currently experiences a discrepancy. But, the

haptic feedback is not giving the user an actual resistance, which is why this method is probably not the ultimate solution.

5.2.2.3. Audio feedback

We can also “hear” discrepancies with the help of audio. The idea is to choose a relative monotone sound which is not too disturbing, but which also stands out when there happens to be other sounds as well. The sound is played every time discrepancies occur at the hands and arms. The user could identify discrepancies by simply listening to the sound, as the sound source is located at the positions of each controller (given the stereo function is set up correctly). Using this method anyone could technically identify discrepancies. In the user study it will be seen how much impact it would have on one’s immersion.

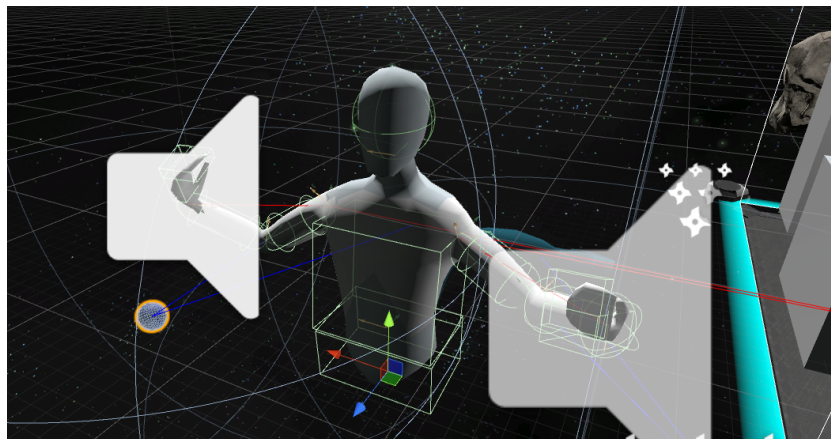


Figure 5.10.: Audio Listeners attached to each Hand

5.3. Sample Environment Design for the User Study

In order to test these effects, we need to create a suitable sample environment, where the user is able to test these different methods. This environment is used for the user study as well. The sample setting is in space and the user has different objects to interact with.

Levers and buttons are also added for the user to interact with. These were done using the Unity physics engine, where the user is able to exert forces upon the lever or buttons and thus activate them. Upon operating them, the user is encouraged to go into walls due to different scenarios: For one, this is achieved by firing a missile which shoots at an object behind the wall. Additionally, another button also slides a wall object directly onto the position of the player, thus pushing the virtual body away and creating a discrepancy.

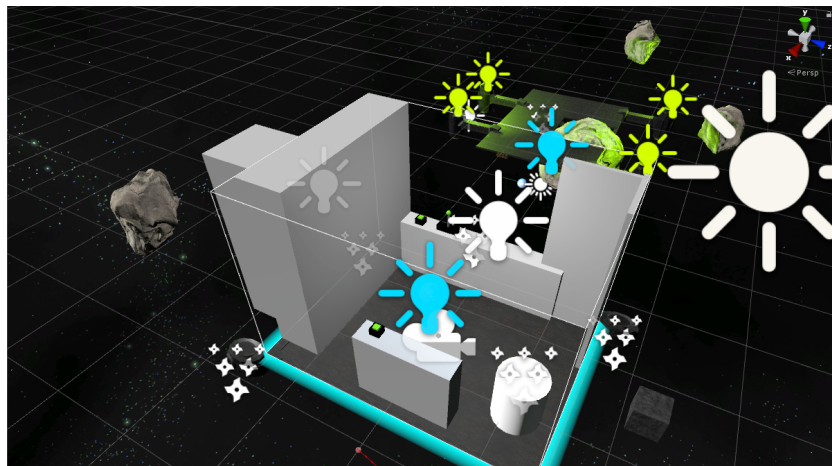


Figure 5.11.: Sample Environment

6. User Study and Results

In the following sections the user study will be described and the results analyzed.

6.1. Study

The point of this study is to identify the most rewarding way for the user to identify discrepancies that occur with his head and his arms and hands. People will be invited to participate in the study. The study will consist of multiple parts in order to test the implemented methods.

User Study Process

1. Questionnaire which will collect the data for the demographics
 - These results will be analyzed in section '5.1.3.'
2. First testing phase where the user will be asked to perform different tasks. During this phase the focus will be on the user's hands and arms
3. Answering a few questions regarding discrepancies of one's hands and arms
4. Followed by a short discussion to gain additional insight
 - These results will be analyzed in section '5.1.4.' and discussed in '5.1.5.'
5. Second testing phase consists of applying effects to one's view as this phase deals with discrepancies at the head
6. Further questions regarding discrepancies at one's head in addition to general questions
7. Followed by a short discussion to gain additional insight
 - These results will be analyzed in section '5.1.6.' and discussed in '5.1.5.'

6.1.1. Methodology of the Study

The books 'Questionnaire Design' by Ian Brace and 'Measuring The User Experience' by Tom Tulli and Bill Albert are helping to create a successful design for the user study. According to Brace, a subject loses attention after 90 minutes, whereas 30-45 minutes would be a realistic scenario. However, there are a lot of things that need to be tested and asked and there is only a limited amount of participants that can be invited to participate realistically. We will thus make every participant perform all tasks and test all trials, but are limiting the study to 45 minutes a person. This is done by having only about 20 questions with the addition of a discussion phase. In order to maintain more accurate results, where the participant is still able to remember and to reflect, we are splitting the study into two parts. A discussion phase and an interview phase, which would also help to understand the reasoning for some answers and also mask incorrect answers. Incorrect answers may occur when the participant gives answers such as "Yes, I agreed, except I think that...", whereas the real answer would be actually very opposite. [BRA08] Nevertheless, the questionnaire will help to gather data and statistics to help to see tendencies and create patterns, whereas the discussion will help to understand these tendencies in order to come to an effective conclusion. For the questionnaire, we will rely on the use of multiple choice, rank order and likert scale questions which the user is tasked to answer. If the participant is lost or stuck, he or she will have the ability to inquire for further information about the question. Additionally, there are only a few questions on one page as well, which enhances the attention of the participant.

6.1.2. Test Cases of the Study

During the study the participant is asked to perform different tasks in order to test the different methods.

1. Activate a button which fires a missile at an object behind a wall.
 - The user is asked to look at for target, resulting in the user trying to position themselves inside a wall
2. Activate a lever which instantiates a stationary, static box
 - The user is asked to try to pick up the item.
 - *Due to physical complications picking up boxed purely relying on physics and inverse kinematics is not possible. See the chapter 'Future Work' for further information.*

3. Activate a button which moves a wall

- The wall displaces the virtual body of the player by moving to the player's position

4. Floating Objects Interaction

- User is able to move floating objects in the environment

6.1.3. Demographic Questionnaire

There were 13 participants in the user study. There were 84.6% male participants and only 15.4% female participants with ages ranging from 21 to 24. Although the lack of variety might affect user study results, an online demographics questionnaire done by a reddit user with around 700 participants shows that the HTC Vive market consists of mainly men with 98% of the participants being male and only 2% being female. Furthermore, 54% of the participants are between 19 and 30 years old. We are thus dealing with a similar demographic pattern in this paper.

6.1.4. Results from the First Questionnaire

These questions have been answered by participants directly after the first testing phase. In the testing phase, which was carried out as described in '5.1.2. Test Cases of the Study', the participant interacted with virtual objects, levers, buttons and static objects such as virtual walls.

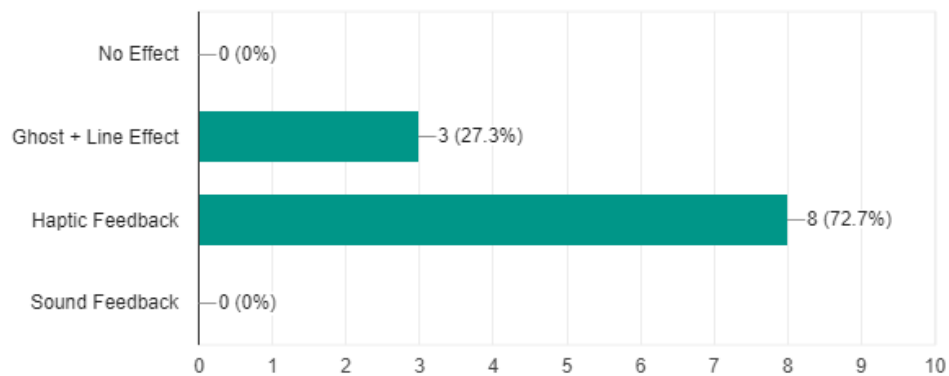
Here are some selected questions with results:

(The entire user study can be found in the 'Appendix' chapter.)

First Impression:

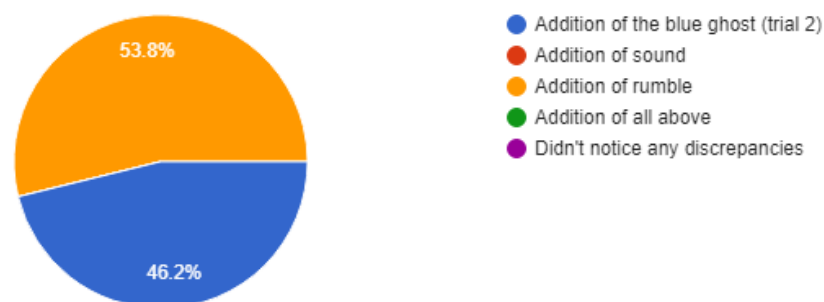
During which trial did your virtual hands feel the most natural?

11 responses



After which addition did you notice the discrepancies/collision the most?

13 responses



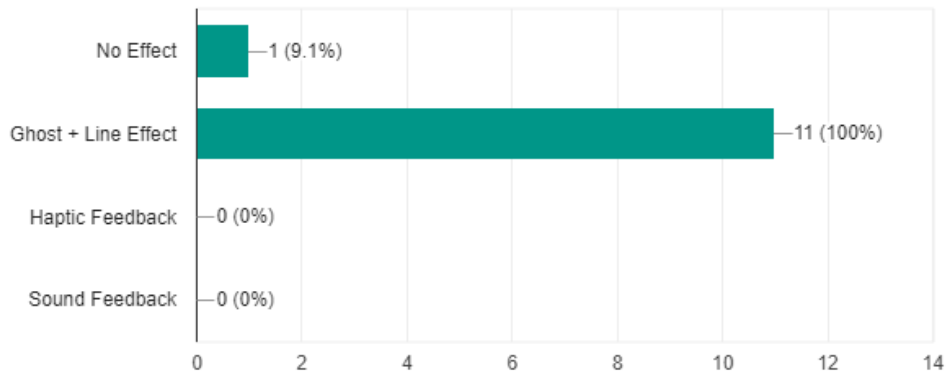
Many participants immediately mentioned the realism of the arms and hands. However, from the results at least 50% agreed that you could definitely notice discrepancies as soon as they happened - even with no additional effect. 53.8% felt that during the test case with the haptic feedback, they could recognize collisions the best, whilst 46.2% felt that it was with the addition of the ghost image. During these discrepancies 61.54% (8 out of 13) participants also conceived that the haptic feedback was the most natural reaction to collisions and 23.07% (3 out of 13) said that it was natural when the ghost image was introduced. Two participants didn't find the control of their virtual hands natural at all.

As the first impression of the user doesn't accurately reflect the true meaning behind the effects, we have to look at the five criteria: Orientation, Immersion, View, Discomfort and Nausea

Orientation:

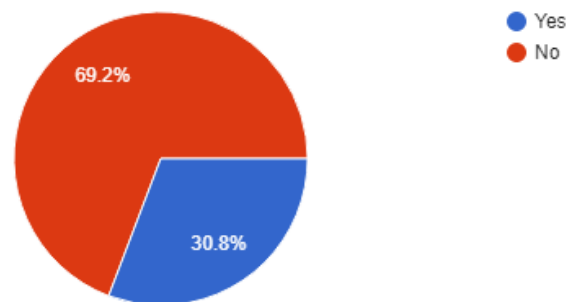
In which trial did you have a consistant idea where your actual arms/hands are in comparison to the virtual arms/hands

11 responses



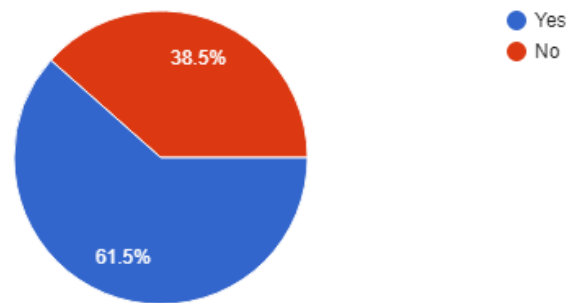
Did the addition of the two green lines encourage you to resolve the discrepancy?

13 responses



Did the addition of the two green lines help you to estimate the size of the discrepancy?

13 responses

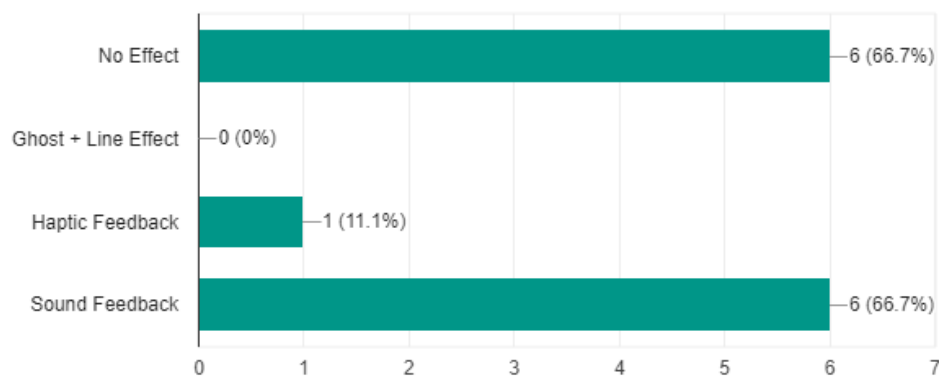


84.62% (11 out of 13) participants felt that with the addition of a ghost image and their respective lines between ghost hands and their virtual characters hands, they always had an idea where their virtual hands were and where their real hands were. The green lines proved only to be a little helpful with 69.2% mentioning that they were not encouraging to resolve the discrepancy, however it helped 61.5% to see how big the discrepancies were. Overall during the conversation, most of them agreed that the ghost image was very helpful in identifying discrepancies and helped them to see where to go in order to remove the discrepancies.

Immersion:

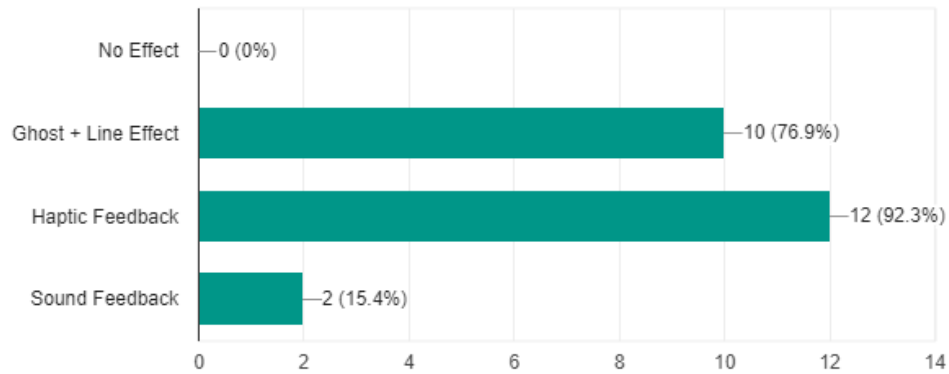
Which trial(s) had a negative impact on your immersion?

9 responses



Which trial(s) had a positive impact on your immersion?

13 responses

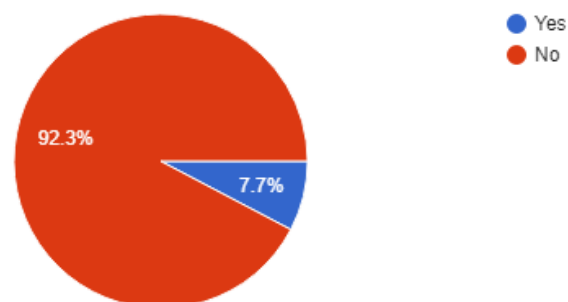


During the questions about immersion, 46.15% (6 out of 13) felt that having no effect had an impact on the immersion, in addition to 46.15% (6 out of 13) who also felt that sound had a negative impact. 92.3% (12 out of 13) participants agreed that the haptic feedback was a very effective method to increase immersion, similar to having a ghost image which deemed to be effective for their immersion by 76.9% (10 out of 13) participants.

Discomfort and Nausea:

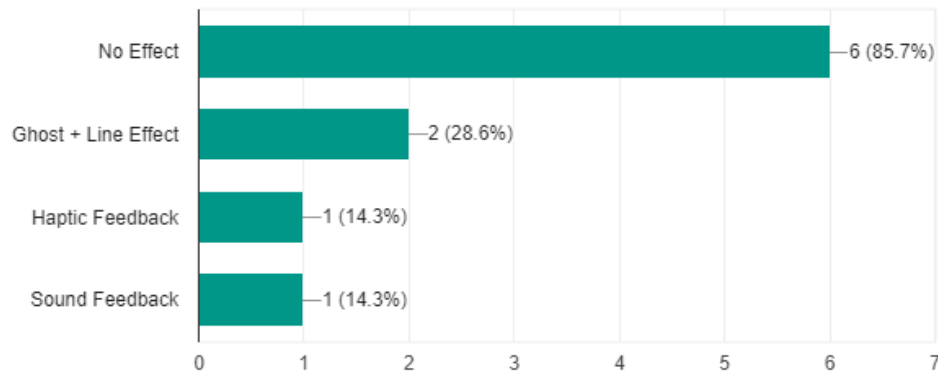
Did you ever feel motion sickness, nausea or disorientation?

13 responses



In which trial(s) did you feel discomfort due to discrepancies (meaning that the hands felt weird due to the offset)

7 responses



92.3% of the participants did not feel any nausea or disorientation during the trials. 53.85% (7 out of 13) people felt some discomfort due to discrepancies. During the discussion some expressed discomfort due to the character model, especially the way one could rotate their hand in an unnatural way. This will be briefly discussed in the 'Future Work' section.

6.1.5. First Questionnaire Evaluation

For the following evaluation we will refer not only to the results above, but also the entire user study which can be found in the 'Appendix' section. Observations done during the discussion phase will also be included. Having tested these different methods, the study about handling discrepancies at the arms and hands heavily implies that handling discrepancies are important for the immersion, sense of agency and the ability to control the hands and arms. Sound substantially distracts the user and destroys immersion. When asking the participants for the reason, they expressed that it does not seem very intuitive that one notices discrepancies via sound, however that it might still be a good way to alert the user that something is not correct. Nevertheless, the majority agreed that it isn't a good way to handle discrepancies. On the other hand, haptic feedback was praised highly, as it gives the user a physical sensation. But, it isn't comparable to the feeling when actually having an impact with real objects. The ghost image was also well received, as the participant could always tell where their actual hands were, thus maintaining their immersion. The green line did not have a huge impact on most of the participants, although some mentioned that it helps one to recognize which ghost hand belongs to which virtual hand.

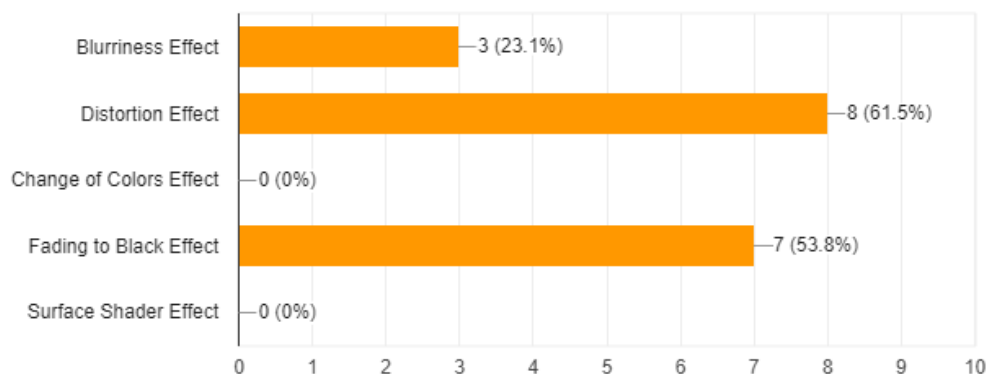
6.1.6. Results of the Second Questionnaire

After the first questionnaire the participants were asked to do the tasks ('5.1.2. Test Cases of the Study') again, particularly the ones where discrepancies with the head occurred. These task were done including all effects from the previous phase: the haptic feedback, the audio feedback, the ghost image including the attached green lines. The following diagrams depict the results from the second questionnaire. In this questionnaire, we specifically focused on the five criteria which were about one's orientation, immersion, discomfort and nausea. The questionnaire was followed by a brief discussion, where people could explain their choices. Here are the results for each of the five effects where the user had to rate on a likert scale each criteria.

General Questions:

Which trial encourages you to try to avoid the walls as much as possible?

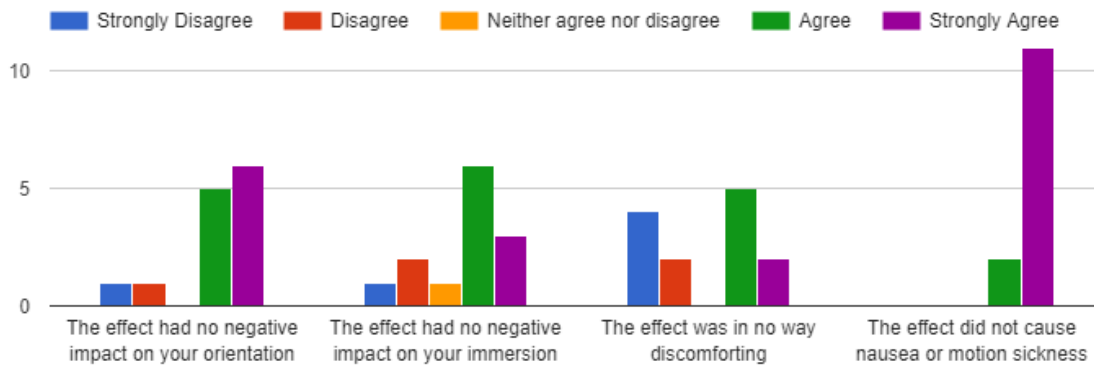
13 responses



Generally, most of the participants noticed the discrepancies whenever they happened or at least realized that something is not right. 61.5% during the 'Distortion Effect' and 53.8% during the 'Fade to Black Effect' felt that the effect discouraged them from going into walls.

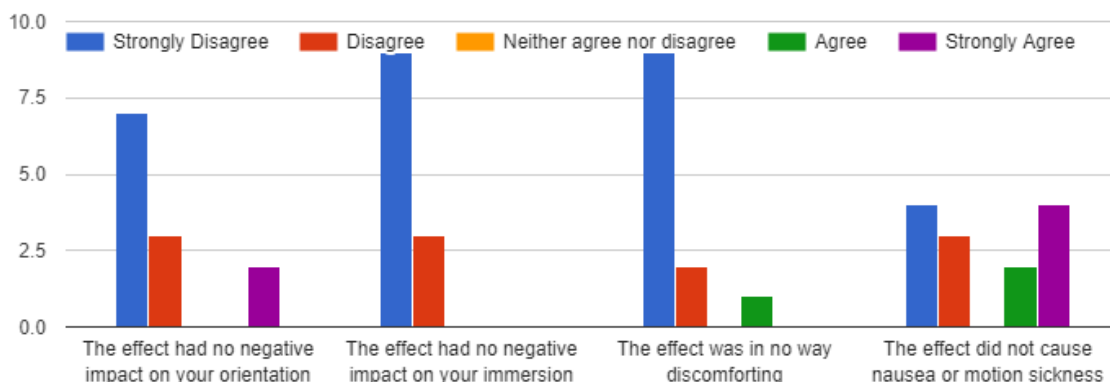
Likert Scale Questions About the Effects:

'Blur' Effect



The blur effect received mixed reviews, although everyone could agree that it did not cause any nausea. However, when asked if it was discomforting, the opinions were split about 50:50. In the discussion phase, people were asked if they were near sighted and most people with bad eye-sight did not feel that the blurriness effect was discomforting at all, whilst the majority of people with good eye-sight did. However, this could be pure coincidence and does not indicate a correlation. But, it would make sense, as people who are near sighted are used to blurry vision, whereas people with a good sight do not.

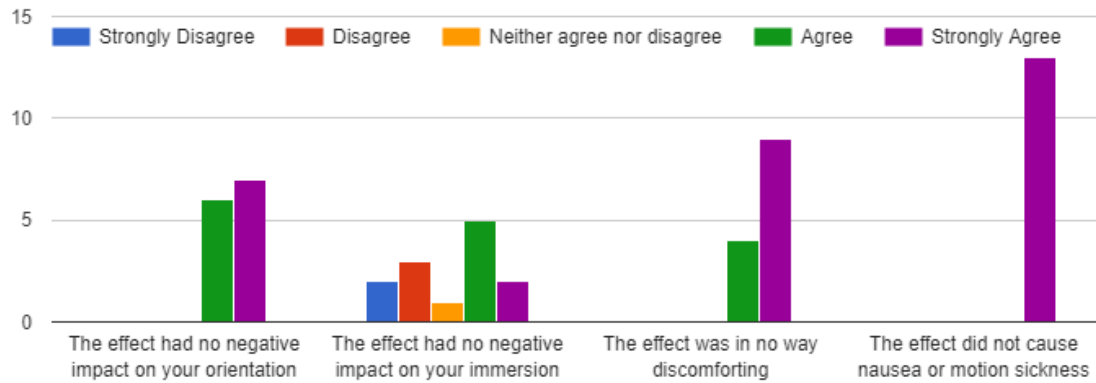
'Distortion' Effect



The distortion effect was not well received at all with most of the people thought it was very discomforting, disorienting and had a huge impact on their immersion. Some had

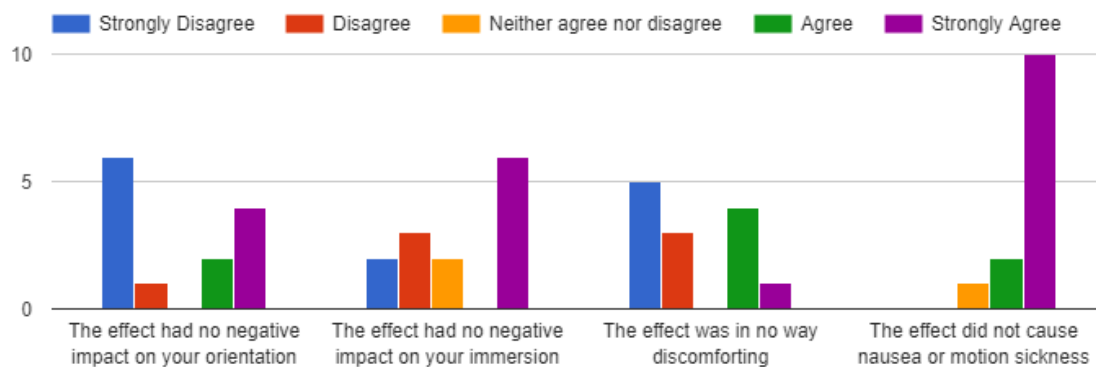
motion sickness and some did not.

'Change of Colors' Effect



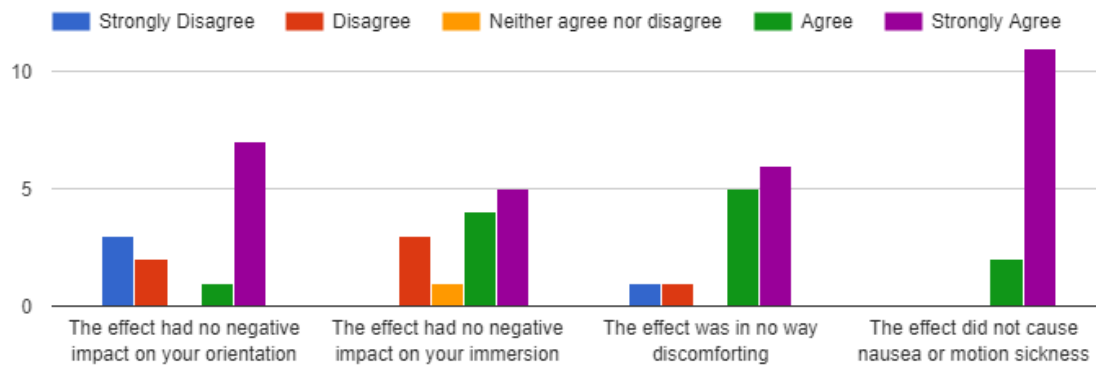
This effect was very well received with most of the participants felt that it was a cool view. After the discussion, the question arose how much of an impact does it have on one's immersion, as changing the color of the view, does not in any way resemble a collision with a wall.

'Fade to Black' Effect



'Fade to Black' seemed to have various mixed answers, were some mentioned that it was very discomforting as one easily loses orientation and it basically could represent anything, such as a simple 'change of scene'.

'Surface Shader' Effect

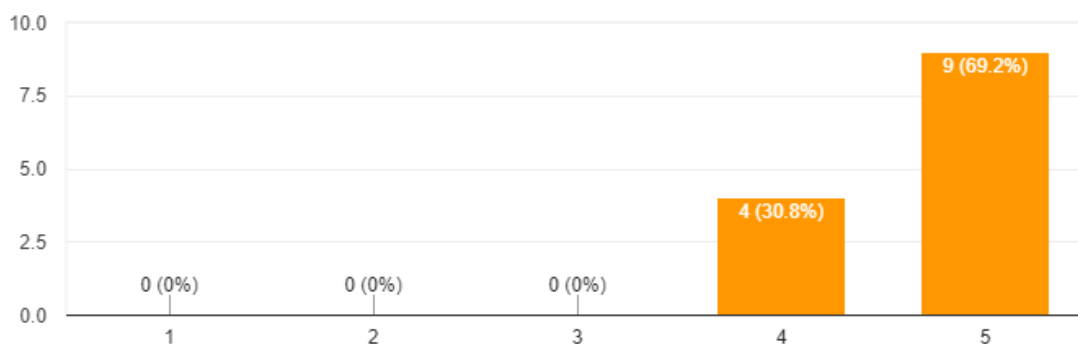


This effect also seemed to have mixed reviews with a tendency of approval. According to some participants, the danger would be that the user is confusing the wall for a room and the idea of actually being in a wall is obscure.

Overall Questions:

How important is the need to handle discrepancies in Virtual Reality in your opinion?

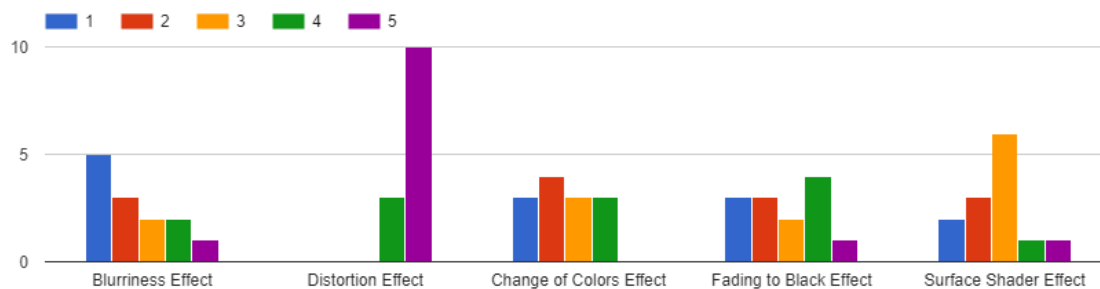
13 responses



Everyone felt that handling discrepancies in VR was important. When it came to the handling of discrepancies, the opinions however varied. For the handling at the arms, people praised the haptic response and ghost image, but did not think much of the sound. The green lines were also deemed as redundant.

6.1.7. Second Questionnaire Evaluation

Arrange the effects from best to worst



Users were told to rank the effects from a scale of 1-5

From the study, the 'Distortion effect' performed the worst and should probably be avoided in the future. This was kind of expected. The 'Fade to Black effect' and the 'Blur effect' was rated the highest, although it should be noted that they received mixed thoughts as well, with some mentioning that the 'Fade to Black effect' was very disorienting and 'Blur effect' was very discomforting for some. A participant suggested combining both effects, where the view would only go a little bit darker and a little blurry. This would probably an effective way to handle discrepancies. In the end, we should note for what purpose we need to handle discrepancies for. If it is important that the user should not be able to see through walls, then the 'Fade to Black effect' would be the best. Similarly, the 'Interior/Surface Shader effect' is effective to stop people from seeing through walls and still keep their orientation. However, this effect might confuse people, as people might misinterpret the wall as another 'secret' room, which the user can explore. The 'Blur effect' would be also effective likely for users with bad eye-sight, however, as mentioned, the correlation could be a coincidence. They would still be able to keep their orientation and barely see through walls. If the situation arises, where the user should only be notified of discrepancies, the subtle change of color would seal the deal.

6.2. Evaluation Summary

For the user study we can identify that every method could be implemented in different situations for different effects. For the hands and arms the main focus should be in the haptic feedback and using the ghost image for one's orientation. For discrepancies at the

head, effects such as the 'Interior effect', 'Fade to Black effect' (But not completely black) and the 'Blur effect' could be implemented in order to stop the user from being able to see through wall, in addition to having some sort of discomfort. Handling discrepancies is, however, very difficult as there is nothing that simulates a physical resistance such as a real, physical object. Investing in gloves that induces haptic, physical impulses could be an approach which would be more effective, but more immerse. In addition to the effects mentioned above, a haptic feedback at ones headset could also be an approach to help indicate discrepancies at ones head.

7. Conclusion

In virtual reality handling discrepancies is optional, however important to make the environment immersive. We specifically deal with discrepancies between ones real body and their virtual body. They occur every time their body collide against virtual objects, as their real body is unaffected by any collision happening in the virtual world. However, the danger with discrepancies is the impact on the sense of embodiment. We thus have to deal with these discrepancies and still try to keep a sense of embodiment, where we refer to the three concepts: Sense of self-location, sense of agency and sense of body ownership.

However, handling these discrepancies according to these concepts, proved to be more difficult than expected. It became clear that there is no perfect way to handle discrepancies during the research and implementation phase, unless there is an actual physical object in the position of the virtual object. Purely relying on the hardware, which HTC Vive provides, is pretty limiting, however there were a few methods that can be used in these cases. With these methods, we are at least able to give the user some sort of realism, reducing motion sickness and nausea, increasing sense of embodiment and convey the fact that discrepancies are happening. We thus dealt with different criteria which are deemed to be important for the user during their virtual reality experience: Keeping their orientation and immersion (embodiment), the ability to restrict the view, controlling their discomfort and not causing nausea. As a result, different methods were tested and not every method proved to be effective. Additionally, discrepancies at the hand and arms have to be treated differently to discrepancies at ones head.

Regarding discrepancies at ones arms, haptic feedback in form of a rumble seemed to be very effective, as the user instantly recognizes where discrepancies occur, and a physical feedback somewhat resembles what happens in reality. Having a ghost image and green lines to connect the ghost image and virtual body, helps the user to actually see the discrepancies and are very instrumental for users to identify the position they would have to go (in order to remove the discrepancies). Whenever the user leaves the virtual body, it will have a negative impact on the sense of self-location. With the ghost image, the user still feels to be inside a body, albeit the ghost body. Sound is only partially useful, as on the one hand, it could signal the user of discrepancies, however on the other hand,

it has a big effect on ones immersion. Regarding discrepancies happening at the head, a mixture of blurriness and darkness at ones view could indicate discrepancies. Combining blurriness, darkness and a surface shader, which creates surfaces for the insides of a 3D model, could even be better, as the user won't be able to see past the wall. But in most cases, the effects that need to be implemented would need to depend on the intent of the developer. Sometimes the user should just be notified of discrepancies, but in order to maintain their orientation, they should still be able to continue to see their environment. In other cases, the user shouldn't be able to see through walls at all, which could have an impact on ones orientation and immersion. It would also be interesting to explore further options, such as using additional hardware, where we can give the user a haptic feedback at ones head as well. The idea to give the user their own option, how discrepancies in their simulation are handled, could also be explored.

8. Future Work

8.1. 3D Models

Throughout the implementation, it became clear that investing in good 3D models for virtual environment project is very important. The 3D models used in this thesis were not the most realistic 3D models, which thus had an impact on one's immersion. For instance the hands were represented by abstract virtual hands. For future work, realistic and accurate 3D models could massively improve immersion, although high poly models are very performance demanding.

8.2. Tracking The Entire Body

With the addition of more trackers, we could map the entire body of the user onto the virtual body. On the legs, we would need to apply inverse kinematics and the same effects that are used to show discrepancies at the arms and hands. Additional trackers could also make the calculation of inverse kinematics more accurate and basically, the more tracker, the better the tracking. Another study could find the optimal amount of trackers needed without a tracker being redundant and without restricting the user's movement. However, it should be noted that one is innately limited to 11 trackers, but there are possibilities to increase that number. [HTC18]

8.3. Physics and Inverse Kinematics

As mentioned, additional trackers would make inverse kinematics more accurate. Unity physics engine was not fully supportive of an immersive VR experience. There were issues with creating accurate colliders and picking up objects. It would be wise to pursue other detection methods and ideally the inverse kinematics should fully rely on the physics engine as well.

8.4. User Study

The user study was done with 13 participants with some answers being very different from each other. Ideally a larger sample size should be explored in the future, where more people from different backgrounds test the different methods. Additionally, a user study that is several hours long, would provide more accurate answers. For example, a player is required to play a game for several hours whilst his or her emotions and reactions are captured. These result would have less bias and would be more accurate. However, more equipment, man-power and a bigger budget would be needed.

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Appendices

A. User Study Results

A.1. Demographics Questionnaire Results

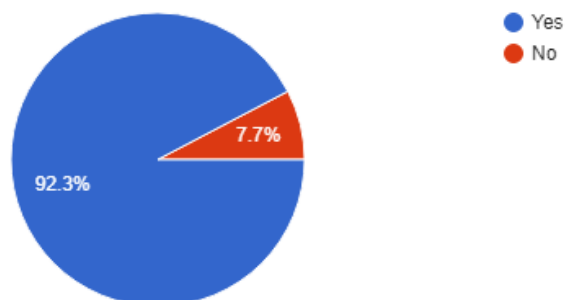
Which is your dominant arm?

13 responses



Are you Familiar with VR Headsets (Oculus, HTC Vive...)

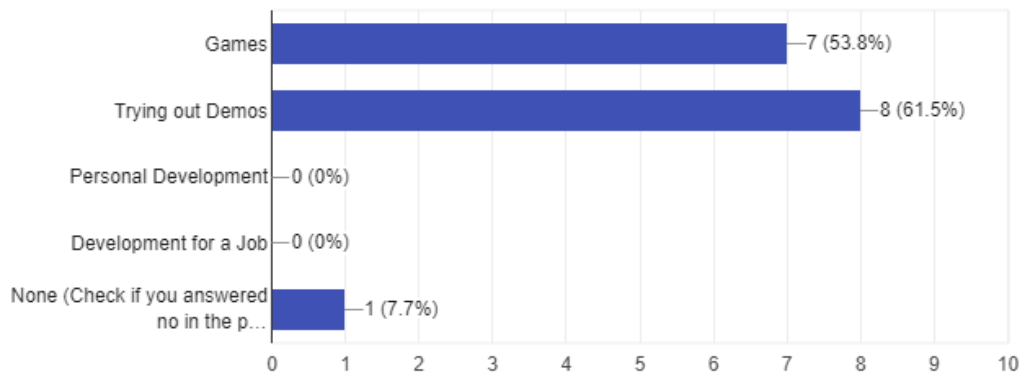
13 responses



Appendix A. User Study Results

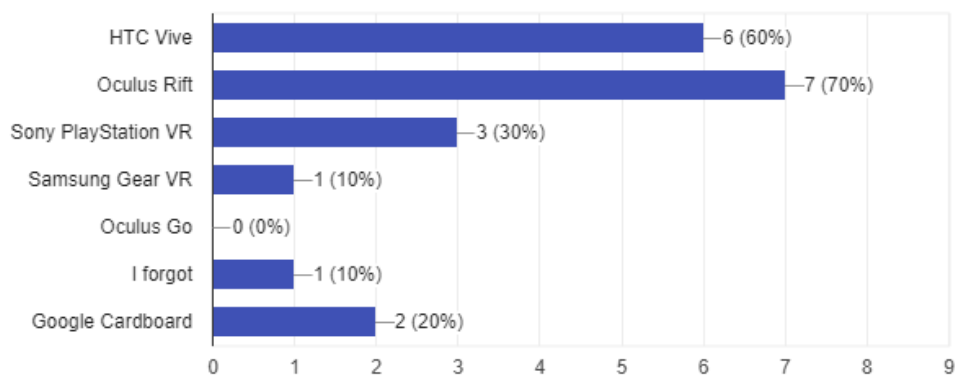
If yes, what is the main context you use or have used VR Headsets?

13 responses



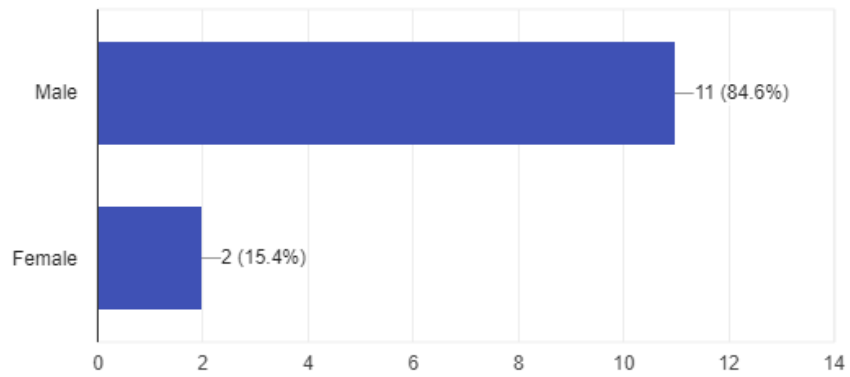
What gesture devices have you previously owned/used?

10 responses



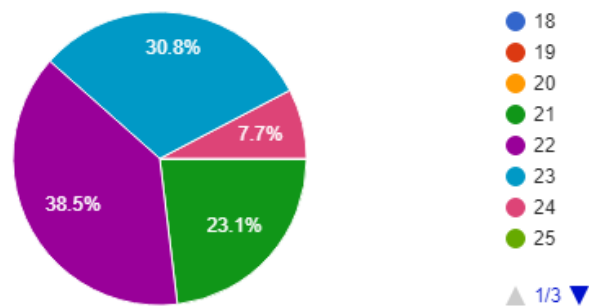
What is your Gender?

13 responses



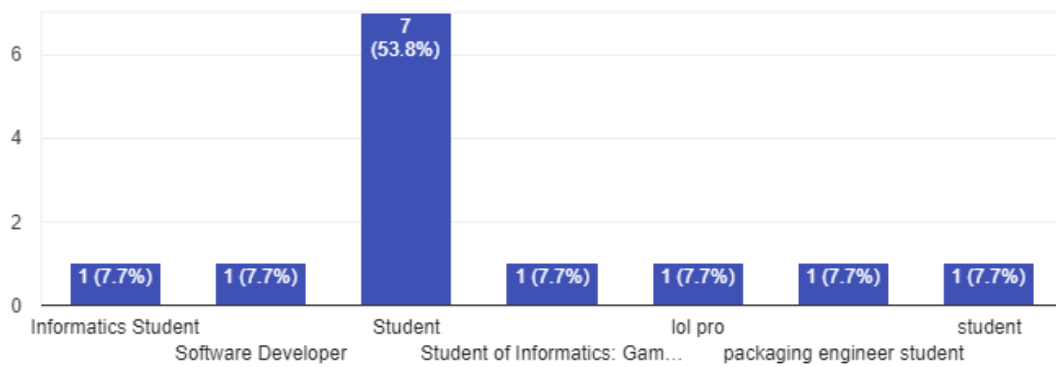
How old are you?

13 responses



What is your professional background?

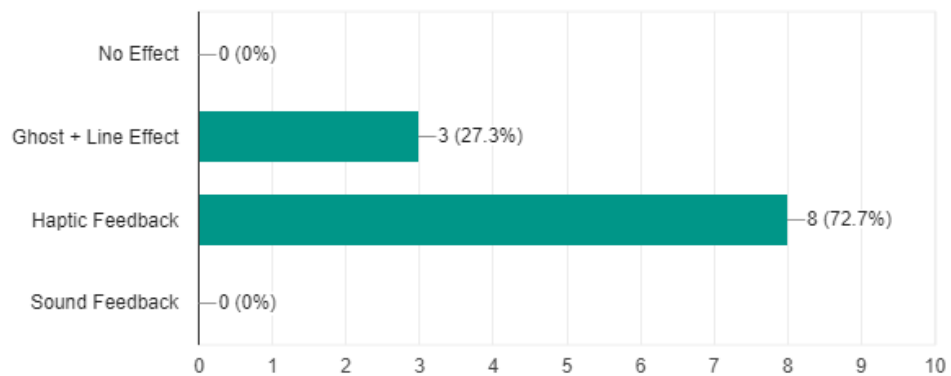
13 responses



A.2. Virtual Embodiment Questionnaire Stage One Results

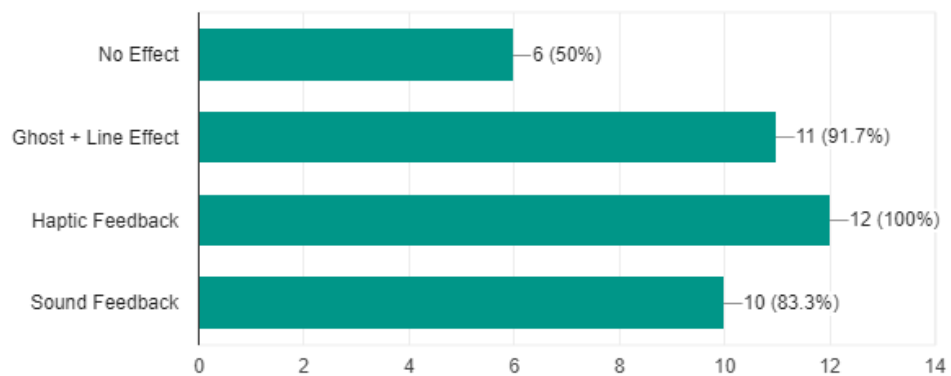
During which trial did your virtual hands feel the most natural?

11 responses



In which trial did you notice slight discrepancies (Unstimmigkeiten) between your virtual body and your real body?

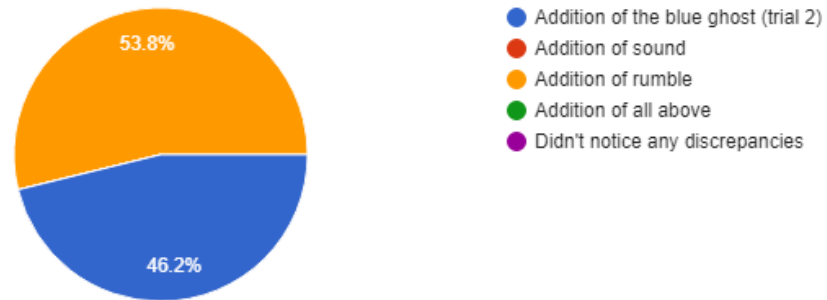
12 responses



Appendix A. User Study Results

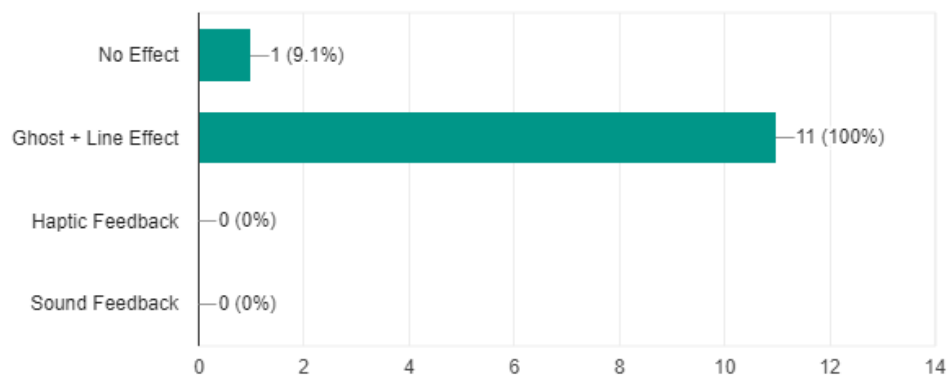
After which addition did you notice the discrepancies/collision the most?

13 responses



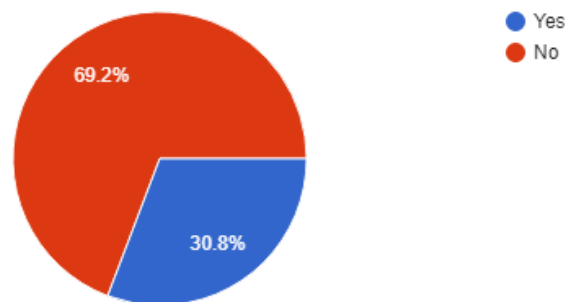
In which trial did you have a consistent idea where your actual arms/hands are in comparison to the virtual arms/hands

11 responses



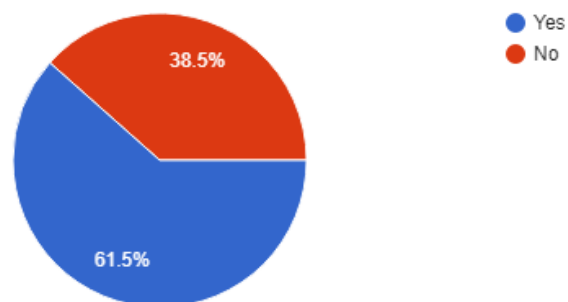
Did the addition of the two green lines encourage you to resolve the discrepancy?

13 responses



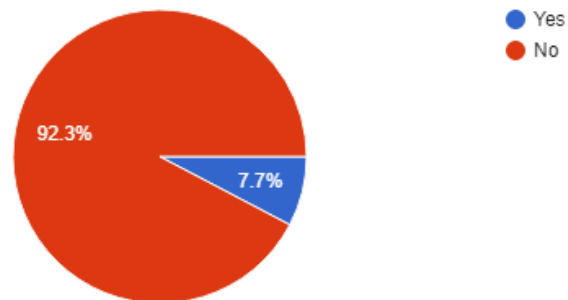
Did the addition of the two green lines help you to estimate the size of the discrepancy?

13 responses



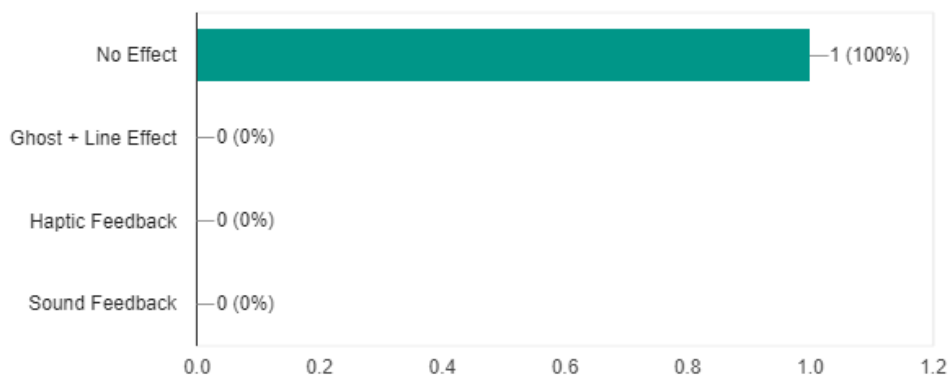
Did you ever feel motion sickness, nausea or disorientation?

13 responses



In which trial(s) did you feel nausea(Übelkeit)/motion sickness?

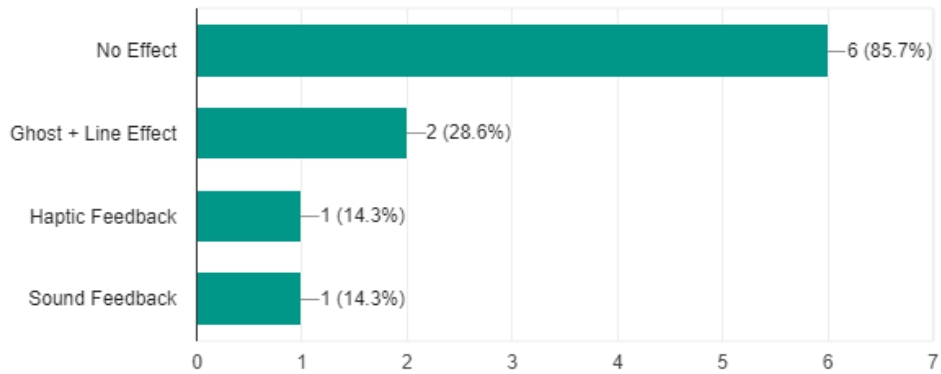
1 response



Appendix A. User Study Results

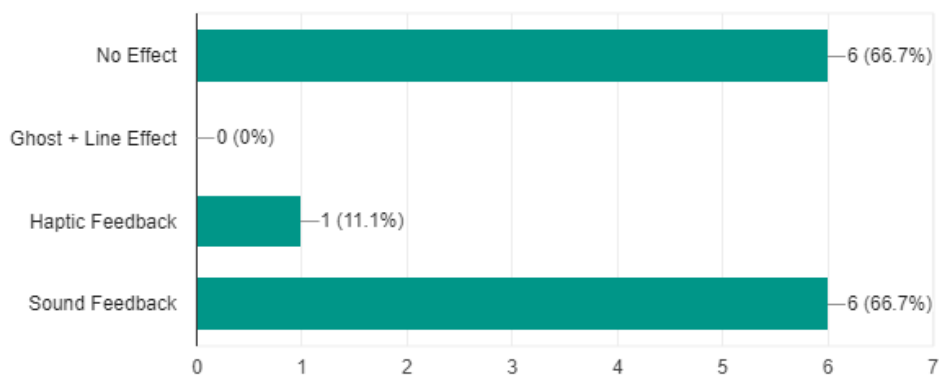
In which trial(s) did you feel discomfort due to discrepancies (meaning that the hands felt weird due to the offset)

7 responses



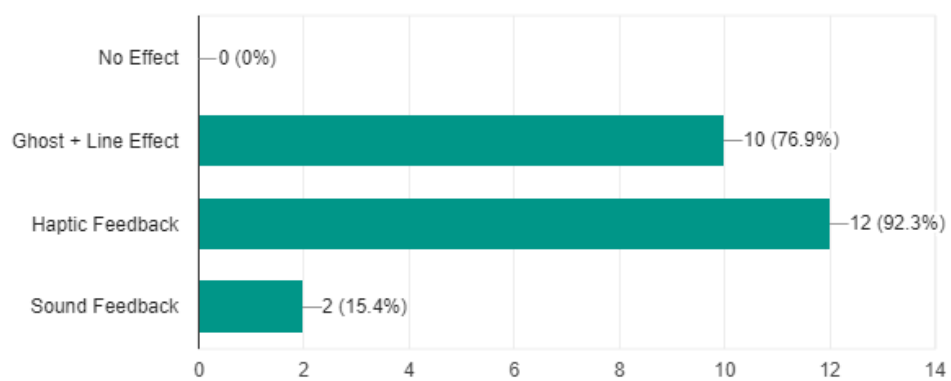
Which trial(s) had a negative impact on your immersion?

9 responses



Which trial(s) had a positive impact on your immersion?

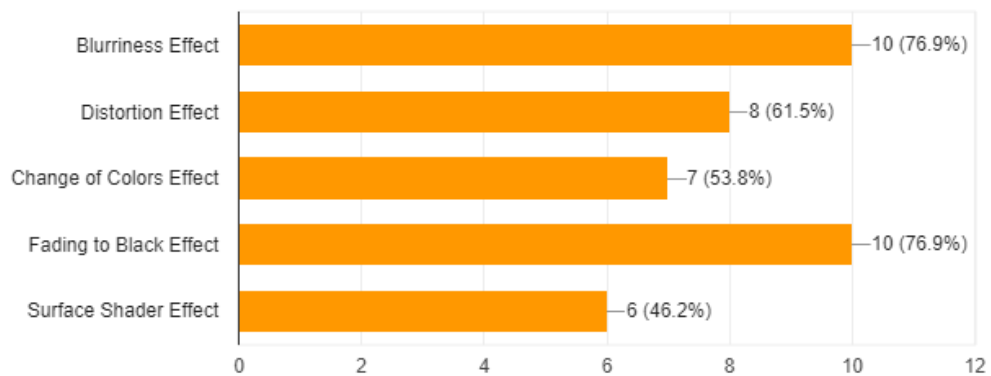
13 responses



A.3. Virtual Embodiment Questionnaire Stage Two Results

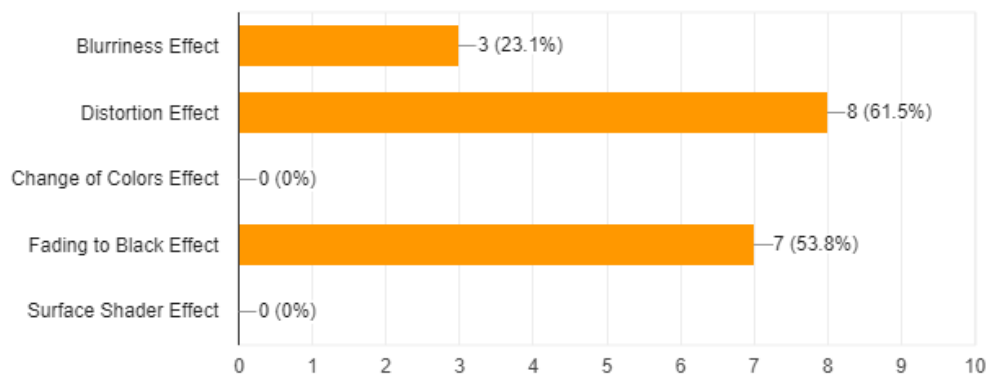
In which trial(s) did you immediately notice discrepancies?

13 responses



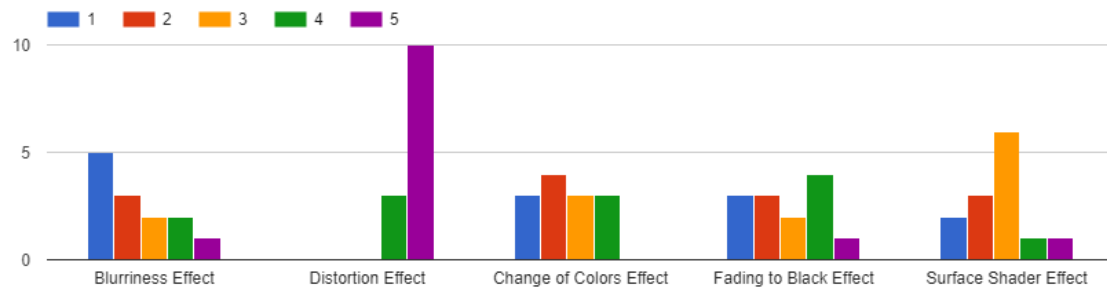
Which trial encourages you to try to avoid the walls as much as possible?

13 responses

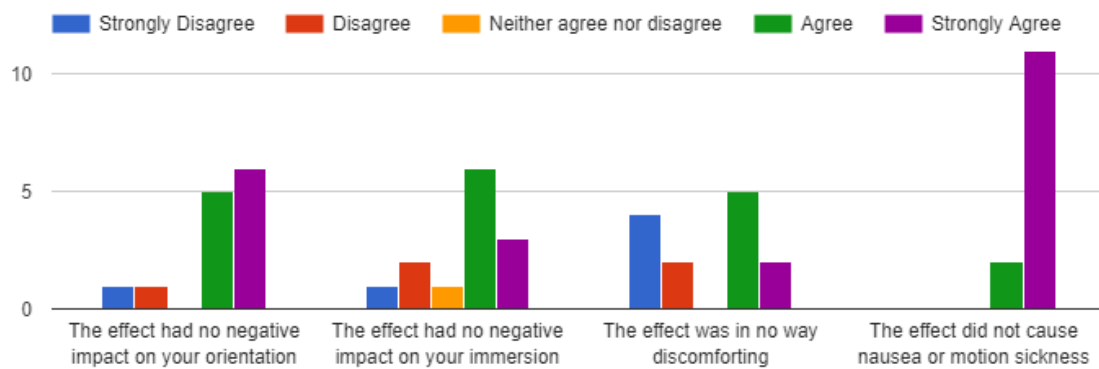


Appendix A. User Study Results

Arrange the effects from best to worst

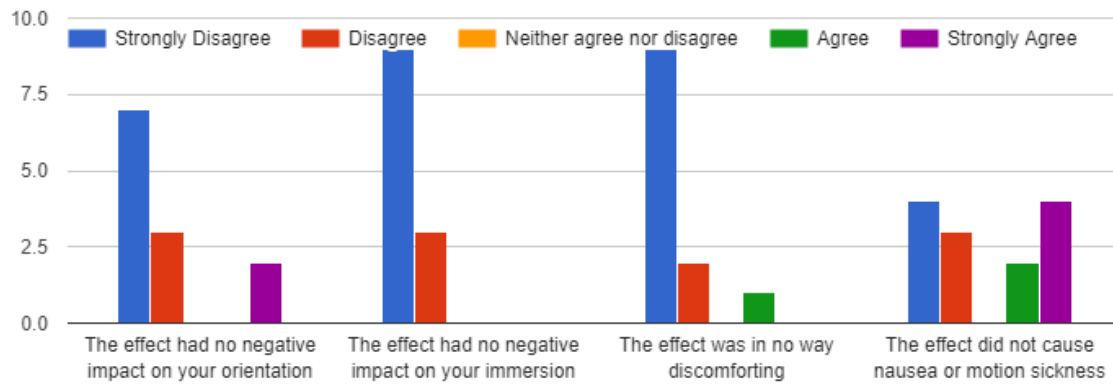


'Blur' Effect

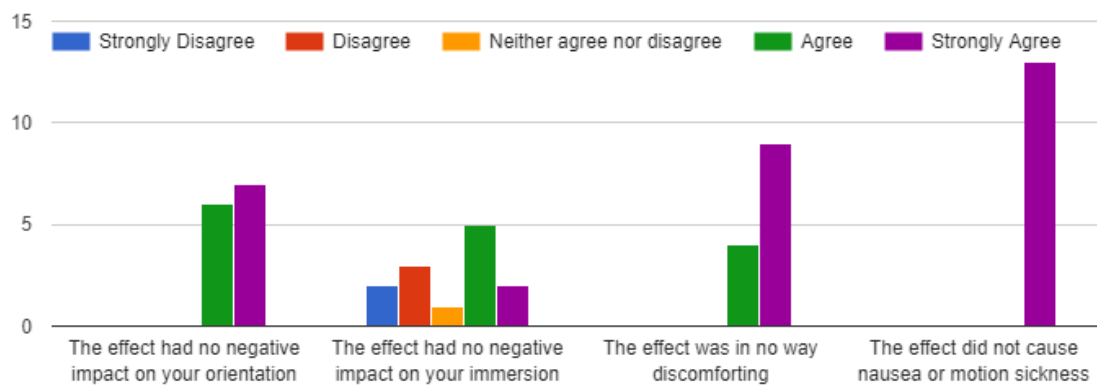


Appendix A. User Study Results

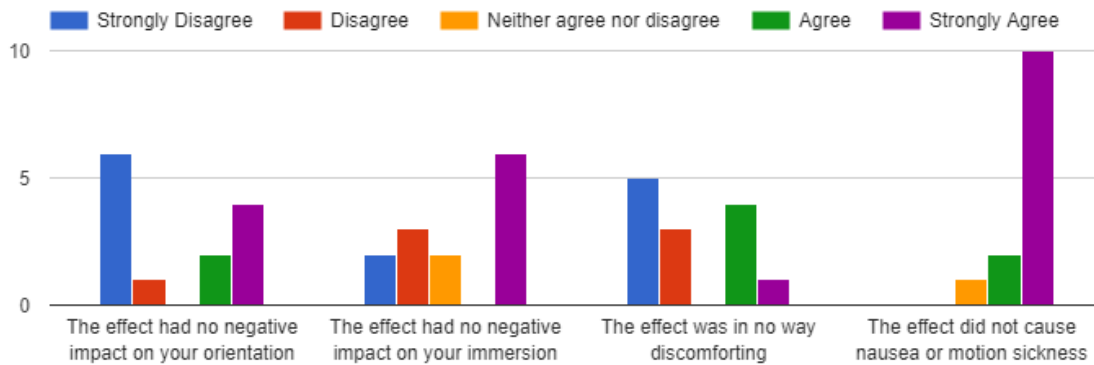
'Distortion' Effect



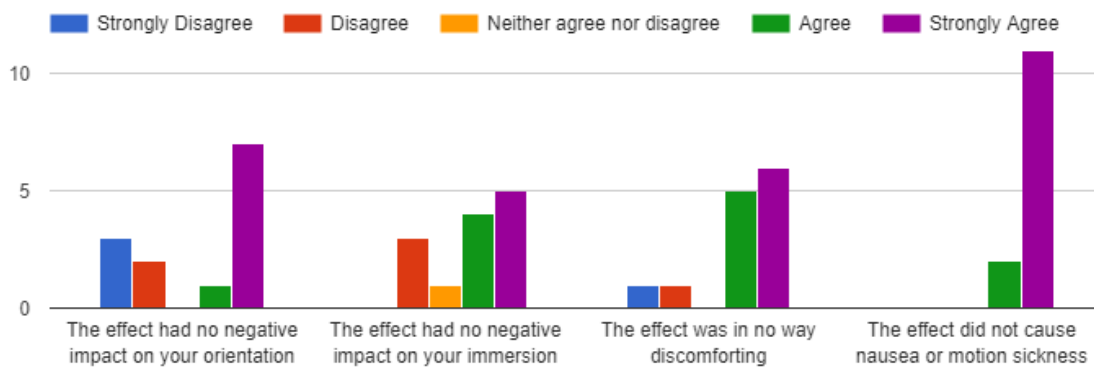
'Change of Colors' Effect



'Fade to Black' Effect

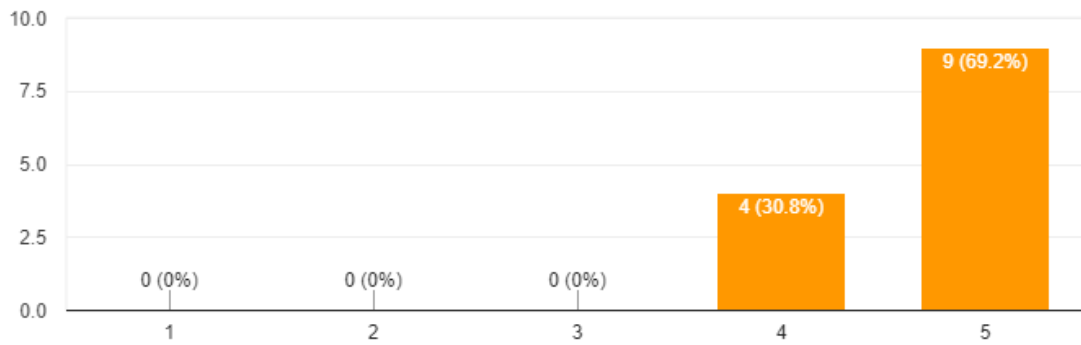


'Surface Shader' Effect



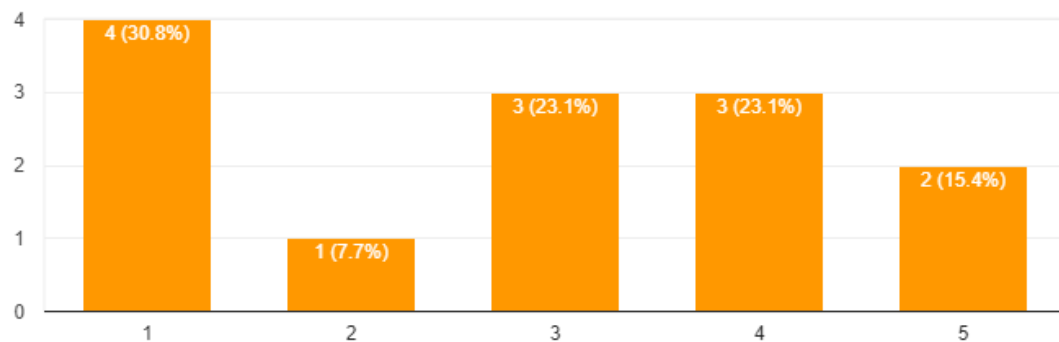
How important is the need to handle discrepancies in Virtual Reality in your opinion?

13 responses



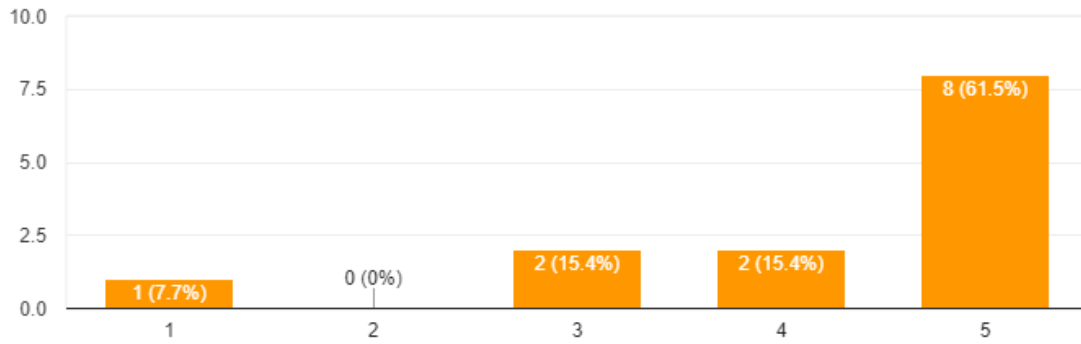
How important is the addition of the sound in your opinion?

13 responses



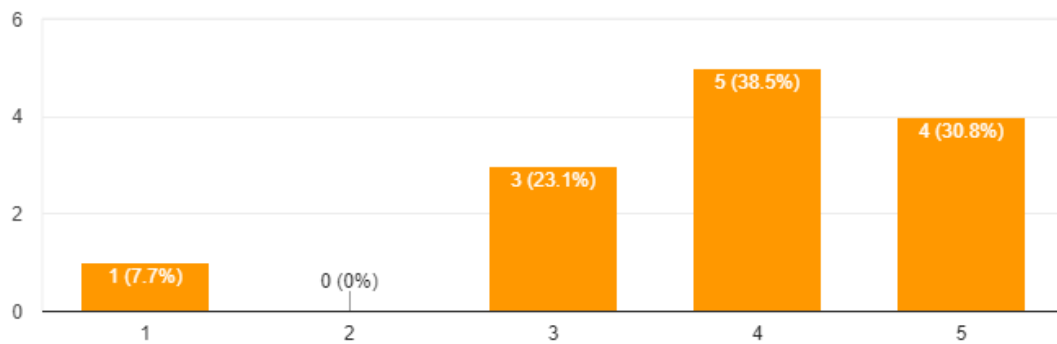
How important is the addition of the haptic feedback in your opinion?

13 responses



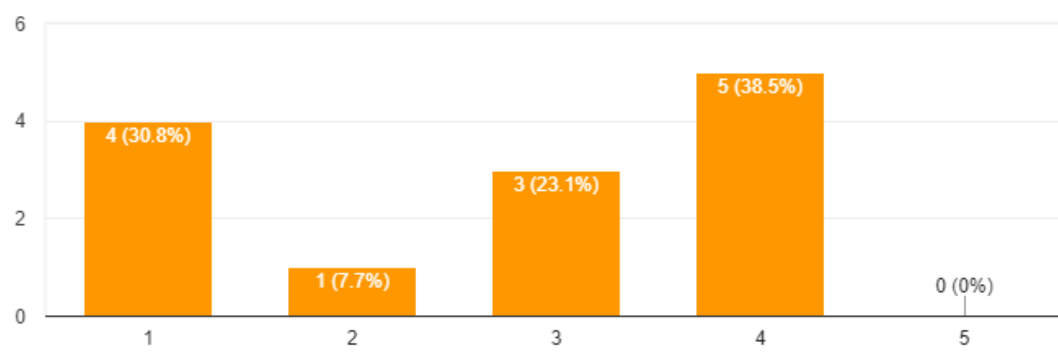
How important is the addition of the ghost body in your opinion?

13 responses



How important is the addition of the green lines in your opinion?

13 responses

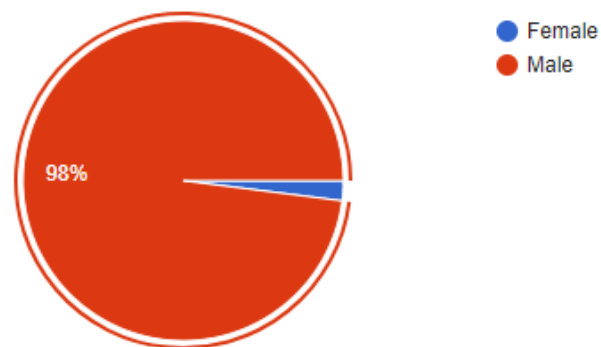


A.4. HTC Vive Questionnaire

Source: Reddit.com¹

Gender

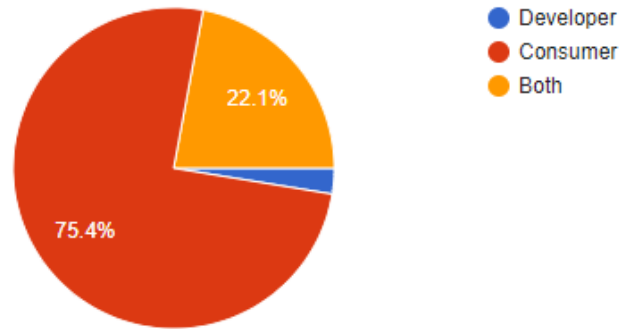
697 responses



¹[uch17]

Vive usage

698 responses



Age

698 responses

