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Stay In Place: Guiding players with Haptic Nudges in Virtual Reality

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Abstract:

In this research focused report, we sought to investigate the current state of Virtual Reality and the potential safety danger it could create in small scale areas. To solve this problem, we created a Haptic based Nudge that sought to alert users by making their controllers vibrate upon proximity towards the edge of their play space. For this, three different tests were conducted, each looking into different aspects during the play. As well as looking into the area of engagement, looking into how a player's engagement and immersion may be a potential factor that can be a part of the problem. Results showed a less then satisfying answer regarding reliability. With follow-up testing, providing more defined feedback and responsive from users points towards the usability and want of additional feedback during play.

Preface

This study was written by Lenette Kappelhøj Langsø and Simon Bredahl Andreasen, both students at Aalborg University Copenhagen and studies their masters in Medialogy.

The study was supervised by Rolf Nordahl.

A thanks to the different creators that help with inspirations, sounds models and tutorials. Hereby namely BinaryLunar, Elcanetay, Neon3D, Papersy, TridentCorp, SuperhotTeam, EpidemicSound, BrokenVector, ShadowballGames, MuddyWolf and Andrew.

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Contents

Chapter 1

Introduction

The growth of virtual reality (VR) has only seen an increase during the following years, with more and more models of head mounted displays (HMD), becoming available on the market. In the same vein research into VR has been a focused topic as well. Especially in the concept of realism such as the concept of Redirected walking Nilsson et al. (2014), which seeks too mimic real world walking inside of a virtual environment, through the user of clever guiding of an unbeknownst player. Commercially we have seen the inclusion of roomscale VR in both the HTC Vive and Oculus Rift, allowing an individual's whole room to be transformed into a space for play. This higher focus of full utilization of space available does comes with a common drawback both fields have, the hard requirements needed to fulfill said spatial criteria.

When one is filly engaged in VR, their sense of space would be affected by the virtual world they are in, forgetting about their physical position. For this reason the Guardian function exist in all modern VR HMD as a safety procedure. A virtual border whose purpose is to act as a warning for the player, informing them when they are about to reach the edge of their available space, if the player exit said border, their current activity will be pause until reentering. But how effective is the guardian in informing the player? Especially while engage, is it a strong enough warning that can suspend engagement for that of safety? This is the main motivation behind our research. Wishing to look into if it is possible to inform a player about potential hazard in their surroundings, with the inclusion or exclusion of the current guardian system. Creating the following Final Problem Statement:

> *Does the usage of an haptic-feedback based nudge provide better spatial awareness for an user during virtual reality?*

Chapter 2

Analysis

2.1 Engagement

The concept of engagement is something that is almost universally relevant to any field of work. But the exact definition of engagement can be different from each field to another. As such, we will define our own view of engagement based upon the findings of Schaufeli and O'Brien and Toms. Schaufeli's findings are based upon primarily work and academia view point of examination. The main take away from their findings is that the concept of engagement is inherently unique from an individual perspective, but at the same time being supported by an large amount of empirical research. Schaufeli suggestion to solve this here dilemma is: *A pragmatic solution could be to consider engagement as a psychological state in conjunction with its behavioral expression. That way the uniqueness of the concept is preserved and its practicability is guaranteed.* Schaufeli By doing so it helps includes the idea that engagement is purely a physiological state that can be defined through self-reported questionnaires as well as the inclusion of it's behavioral expression in relation to the user's experience.

For the purpose of this report we will define Engagement as the following based upon the findings of O'Brien et al.: *User engagement is the quality at with the experience an user have is defined by the depth of their investment during interaction with a digital system.* O'Brien and Toms (2008) O'Brien et al. (2018). Engagement is not the same as user satisfaction, it is thought to be the ability to keep sustained engagement in a digital system O'Brien et al. (2018).

2.1.1 User Engagement Scale

The User Engagement Scale (UES) is a proposed method for self-reported measurement in Human Computer Interaction, being created by O'Brien et al.. The tool consist of an 31 item index separated into six categories relating the certain context, such as the *Perceived Usability* of the product test. O'Brien et al. makes it clear that the questionnaire only measure a specific component of engagement, and does not fully evaluate how engaged a person is. As such through the usage of the UES questionnaire one has to be clear what type of engagement they are using, and change the questionnaire to fit thees requirements.

A different version of the UES was also created, known as User Engagement Scale short form (UES-sf) this version consist of a smaller self-reported questionnaire containing 12 items and four dimensions: *Focused attention, Perceived usability, Aesthetic appeal and Reward.* Explained by O'Brien et al. as so:

- FA: Focused attention, feeling absorbed in the interaction and losing track of time
- PU: Perceived usability, negative affect experienced as a result of the interaction and the degree of control and effort expended.
- AE: Aesthetic appeal, the attractiveness and visual appeal of the in- terface (5 items).
- RW: Reward, overall success of the interaction, the user's interest in it and their sense of being "drawn in".

The Reward categories was combined of the different categories from the normal UES, that of Endurability, novelty and felt involvement.

O'Brien et al. notes that user engagement is keenly tied to what type of application that is used on the user as well as the application's desire/purpose. For the purpose of this report the application made will work as a component of the overall VR experience. As such being aware of how it affects engagement, either positively or negatively is useful for fine tuning it to serve its main purpose of nudging users, the concept of nduging being describe in section 2.4.

2.2 Embodiment

Embodiment refers to the concept that cognitive processes and experiences are deeply intertwined with the physical body. It suggests that our understanding of the world, emotions, and consciousness is not the only product of abstract mental processes but is also influenced by our bodily experiences and interactions Meier et al. (2012). To understand embodiment, it must be taken into consideration that both mind and body are influenced by social and cultural factors. Emphasizing that the cognitive functions and sensory experiences are integrated with the body. Hereby our perceptions, emotions, and thoughts are not separate from the physical experiences and sensations of our bodies.

Moreover, our interactions are heavily influenced by the environment and the feedback from our senses and shape our cognitive processes. This means that even if two people are looking at the same object there is a possibility that they will not see it the same way, or describe it the same, depending on the social and cultural factors Meier et al. (2012). This also means that while testing and during observations is highly subjective, even with body language, gestures, and facial expressions as they also are an integrated to individuals' expression in the communication.

Hall explains in his paper how people use and perceive space in different cultures, hereby he divided it into four spaces. He argued that these spaces are culturally influenced and can vary among societies. The four spaces as Hall explain is:

- Intimate space: reserved for close relationships.
- Personal space: Common in personal conversations among friends and family. This distance is often maintained in informal social settings.
- social space: Maintained in formal or business interactions, where a certain level of formality is expected. It is also the distance observed in casual social gatherings.
- Public space: Reserved for public speaking or situations where individuals are not directly interacting.

One way to illustrate this can be seen at figure 2.1, as Hall describes in his study of proxemics. He demonstrated the impact of ethnicity and culture on nonverbal behaviors. During the studies, the spaces were divided to indicate what would separate ourselves from others, in terms of areas.

His Proxemics is not only about physical space but also involves the study of territoriality, body language, and other non-verbal cues that contribute to the understanding of human

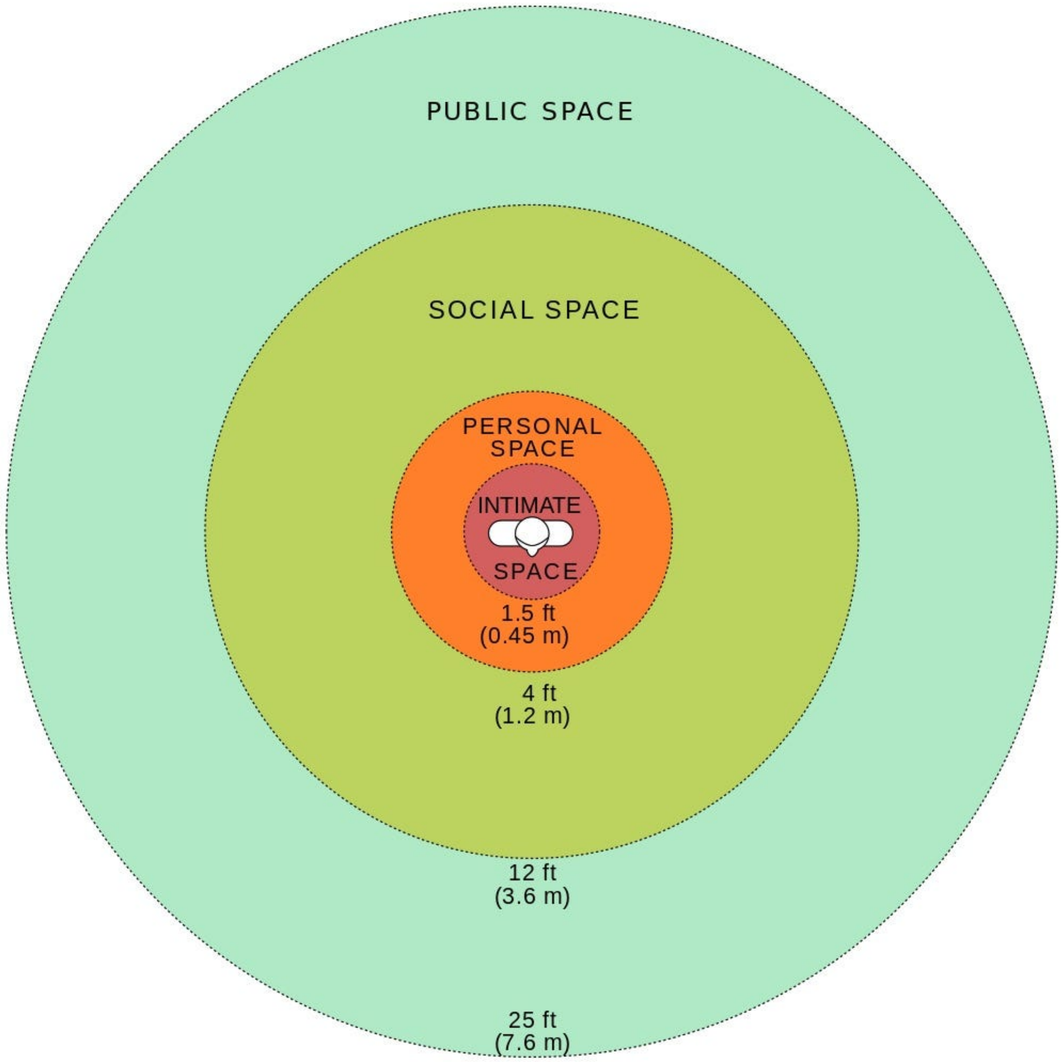

Figure 2.1: Proxemics by Hall - an illustration for the perception of space. The spaces are divided into four spaces; 'Intimate space', 'personal space', 'social space' and 'public space.'

interactions within a spatial context. This concept has practical applications in fields such as communication, design, and cultural studies, helping to explain and navigate the subtle dynamics of human spatial behavior across different cultures and contexts.

By understanding the western individual social spaces, it is possible to experiment or rather challenge this space. This happens by utilizing the two most inner spaces 'personal space' and 'Intimate space'. As these spaces are close to the individuals invading or challenging it could have the possibility to make the individual uncomfortable. This is because the individual usually invites others into the spaces and others have the courtesy to respect the personal space. The invasion of an individual personal space and their aversion to such actions, could be a potential implementation in the realm of VR.

2.3 Breaking immersion

Breaking immersion is the removal of the illusion that transports individuals from their reality into the world of the story or experience. It's a disruption that pulls them out of the narrative flow or experience, reminding them that they're merely observers or participants rather than fully immersed in the fictional world or activity. According to Aeschbach et al. immersion to be universally understood as good for the experience, however through their research, that immersion have been used to reduce counter arguments when persuasion of the procedural rhetoric of play in video games. And can be seen in opposition to critical thinking. As Aeschbach et al. states "Immersion can, therefore, be seen as in opposition to critical reflection, because it requires people to suspend their disbelief and uncritically accept the rules of the game as true. This is problematic, because the rules of a game are an inherent part of its rhetoric and to appropriately represent complexity, these rules also need to be critically reflected on by the audience." Aeschbach et al. (2022).

Although immersion is good for maintaining the engagement and ensuring that the player is captivated by the experience, there are some points that help with immersion or the lack of could break it. The immersive experience should have established rules and logic to remain consistent, this also applies to narrative and the rest of the product. Since inconsistency in the setting or sudden change in a character could break the immersion and leave the player less invested in the experience Schrimshaw (2015). By avoiding the common pitfalls and focusing on consistency, realism, attention to detail, technical reliability, audience respect, balanced challenge, and seamless transitions, creators can create immersive experiences that captivate and enchant participants, allowing them to lose themselves in the world of the story or activity Schrimshaw (2015). As Aeschbach et al. study say that developers in games that explore ethical education have to be careful when using immersion since the goal not necessarily require a strong immersion Aeschbach et al. (2022). The study Aeschbach et al. (2022) created a provision that games should have an appropriately form of play, that could facilitate critical reflection rather than he visceral emotional experience of immersion.

2.4 Nudging

It is possible for someone to have their behavior manipulated, without the constraints of dislocating choices, this is more broadly known as the concept of *nudging*. Introduced by Thaler and Sunstein, and further defined; "*as any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any option or significantly changing their economic incentive.*" Caraban et al. who narrowed the broad concept of nudging down into six categories for usage during Human Computer Interface (HCI), that of *confront, deceive, facilitate, fear, social influence* and *reinforce.* The Reinforce nudge shows to be the most beneficial for the behavior we wish to enact and will be the only one in focus for this research.

As the name implies the reinforce nudge seeks to provide users with reinforcement, strengthening the user's behavior through ambient feedback, without disrupting the user's current activity. It has been shown that nudges can be used to correct and change an user's behavior, as such nudging has been used to help protect individual from potential harm or misuse of actions Schneider and Graham (2017). The main challenge in regards to nudging relates to how strong of a push, or nudge is needed to affect an user's behavior, as too strong a push can be viewed as disruptive and immersion breaking. Still there exist cases where it is important to break this rule, where a strong push may be required depending on what behavior the nudge is trying to enforce or change Thaler and Sunstein (2009).

2.5 Haptic Feedback

With the introduction of rumble in DualShock Controller for the original PlayStation, the usage of rumble had become a mainstay in most games, providing the player with haptic feedback upon certain actions such as the push of a button, or action done ingame. Now we can receive this type of tactile feedback not only in video games, but in everyday most commonly through our phones, as well as in the realm of virtual reality. As it name implies haptic feedback governs everything in the field of touch-based sensation, for the purpose of this report, haptic feedback will be focused solely on the aspect of vibration-based interactions Våpenstad et al. (2013). Haptic feedback has been shown to help with an user's perception and cognitive ability to help increase the presence of certain actions, by its ability to closer emulate real-world touch and feedback MacLean (2000) Gibbs et al. (2022). In comparison to vision, tactile provides a faster reaction when subjected to stimuli, meaning in scenarios that require quicker responses from an individual, haptic feedback could help provide a quicker response then pure vision stimuli Lederman and Klatzky (2009).

2.6 SOTA

Investigating guardian awareness techniques to promote safety in virtual reality is a report by Wu et al. that looks into the effectiveness of the **Guardian** found in most virtual reality head mounted displays. When an individual start up their headset they will first be prompted to define a *boundary*, the amount of space they have available to use. This guardian is used to help keep users safe as well as letting some expedience take advantage of the space, typically room scale to emulate a custom-defined environment. Wu et al. wishes to explore the problem of non-VR users invading one's boundary, providing a potential risk to both. They proposed four different techniques that all uses smart phones or smart watches; *Augmented Reality, Visual Alert, Haptic Alert* and *Auditory Alert.*

- The first technique uses one's phone camera to display the guardian as an three-dimensional barrier overlaid into the real world, providing the ability to see the full shape and size of the boundary zone.
- The visual alert utilized a flickering red bar on top view of smartphones, where if individual entered within one meter of the guardian, the flickering frequency and color would change based upon distance. This approach used a simple minimal visual indicator to illustrate how close participants were to the guardian.
- Both the Augmented Reality and Visual Alert required one to still be actively looking on their phone. For this reason the Haptic Alert served as what Wu et al. described as a background element, being non-disruptive to one's current activity Wu et al. (2023). It followed a similar logic to the Visual Alert, but instead used vibrations from one's smartwatch to help inform user's of their proximity to the guardian, increasing in amplitude and frequency as the distance shortened.
- The last technique tested was the Auditory Alert, following a similar design principle as the prior technique, serving to be non-disruptive to an user's current activity. in its case it used auditory beeps that just like the two prior techniques would decrease in length, while increasing in volume depending on the distance towards the guardian. It was noted that it could be too disruptive of a technique for both the non-VR and VR individual.

Out of the four techniques each proved some form of positive results, the augmented reality results showed it as the most effective of all the techniques. Its ability to fully expose the guardian zone allowed users to easily plan route to avoid or minimize exposure and risk. In contrast to the other techniques that only relied upon distance that was invisible for the users, needing them to create a mental map slowly. The Haptic Alert proved to be the least distracting serving its purpose as a background technique. Wu et al. concludes that all techniques could help reduce bystanders entering the boundary zone, reducing potential risk and harm, the type of technique most efficient depends on an user's current engagement based upon the efficiency and distractions on an user's current engagement.

Chapter 3

Design

3.1 Preliminary Design

Preparing in the preliminary test, it was decided to use an already made game to have understand peoples' movements and see if there is a problem that could be interesting to investigate, as well as saving time for the design of the primary test. This led to a small discussion about which game to use. Games varied from exploitative, simulations and horror games, though on the first test day, there were problems connecting with the WiFi, and it was decided to use a demo version of SUPERHOT by SuperhotTeam. This was the for the high intensity action that could force the participants to move around often.

3.2 Primary Design

When preparing for the implementation, there was a small discussion around the design for the game. First was what the type of game. Should it be in style of SUPERHOT like in the preliminary test, where people would move due to the game. Or more exploratory could also work for the game itself would force players to reach out of the game space. due to the project being set in a VR setting. Some certain space and run requirements were made, it was decided to limit the polygon count by choosing low poly aesthetic for the game to better run. Some of the game idea that were discusses was Free-Space Explorative game, though quickly determined that the space idea easily could have give people motion sickness, just by the theme alone. Other ideas were a skyscraper cleaning game, which could also give motion sickness or the fear of highs being to disruptive a factor. A lumberjack chopping game though it was concluded that game would not be best experienced with no movement controls. Therefore, it ended with a low poly underwater exploitative game, where the player is hunting for coins in a small area. For the creation of this game some requirements for both the design and level were made.

3.3 Design requirements:

- The scale for the space should be a minimum of 2m x 2m for the requirement for VR.
- Needs to be able to be run on an Oculus Quest 2 VR Headset
- Low poly design for preventing lag or poor performance during gameplay.
- The game should utilize nudging to inform about border-breaking.
- Haptic feedback should inform the player of their closeness to the border.
- On player disobedience, the game should invade the player's personal space through a shove.

Level Requirements:

- The game should include a basic introduction.
- The game should be easy and intuitive to learn.
- The game should take advantage of the limited 2m x 2m space.
- The game should be casual in nature.
- The game should force the player to move.
- The game should force the player to interact with the border

Chapter 4

Implementation

4.1 VR area

The application was created using Unity[1], Unity was chosen for its innate XR support, here the VR Project Template was used as a starting point as it included various tools and ready-made implementation allowing for easier creation of the main application and its testing parameters. With Unity's well established library, it is easy to set up the basic parameters for VR, such as head and controller tracking.

4.1.1 Affordance system

Project created using Unity's XR interaction Toolkit have access to what is called the **Affordance system.** this specific system provides the ability to create auditory and visual feedback to intractable objects. The Affordance system allows for visual and auditory feedback to users through *interaction states.* These states changes upon what an user is currently doing, such as grabbing an object, hovering their controller over it, or letting go.

[1]The unity Version that was used is 2022.3.8f1

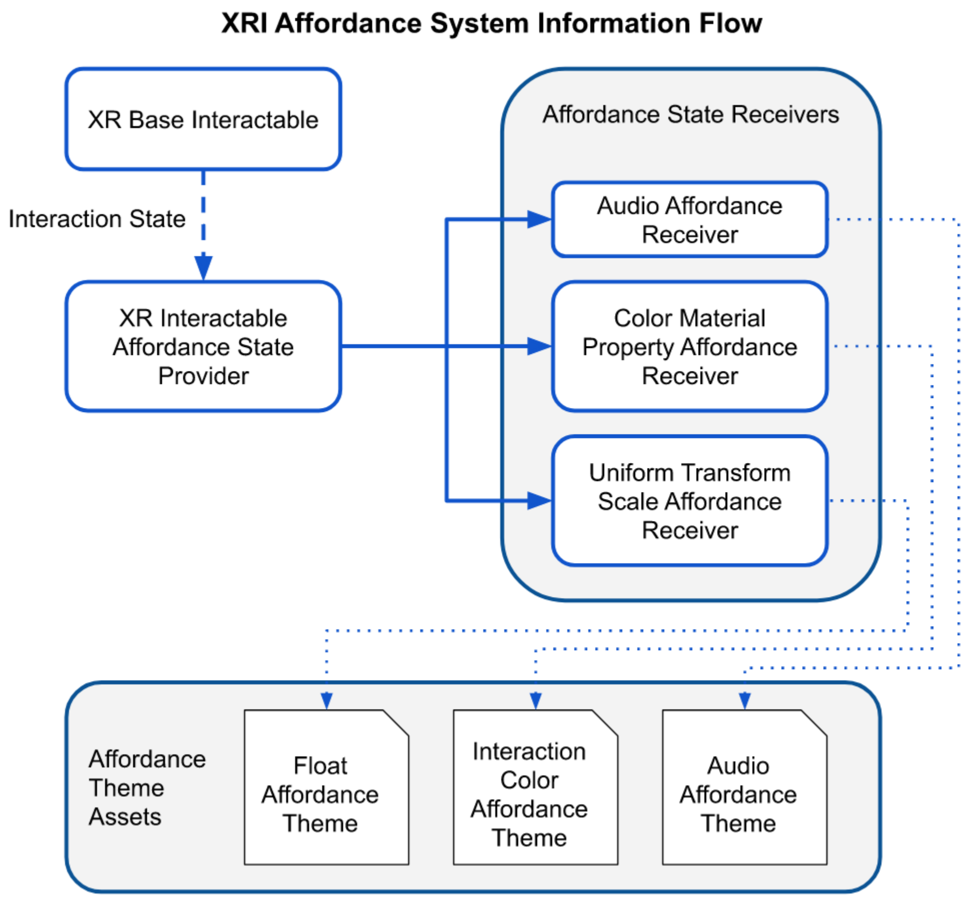

Figure 4.1: The affordance system as illustrated by Unity, showcase the 3 main interaction types. The system also supports custom functions, allowing for it to call upon custom scripts. This serves as the main skeleton for the application Unity. Image taken from `https://docs.unity3d.com/Packages/com.unity.xr.interaction.toolkit@2.5/manual/affordance-system.html`

The Affordance system was used for the primary function of the main test for what was dubbed the *Trigger zone.* The user is placed inside of an invisible box consisting of an area of 2x2m, corresponding with the same space used during the preliminary-test 5.1. If the user's controller reaches outside of the box, an Affordance event will trigger causing both of their controllers to vibrate nonstop until the controller returns back into the border.

```
public class Haptics : MonoBehaviour
{
    [SerializeField]
    XRBaseController leftController, rightController;

    public GameObject TriggerCube;
    private bool HapticTrigger = false;

    Unity Message | 0 references
    public void OnTriggerExit(Collider other)
    {
        HapticTrigger = true;
    }

    Unity Message | 0 references
    public void OnTriggerEnter(Collider other)
    {
        HapticTrigger = false;
    }

    Unity Message | 0 references
    void Update()
    {
        if (leftController != null && HapticTrigger == true)
            leftController.SendHapticImpulse(0.5f, 0.1f);

        if (rightController != null && HapticTrigger == true)
            rightController.SendHapticImpulse(0.5f, 0.1f);
    }
}
```

Figure 4.2: The code behind the Trigger Zone, as the Affordance system handles most of the event system, it is only important to set up the proper functions for the interaction system to use, here being the *OnTriggerEnter* and *OnTriggerExit* allowing the code to send the haptic impulses whenever a player controller leaves the defined area.

4.2 Haptic Test

The haptic test uses a system created by FinlayMac on GitHub, who provided various ScriptableObject for setting up custom vibration patterns. The main advantage of using ScriptableObjects in a scene is the ability to store and use duplicate data, saving on memory and performance. ScriptableObject's data can be stored and access at any time, by referencing to it. FinlayMac provide different premade vibration patterns as well as the ability to create one's own. To activate a controller's vibration motor the function *SetMotorSpeeds(float value, float value)* is used, utilizing a range from zero to one, between the two motors found in the controller for individual vibrations. For XR controller the function *SendHapticImpulse(float* *value, duration* is called for both left and right controller individually.

```
[CreateAssetMenu(menuName = "Sciptable Objects/Vibration/Curve Part")]
Unity Script | 0 references
public class VibrationCurve : IVibrationPart
{
    [Header("X Axis = Duration: \nIs the longest curve.\n\nY Axis = Strength: \nShould be between 0 and 1\n")]
    public AnimationCurve leftVibeOverTime = AnimationCurve.Linear(0, 0, 0.3f, 1);
    public AnimationCurve rightVibeOverTime = AnimationCurve.Linear(0, 0, 0.3f, 1);


    private float duration = 0;
    private Vector2 strength = new Vector2(0f, 0f);

    //to check how long the update has gone
    private float timer = 0f;

    //the Unity editor stuff is to be able to test the animated curves in the inspector
#if UNITY_EDITOR
    private float startTime;
#endif

    3 references
    public override void Activate()
    {
        timer = 0f;
```

Figure 4.3: FinlayMac script for the Vibration curve pattern. This curve allows for a slow gradual increase in the controller's motor power as time passes. Exposed AnimationCurve and duration float allows the ability to create a custom curve pattern in the unity editor without having to change the script.

```
            //gets longer of both the curves
            duration = leftVibeOverTime[leftVibeOverTime.length - 1].time;
            if (duration < rightVibeOverTime[rightVibeOverTime.length - 1].time)
            { duration = rightVibeOverTime[rightVibeOverTime.length - 1].time; }
        }

        //needs to loop so marked true
        5 references
        public override bool UpdateFrame()
        {
            timer += Time.deltaTime;

#if UNITY_EDITOR
            timer = Time.realtimeSinceStartup - startTime;
#endif

            strength.x = leftVibeOverTime.Evaluate(timer);
            strength.y = rightVibeOverTime.Evaluate(timer);
```

Figure 4.4: As the duration value increase the value of leftVibeOverTime and rightVibeOverTime follows along as well This is then given to the Vector2 strength which dictates the vibration power for the left and right motors on the controller FinlayMac (2022).

The different patters are attached in a sequence ScriptableObject and attached to a button, allowing for free execution of each vibration pattern upon clicking. Five different patters where created:

- Pattern 1: A sequence of vibrations with a pause of 0.25 seconds between each vibration.
- Pattern 2: A constant vibration with the power of 0.4 out of 1, this is the same amount of power as used in the Primary test
- Pattern 3: The curve functions as mention in 4.3 and 4.4. A gradual buildup until it hits maximum power.
- Pattern 4: The same constant vibration as found in Pattern 2, only at full power instead.
- Pattern 5: A series of vibrations identical to Pattern 1, only the pause is of 0.5 seconds instead of 0.25.

Chapter 5

Method

5.1 Preliminary testing

Before the primary testing had been conducted, a question in regards to the movement during VR usage needed to be examined in more depth. For this reason an initial preliminary testing was conducted before the design of the main solution. As well as testing its purpose to help provide some observational knowledge and clarity. The test consisted of two parts, the first one was an observation phase, here participants where tasked with playing the VR demo for the game SuperHot[1]. The player would be first position on an marked **X** on the ground, surrounding the X are two square boxes, as what can be seen in Figure 5.1

While the participants was playing the game two observers noted down any specific actions, one focusing on how often the participant would overstep one of the borders, while the second noted down general comments in the participants body language, such as how active or extreme their movement was. Upon completion of the demo or after a short time had passed, averaging around too 5 minutes. The participant would be asked to complete a quick questionnaire, it consisted of the UES-sf described in section 2.1. As well as an question in regards to how invasive the game felt, the question and answer can be seen in the Appendix 8.

[1]SuperHot is a game created by SuperhotTeam, the main mechanic being that time only moves when the player moves. The player is tasked with completing a series of short-burst action levels.

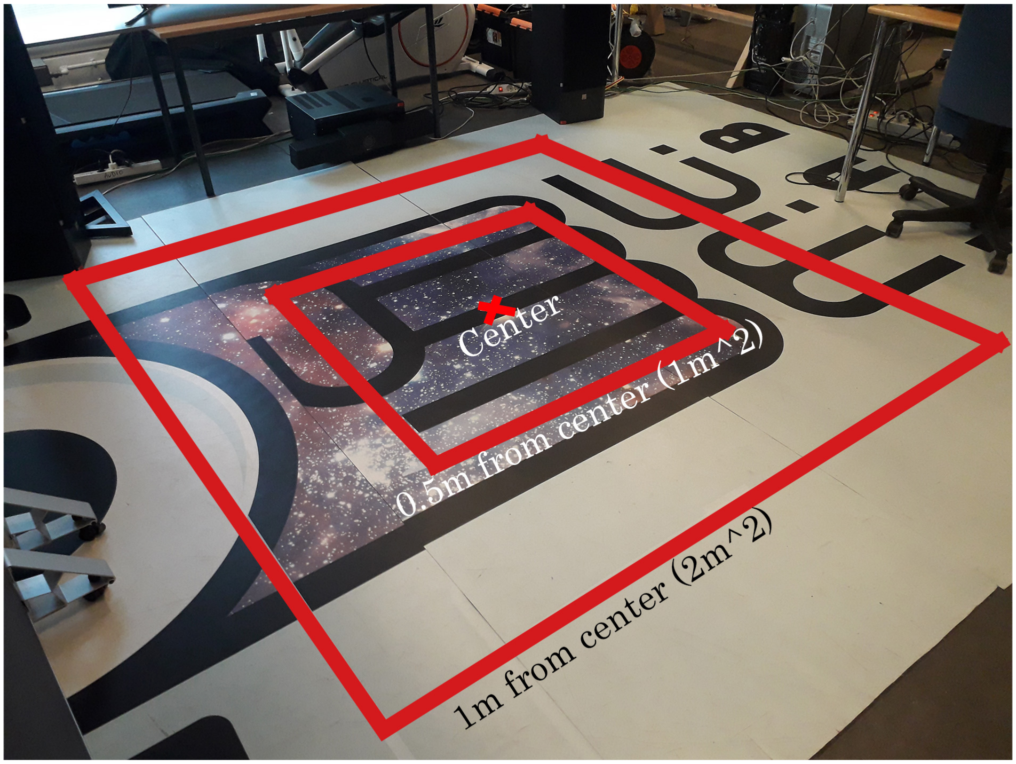

Figure 5.1: A spacious area of around 2x2 M with a X in the middle of it, surrounding it was two taped down marked squares. Used to help noted down how far out the participant would move doing testing, with the outer square being lined up the border defined by the VR-headset.

5.2 Primary Test

Based upon the findings found in section 6.1 it was noted the majority of the participants frequently moved off center quickly typically at the beginning. Based upon these findings the primary test focused upon this behavior, specifically how to minimize it through the usage of haptic feedback and nudging. An custom VR-experience was made for the test. This experience used the same 2x2 M area for available space. During the test the participant is put into an underworld experience, with the purpose of finding 5 coins. 2 of the coins were deliberately placed in such a way they would be right on the edge or outside of the 2x2 M guardian. Depending on whether the participant was either playing the control version or not, two things would happen. If playing test version the participant would be subject to our haptic nudge, by their controller vibrating until when exiting this specified area. In contrast nothing would happen for the control version.

Upon completion of the task, the participant would be asked to answer a questionnaire 8 8. This questionnaire used the same UES-sf as the preliminary test, as well as an inclusion for the test version specifically in regards to the haptic feedback received. The idea to use UES-sf once more was to check if the inclusion of haptic feedback would affect a player's engagement, with hopes of it seeing, since the purpose of the haptic nudge was to be attention grabbing. Test participants were asked to explain if they understood the purpose of the haptic nudge, as no prior information had been given about it.

5.3 Follow-up Test

Based upon the results discussed in section 6.3 it was noted that around six participants did not fully expedience the vibrations during play, as well as the less then favourable answers in regards to the ability to understand the Haptic Nudge's purpose. This follow-up test seeks to gain further user opinion in regards to haptic feedback, so it may be Incorporated into future test, as well as be taken into consideration in the effectiveness of the FPS.

The Follow-up Test consist of an quality User evaluation, where participants are tasked with evaluating five different vibration patterns. For the purpose of test accessibility an XBox 360 Controller was used as a substitute VR controller. Participants were first instructed about the purpose of the test, and reassured that the point is to not compare the different vibrations during the testing. A pre-test question in regards to their experience and familiarity with VR was initial asked. Where afterwards participants were blindfolded to help reduce the cognitive load and focus fully upon the haptic feedback.

Each participant would receive the same following procedure, 5 different vibration types would be played in sequence, with small breaks, before being repeated one extra time. Details about the specific types can be found in section 4.2, upon completion of the second round. Participant would be asked to return the controller and blindfold before the follow open-interview began. Here their opinions in which type of haptic feedback worked the best in gathering attention, both by itself but also in the context of VR experiences, as well as if would prove beneficial in a participant's spacial surrounding while engaged.

Chapter 6

Results

6.1 Preliminary Test

The observations noted by the two observers both contain similarities, as what can be seen in Appendix 8 in regards to participants movement and habits, as what was theorised through that of engagement is strengthen by the findings found in the UES-sf, both observers noted participants tenancy to move away from the middle and rarely return to it perfectly, with most participants lifting their foot of to never return to it once more.

Before the initial playing of the game, some participants had questions in regard to how to move and interact with the game, indicating an inexperience which was also noted down whenever informed to the observers. Some participants also asked into if they were allowed to move, where upon they was encouraged to do so. It is unknown how this factor could affect the results as each participants was encouraged to move, or no need to instruct them to do such.

A common factor between every participant was that of their arm movements, even if they stayed inside of the middle of the play area. They arms reached out of it extremely frequently and with wide movements, when trying to grab items and use them. Following suit was the upper body movement, here participants leaned and weaved to dodge projectiles while playing. It was observed that while participants moved around and twisted their body, they very rarely did both at the same time, instead using their body to dodge and walking for traversal.

Still the frequent movement seemed to occur naturally for the participants the more engaged and time playing the game, as observed by the amount of overstepping the various zones and general observations. These observation were also reflected in the UES-sf questionnaire, where upon we can see that the majority of the participant felt lost in the experience and the time spent in the game. this can contribute their movement as they would have lost the spacial awareness outside of the game, and therefore moved around a lot more.

when asked how invasive the game was for each participant gave a different number from a scale 1 to 10 [1], this of cause can not give a concrete answer to the question and only that the more the participant had played the less invasive was the game, when looking a the individual data.

6.2 Primary Test

As describe in section 5.2 two test where conducted in total, each gathering the same number of participants, that of 11, for a total sample size of 22. Each participants whether part of the control group or the main test would answer the same UES-sf questionnaire. The control test served as a standard VR session, providing a baseline to compare our results from the Main test, which included the *triggerzone* and Haptic Nudge as described in section 4 as well some additional questions for the Haptic Nudge itself.

The rest of the results of the UES-sf results were analysed with Python, checking for the validity of the data. Both datasets were first validated using Shapiro-Wilk, the p value for the two data sheet returned was of too low a value showing that both test are not normally distributed, this is not a big surprise given the low participant number of $n = 11$.

[1] with 1 being the least invasive and 10 being the most invasive

```
[ ]  ShapiroMain = 0
     ShapiroMain = shapiro(df_Main)
     print(ShapiroMain)

ShapiroResult(statistic=0.8428356647491455, pvalue=1.5026888067204425e-10)
```

```
[ ]  ShapiroControl = 0
     ShapiroControl = shapiro(df_Control)
     print(ShapiroControl)

ShapiroResult(statistic=0.8385533094406128, pvalue=1.01511306305202e-10)
```

Both test and control are not normally distributed because the p-value is way too low, as can be seen from e-.

```
[ ]  from scipy.stats import mannwhitneyu

     U1, p = mannwhitneyu(df_Control, df_Main, method="auto")

     # Level of significance
     alpha = 0.05
     # conclusion
     if p.any() < alpha:
         print('Reject Null Hypothesis (Significant difference between two samples)')
     else:
         print('Do not Reject Null Hypothesis (No significant difference between two samples)')

Do not Reject Null Hypothesis (No significant difference between two samples)
```

Figure 6.1: The Main test contained an p value of *1.5026888067204425e-10* while the Control value was *1.01511306305202e-10* because of the low p-value it means that the data is not normally distributed, leading too extreme values in the form of outliers as well as making it harder to estimate the overall opinion of the participants. To combat this one would have to acquire more participants.

Even if it is known that the data is not normally distributed, but to further test the reliability of the data both data sheet's alpha value were calculated as well using the Cronbach Alpha test. The Main test returned an alpha value of 0.61 and the Control test returns an alpha value of 0.45. We can see that there still is some reliability in regards to the Main test, as its alpha value lies above the minimum defined threshold of 0.5.

It is clear that the test data is not fully usable for deeper data analysis, with only the Main test having some form of reliability. The Mann-Whitney-U Was used to help see if there was any noticeable difference between the two group, as the alpha value indicate one having more internal consistency. Upon conducting the Mann-Whitney-U, we need to be aware of type two errors given the small sample size[2]. According to the test, we do not reject the Null Hypothesis, showing that there is no significant difference between the two, even if given the different alpha values. To help check for any potential type two errors box plots of both data sheets were created, to visually the findings for better ease.

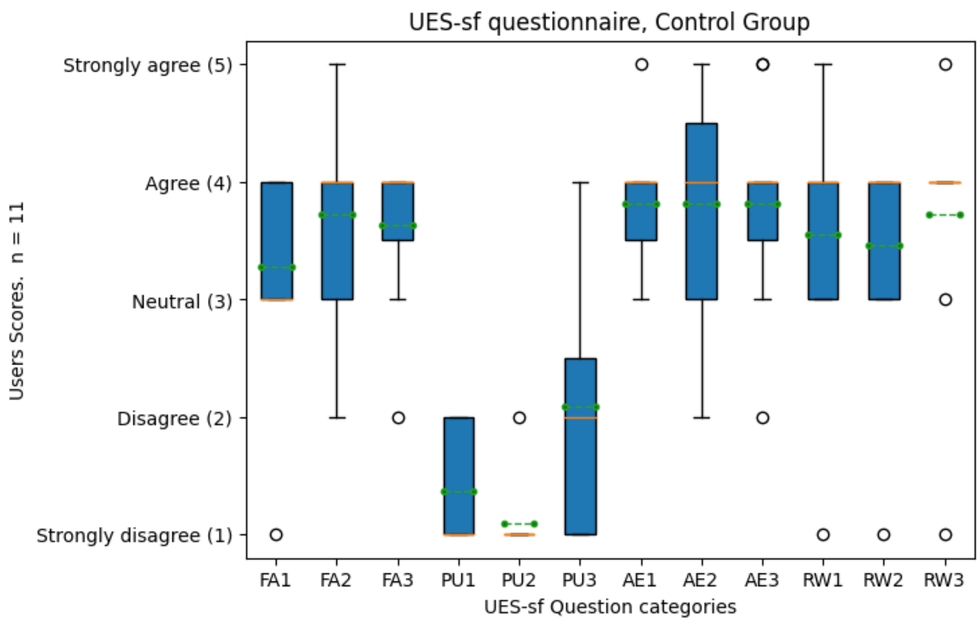

Figure 6.2: Boxplot visualisation of the control group.

[2]A type of error that occurs when one fails to reject their null hypothesis. that is shown to actually be false returning a false negative.

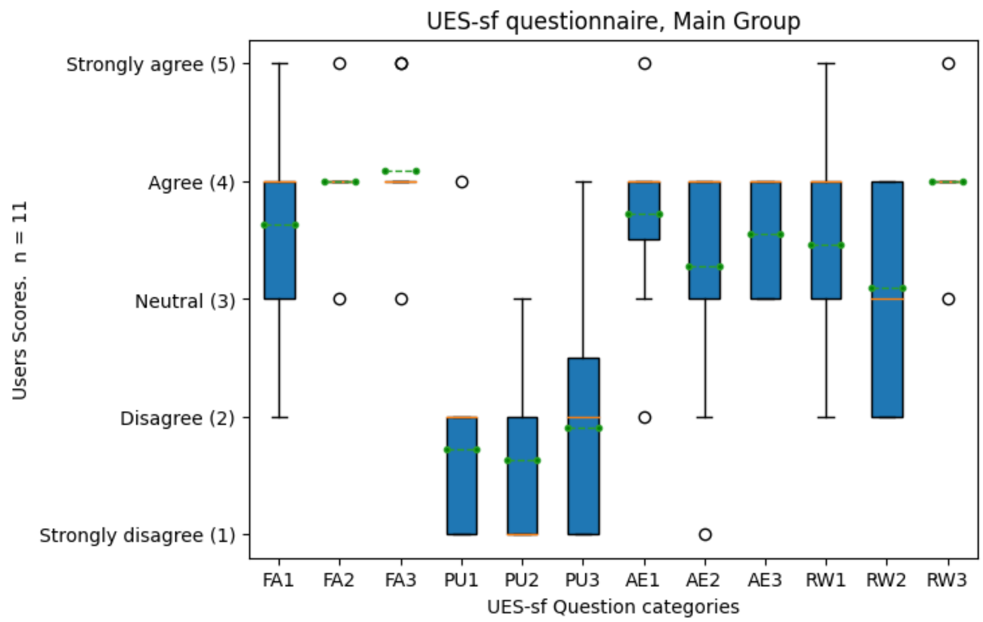

Figure 6.3: Boxplot visualisation of the Main group.

In the visualisation for both Boxplots we can see both groups rating the Perceived usability (PU) categories low, with the rest of the categories lying in the neutral bracket, the many outliers is to be expected given the low amount of participants. For question 12 *RW3* on the control group three outliers are shown, but looking at the data gathered, eight participants reported Agree while the outliers where all individuals who each choose Strongly disagree, Neither and Strongly Agree. This patterns is reflected in all of the outliers shown in the boxplot and as such they should not be discarded but still be considered for discussion.

6.2.1 Haptic Feedback

The Main Test had 5 additional questions in regards to the Haptic Nudge Incorporated into the design of the application. A quick overviews of the results showed the most pressing matters in regards to the Haptic Nudge as 6 participants when answering the first question in regards to register the vibrations, leading to confusing follow-up questions by them, if they had done something wrong. The second question asked participants: *I could easily feel the vibrations during the game.* Here 3 answer were given to both Strongly Disagree and Disagree, mimicking the six participants who did not feel the vibrations while playing. The next two questions were in regards to the user's understanding and feeling of invasion from the vibrations. Some participants replied they did not understand what they meant, rating it Strongly disagree or Disagree, but the majority of 5 were neutral on the matter, while 3 agreed in believing their understanding. The vibrations did not reach any level of

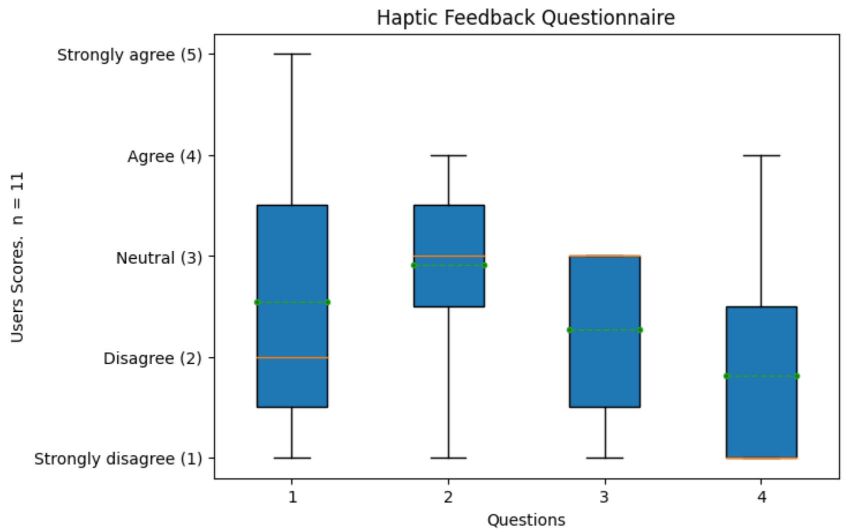

Figure 6.4: Boxplot visualisation of the specific questions regarding haptics. The four questions can be seen in Appendix 8. The 4 questions all related to if participants understood the purpose of the vibrations and how invasive they felt rated on a likert scale of 1 to 5, with 1 being strongly disagree and 5 being strongly agree.

invasion as no participant rated a score higher then 3, shown again with the majority of 6 choosing Strongly Disagree, still should be important to remember that participants who did not experience any supposed vibrations did also choose the option.

As the design of the test prevented any possibly to completely avoid the vibrations, these initial findings as discussed in section 7 served as the main inspiration for the follow-up test afterwards.

6.3 Follow-Up Test

Based upon the findings found in the Primary test and the conclusion drawn about it, especially that of the nudge itself a follow-up test was conducted. Its purpose to be an evaluation based upon different vibration types as the main Haptic Nudge was not sufficient enough. The test was conducted on n=7 individuals and consisted of an user evaluation followed by a open questionnaire. A general question was asked initial to gain an understanding of the user's VR experience before the test and following open interview. Three main topics where discussed with the participant that of:

- Out of the 5 different vibrations, which one do you believe would catch your attention the best?
- Which of the 5 did you find to be the weakest at getting your attention?

- Do you think this will help you be more aware of your surroundings during VR? Why, why not?

Each questions[3] served as a starting point allowing for the conductor to ask further details or topics related to what participants answered. In particularly when asking them to evaluate each type they were asked to explain their reasoning for choosing one type over the other, comparing the positive and negatives of each type. Participants were also asked if they agree with their statement when put into a general VR-scenario.

When choosing which one was deemed the best at grabbing an individual's attention, the majority of participants that of six choose Pattern 4 as their choice, being the constant vibrations while outputting the maximum power. The same participants also made comments in regards to Pattern 3, being a curve starting low and slowly getting more powerful. Here the participant discussed and talked about the possibility of it being distance based, becoming more powerful as the distance between the edge of the boundary and controller shortened, an idea many other echoed while talking about it, and their interpretation of the pattern.

In contrast to the type that was the weakest in garnering attention, Pattern 2 was discussed between participant and conductor for its lack of impact, being too weak in its power to be of any note two participants explained. As Pattern 2 mimicked the type of vibrations found in the Primary test, it was important for the conductor to ask in more deeply about what they felt it lacked, the most common solution participants said was for it to be much more powerful as Pattern 4 was. Pattern 1 and 5 both consisted of a series of pulses, with the first being of a quicker pace, and the latter containing longer pauses. Thees two types proved the most polarising between participants as there was no clear common opinion shared. One participant felt Pattern 1 was the most efficient as they associated it with blinking lights, and that of warning. Another participant instead felt they were too similar to that of a phone notification.

In regards to the last question and awareness during play, Participant number 2 had specific comments in relation to their engagement while playing. This participant was the only individual who described themselves as experience VR user, the participant talked about visual blindness commenting on how it often occurred to them that the guardian would disappear for them during play. For this reason they believed the inclusion of the Haptic Nudge would be a good inclusion to help get them more aware.

[3]These Questions and results can be found in the Appendix 8

Chapter 7

Discussion

7.1 Preliminary Test

As described in a previous chapter 5.1 the purpose was to gain an insight of the potential area of research and served as the main inspiration. Even with observations in the preliminary test had the tendency that the participants with less experience in VR the more willing they were to move in the space and those with more experience stayed in the same area of space. this is taking account for the feet movement, whereas the arms would have a similar pattern for the game they played. Through this, it was deemed that participant lost their spatial awareness and was it not the guardian wall, some participants would have extended their reach and potential hint objects in their surroundings.

The game itself was SUPERHOT and encouraged them move around, it was evident that the participants felt immersed in the game and had a positive degree of engagement in the questionnaire when asked later. Though it set the ground walk for the main research in limiting a player's movement, it could be argued that due to the different style games (between the preliminary test and primary test) that the game was not the optimal choose. However, it did show that player with a high engagement would lose their spatial awareness, specially in an action game which was the main focus area wishing to observe.

7.2 Primary Test

One of the most important aspect found in the results was in regards to their credibly, as was shown with the Cronbach Alpha and Shapiro-Wilk tests. The data acquired was neither normally distributed or of high credibility. As briefly mentioned in the results section 6.2, the best way to ensure one's data credibly and and distribution is to increase the sample size. The sample size proved to be the biggest problem in regards to the test as the availability of participants was heavily limited by the constraints needed for a proper testing location containing both a powerful enough computer to run the VR game as well as the 2m x 2m space needed for it. With the basement of the university being the only suitable space that fulfilled this criteria. To better gather participants, a public or more accessible space would been the most desired, but given the prior constraint of needed a more powerful enough computer nearby. It was not feasible to do such an action with the current tools and funds available. We do not deem this data to be unusable but it cannot be used to draw any deliberate conclusions. The data can only be used to give rough estimates and be utilized as a guideline for future testing in the same procedure.

The test itself compared to the prior preliminary was completed quite quickly by the participants, with most participants completing it in under five minutes. As the main focus of the test was not to see how engaging an VR experience was, but only to check the effectiveness of the Haptic Nudge, it was deliberate to create a simple to understand experience. Because of its simple and short nature it is not surprising that both the control and main group rated the Perceived usability of it low, as seen in both Boxplot figure 6.2 and figure 6.3. These questions related to the player's frustration and confusion while playing. The biggest observation made while participants played in regards to any potential frustration was trying to find the last coin, typically either by their feet or behind them. Because of the low frustration for both version, it also helped in facility the findings that the Haptic nod did not provide any big distraction, matching with what participants for the Main test replied.

Evaluating the results of the UES-sf for both groups shows that the engagement did not get affected by the Haptic nudge. It can of course be argued that this also shows that the Haptic Nudge was not invasive enough to draw the user's attention towards it. But as shown in Figure 6.4 both the ones that felt and did not felt replied similarly with no noticeable groups forming between the two of them. Comparing the findings found here with the findings conducted by Wu et al.. A rough estimate of success for the Haptic nudge can be made, as it feature similar mechanics to the Haptic Alert described by Wu et al., which was rated positively by participants for not being too disruptive while still remaining informative enough.

It is important to not forget that the majority of the participants did not register the Haptic nudge. It is for this reason needed to gather more information based upon the Haptic themselves, which type of haptic patterns works the best in acquiring an individual's attention and how effective would it be in making one more aware of their surroundings. A follow-up test is needed to find out these questions for future iteration for this test.

7.3 Follow-Up Test

As described in the prior chapter 6.3 the main purpose was to gain insight into what different type of vibration pattern would garner better results. It was interesting to note that one of the types deemed the weakest, Pattern 2. Was the same as the one tested in the Primary Test, given its poor reception specially in its lack of impact. The prior findings where 6 participants did not expedience any vibration, as such one can draw a connection between both test showcasing the main liability of the Primary test.

It was shown that Pattern 4 was seen as the most effective in grabbing a participants attention, likely from the constant vibrations it provided over the duration. If this pattern was to be used in the same test procedure as in the Primary Test, it may have had a bigger effect in making participants aware of it, given its nature as the opposite of Pattern 2. Participant 2 being the only one with proper VR experience had some common thoughts shared by the rest of the group, but still some unique comments based upon their experience. Especially how they talked about the visual blindness they sometimes experienced. This was one of the main motives for conduction this research, helping in showcasing the potential weakness the current guardian system has by itself.

Given the sample size consisting primarily of inexperienced users of VR, their feedback can be used to gain a better understanding of how an novice approaches the VR environment. The participants also only had to give their thoughts on the potential scenario of experience said patterns in VR, serving more as a guiding post for future testing based on their feedback.

Based upon the findings a distance based approached seemed to resonate the most with the test participants. The idea of having a continues feedback that changes based upon the distance is similar to the Haptic Alert describe by Wu et al., given based upon the findings as described by them. It is possible to make an estimated guess by combining the findings we have found ourselves with the knowledge and credibly of Wu et al.

Chapter 8

Conclusion

The main question this report sought to asked was: *Does the usage of an haptic-feedback based nudge provide better spatial awareness for an user during virtual reality?* To answer this two initial test were planned and conducted, the first being to gather behavioral and observations in regards to a player's movement. While the second sought to see the effectiveness of our Haptic Nudge solution. Here the result found proved to be unsatisfactory to fully answer the FPS proposed. For this reason a follow-up test was conducted to acquire more responses from individuals as such their feedback and evaluation could be used for future work.

Because of these reasoning we cannot answer our FPS, what we instead did was create the foundation and groundwork needed for us or others to continue working from this point. From the results shown in the UES-sf we see that a player engagement did not get affected by the current iteration of out test. This is another angle one could go forward with. Looking into how more harsh pushed of nudging and invasion of a person's intimate space could affect the user's engagement, for the explicit purpose of warning them about incoming danger by lack of spacial awareness aroused from immersion.

What we see is still an indication that the inclusion of an additional component to the current VR safety toolkit will still be a beneficial addition given the growing market and usage of VR, given the positive responses and conversation sparked by follow-up Test.

Chapter 9

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Digital Appendix

(A) Preliminary testing(W8)

This following appendix showcases notes and observations of the prerequisite test done in week 8 (February 20th to 22nd). These notes showcase observations of the participants playing SuperHot with marked areas for their surroundings. After they have played the game they were asked to answer an questionnaire about there experience.

Questionnaire data

These following tables show the results of the given questionnaire to the participants after they have played the game. for the question: *"How invasive did you feel the game to be?"* it was told that Invasive here is defined as something that makes you feel a sense of discomfort in regards to your personal space. On a scale from 1 to 10, with 1 being no sense of discomfort and 10 being constant sense of discomfort.

Consent Form

I hereby give my permission for this research for the research of VR experience for a master thesis at Aalborg University to use my answers in the following questionnaire.

I may withdraw my consent at any time, Enquiries must be made by writing to llangs19@student.aau.dk.

By signing this declaration of consent, you accept that Aalborg University will store and process the personal data you provide to us. The prerequisite for this consent form is that all material will be stored securely and confidentially in accordance with the requirements of the Danish Data Protection Agency. Anyone who has permission to view the material is bound by confidentiality. As well as understanding the following points.

1. I confirm that I have read and understand the above and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

3. I understand that my answers will be kept confidential and that I will only be identified by a pseudonym in the publications arising from this research.

	Procent	Respondenter
I Agree to the form	100,0%	10
I disagree to the form	0,0%	0
I alt	100,0%	10

I lost myself in this experience

	Procent	Respondenter
Strongly Disagree	0,0%	0
Disagree	10,0%	1
Neither agree nor disagree	0,0%	0
Agree	50,0%	5
Strongly agree	40,0%	4
I alt	100,0%	10

The time I spent playing VR just slipped away

	Procent	Respondenter
Strongly Disagree	0,0%	0

Disagree	0,0%	0
Neither agree nor disagree	20,0%	2
Agree	50,0%	5
Strongly agree	30,0%	3
I alt	100,0%	10

I was absorbed in this experience

	Procent	Respondenter
Strongly Disagree	0,0%	0
Disagree	0,0%	0
Neither agree nor disagree	10,0%	1
Agree	50,0%	5
Strongly agree	40,0%	4
I alt	100,0%	10

I felt frustrated while playing the VR game

	Procent	Respondenter
Strongly Disagree	20,0%	2
Disagree	60,0%	6
Neither agree nor disagree	10,0%	1
Agree	10,0%	1
Strongly agree	0,0%	0
I alt	100,0%	10

I found the VR game confusing to play

	Procent	Respondenter
Strongly Disagree	60,0%	6
Disagree	30,0%	3
Neither agree nor disagree	10,0%	1
Agree	0,0%	0
Strongly agree	0,0%	0
I alt	100,0%	10

Using the VR headset was taxing

	Procent	Respondenter
Strongly Disagree	50,0%	5
Disagree	30,0%	3

Neither agree nor disagree	10,0%	1
Agree	10,0%	1
Strongly agree	0,0%	0
I alt	100,0%	10

This VR game was attractive

	Procent	Respondenter
Strongly Disagree	0,0%	0
Disagree	0,0%	0
Neither agree nor disagree	10,0%	1
Agree	40,0%	4
Strongly agree	50,0%	5
I alt	100,0%	10

This VR game was aethetically appealing

	Procent	Respondenter
Strongly Disagree	0,0%	0
Disagree	0,0%	0
Neither agree nor disagree	0,0%	0
Agree	50,0%	5
Strongly agree	50,0%	5
I alt	100,0%	10

This VR game appealed to my senses

	Procent	Respondenter
Strongly Disagree	0,0%	0
Disagree	0,0%	0
Neither agree nor disagree	10,0%	1
Agree	70,0%	7
Strongly agree	20,0%	2
I alt	100,0%	10

Using this VR was worthwhile

	Procent	Respondenter
Strongly Disagree	0,0%	0
Disagree	0,0%	0
Neither agree nor disagree	0,0%	0

Agree	50,0%	5
Strongly agree	50,0%	5
I alt	100,0%	10

My experience was rewarding

	Procent	Respondenter
Strongly Disagree	0,0%	0
Disagree	0,0%	0
Neither agree nor disagree	10,0%	1
Agree	50,0%	5
Strongly agree	40,0%	4
I alt	100,0%	10

I felt interested in this experience

	Procent	Respondenter
Strongly Disagree	0,0%	0
Disagree	10,0%	1
Neither agree nor disagree	0,0%	0
Agree	20,0%	2
Strongly agree	70,0%	7
I alt	100,0%	10

How invasive did you feel the game to be?

	Procent	Respondenter
1	10,0%	1
2	20,0%	2
3	20,0%	2
4	0,0%	0
5	10,0%	1
6	10,0%	1
7	10,0%	1
8	0,0%	0
9	10,0%	1
10	10,0%	1
I alt	100,0%	10

Samlet status

	Procent	Respondenter
Ny	0,0%	0
Distribueret	0,0%	0
Nogen svar	0,0%	0
Gennemført	100,0%	10
Frafaldet	0,0%	0
I alt	100,0%	10

Observations data

While the participants played certain behavior was observed. These observations are displayed individually here under.

Test participant 1:

- Big arm movement
- Lots of body movement
- Lots of turning.
- Stepped out of half meter frequently
- Scared of hitting things in the real world
- Of centered from the middle halfway through

Test participant 2:

- Small movements at the beginning
- More erratic movement when punching
- Almost stepped over the 1 meter line when punching
- Sudden shock when a bullet hit him
- Off centered and hit a wall accidentally.

Test participant 3:

- Played vr before
- Leaned back when someone was in front of him.
- Least foot movement noted
- Very rooted in place
- Most active in his upper body
- Moved away from the x halfway though
- More movement as he got more into the game

Test participant 4:

- Know of super hot.
- Leans back when. Almost hit.
- Steps side to side often.
- Sudden movement when hit or almost getting hit. Invasion of space.
- Big single arm movement have them stretched often.

Test participant 5:

- Played vr before a lot but not tried super hot
- Wiggled his upper body from side to side.
- Leaned his body back
- Frequent head turning

Test participant 6:

- Played a little a vr
- Vocally exclaimed surprised over closeness
- Noticed almost hitting de border
- Moves her body a lot
- Large arm movement when punching and throwing things

- Turned her head often
- Leaned back in shock when hit but not moving her feet back
- Turned 360 to check surroundings
- Very quick fast movement lots of quick steps when playing
- did almost fall, do to the floormats

Test participant 7:

- Played vr before
- Lots of quick contained armed movements
- Using his upper body to dodge
- Lean back far with his upper body
- Slightly off centered
- Jiggles controller to move time
- Turned 360 to check surroundings
- Ducked low
- More movement from him as he got further into the game
- Crouched low to gather item

Test participant 8:

- Never played vr before
- Cautious movements
- Moved her body often both in inexperienced
- Walked around often
- Hit the border semi frequently
- Took advantage the most of roomscale moving
- Moving to dodge instead of standing and moving upper body to dodge
- started off centered after starting the game (by taking the gun)

Test participant 9:

- Never played vr before
- Slow cautious movements
- Very close to the border at one point
- Does not audibly mention the border grid when near it
- Slow movements
- Often outside the 1 m area
- Punched outside the boundaries. May not be aware of what it means

Test participant 10:

- Experienced in vr
- Did boxer like movements when hitting enemies
- Playfully dodge bullets mimicking the matrix and dance like moves
- Moved his upper body a lot
- Quick small feet movements
- Low crouching to dodge and aim
- Generally stood in one direction

The following table showcase the results of the observations during testing, this involve the times they stood out of a following square meter, played VR before, the time they took to play the game or give up, as well if they completed the game.

Participant	Played VR before	Times stepped out 1 foot 1m	Times stepped out 2 feet 1m	Times stepped out 1 foot 2m	Times stepped out 2 feet 2m	Time in seconds	Game Completed
1	Yes, long ago	22	0	0	0	345	No
2	Not asked	17	4	2	0	222	No
3	Yes	3	0	0	0	365	Yes
4	yes	21	3	0	0	277	yes
5	yes	10	0	0	0	297	Yes
6	yes, very little	33	7	0	0	303	no
7	yes	5	0	0	0	314	no
8	not much experience	34	20	3	0	434	no
9	yes	19	13	0	0	266	yes
10	yes	10	0	0	0	178	yes

(B) Primary Test Control

This the questioner results for the control group during the primary test. this test was conducted in the ME lab at Aalborg university Copenhagen. the followed that first they played the implementation and then they would answer the the questioner. for the Control group there were only ask about their engagement.

Consent Form

I hereby give my permission for this research for the research of VR experience for a master thesis at Aalborg University to use my answers in the following questionnaire.

I may withdraw my consent at any time, Enquiries must be made by writing to llangs19@student.aau.dk.

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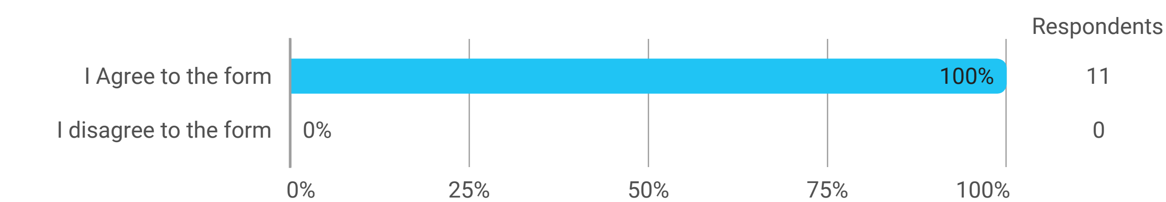
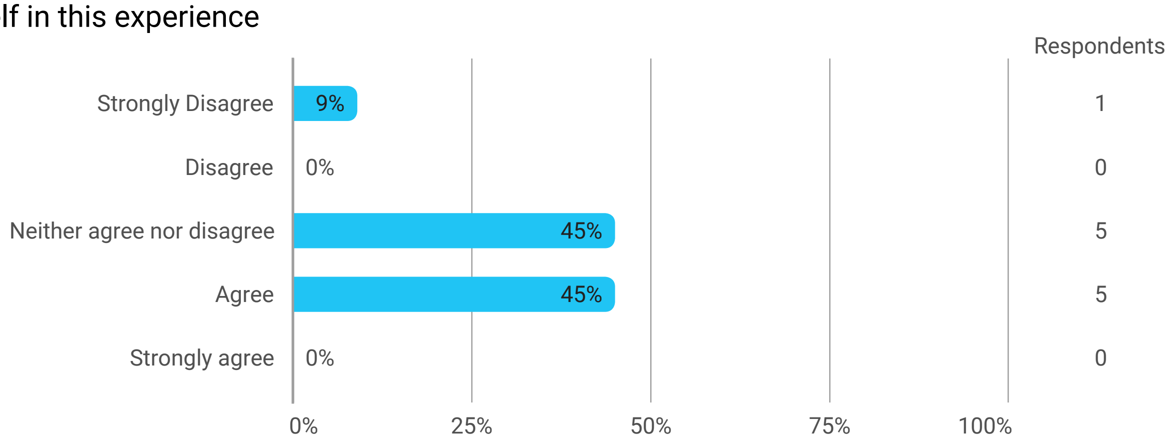
1. I confirm that I have read and understand the above and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

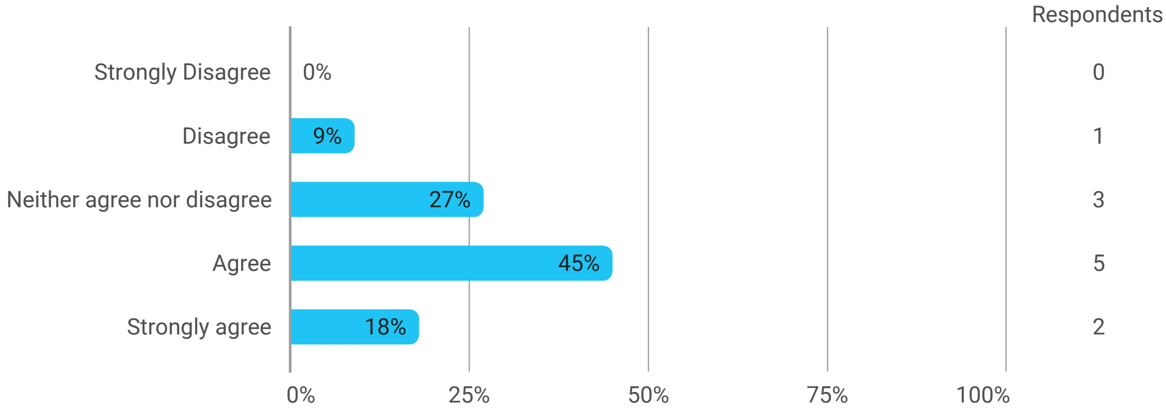
3. I understand that my answers will be kept confidential and that I will only be identified by a pseudonym in the publications arising from this research.



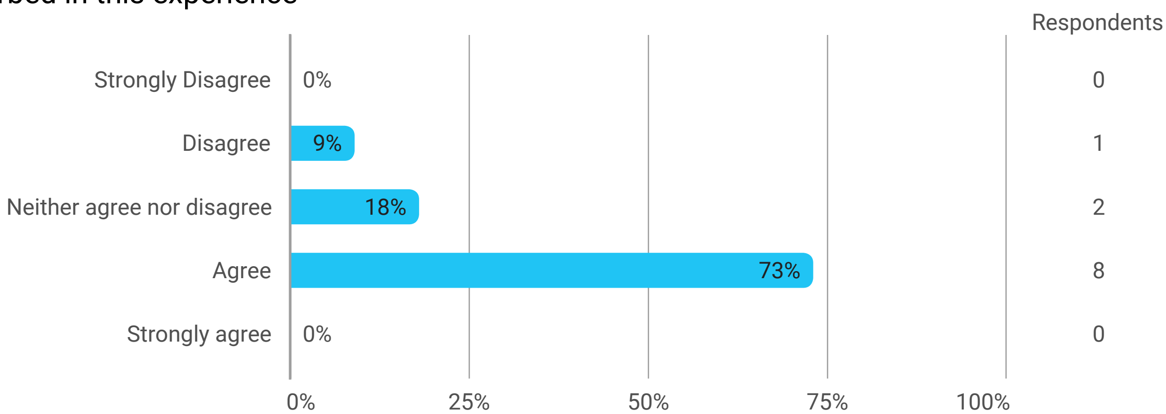
I lost myself in this experience



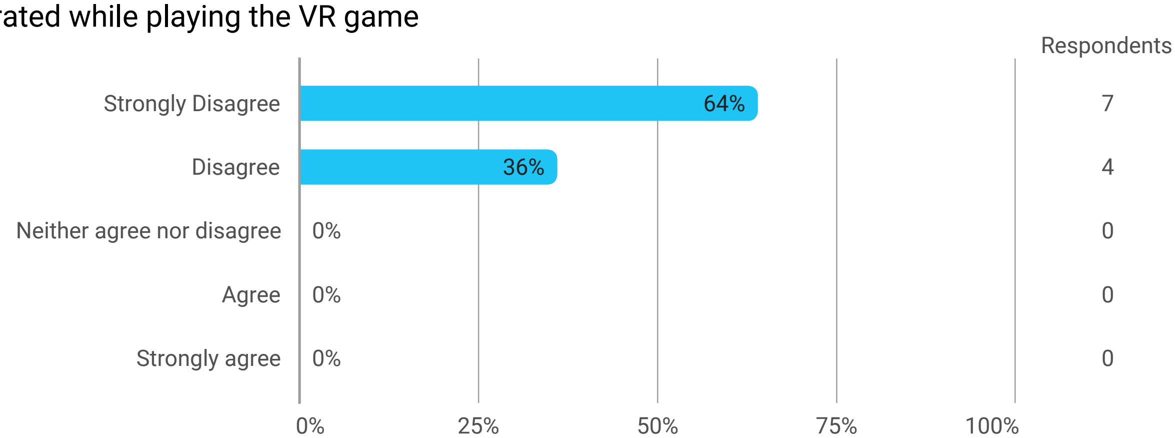
The time I spent playing VR just slipped away



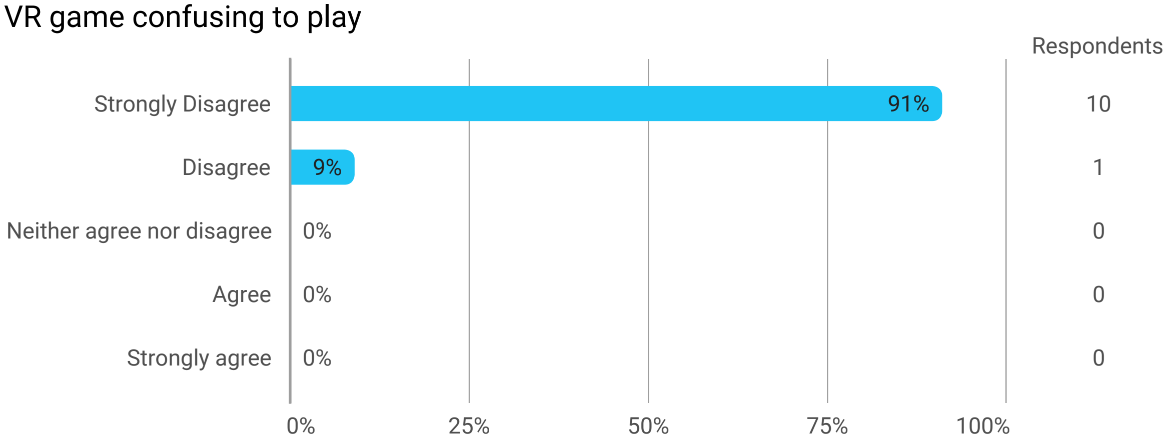
I was absorbed in this experience



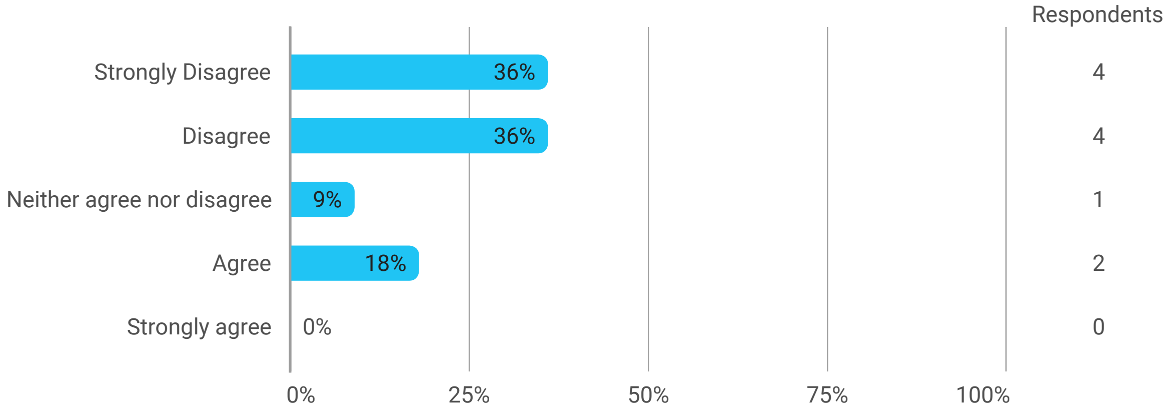
I felt frustrated while playing the VR game



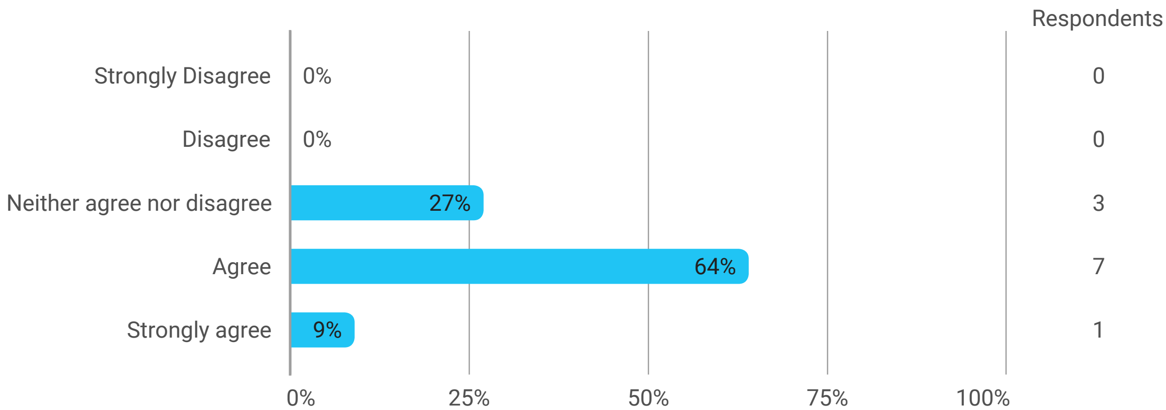
I found the VR game confusing to play



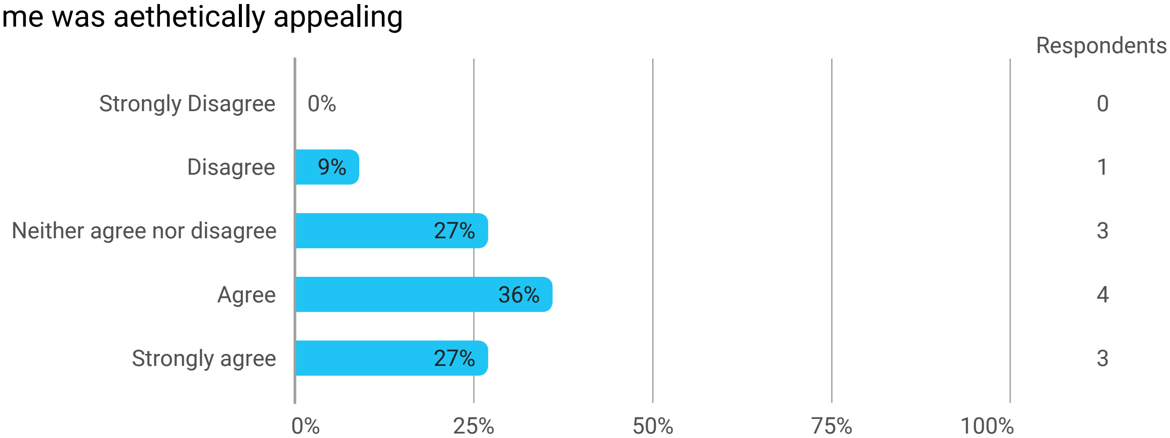
Using the VR headset was taxing



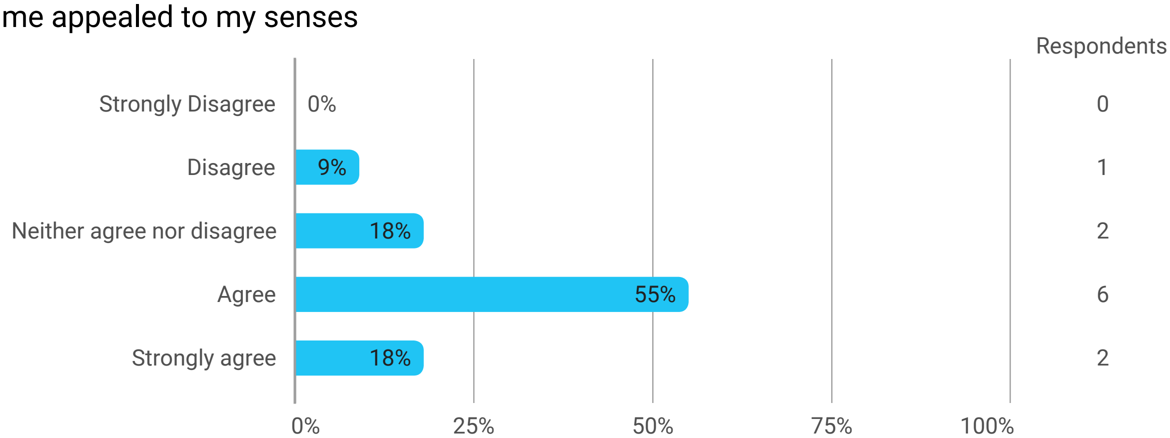
This VR game was attractive



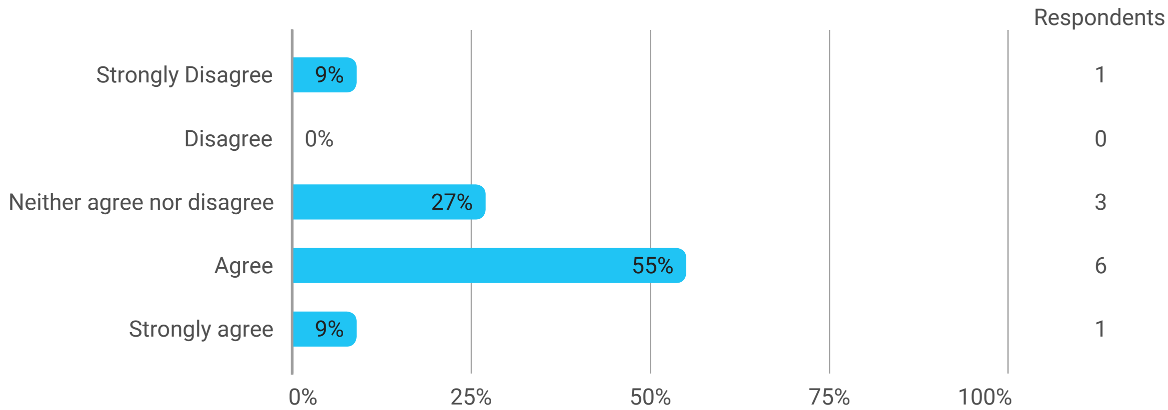
This VR game was aethetically appealing



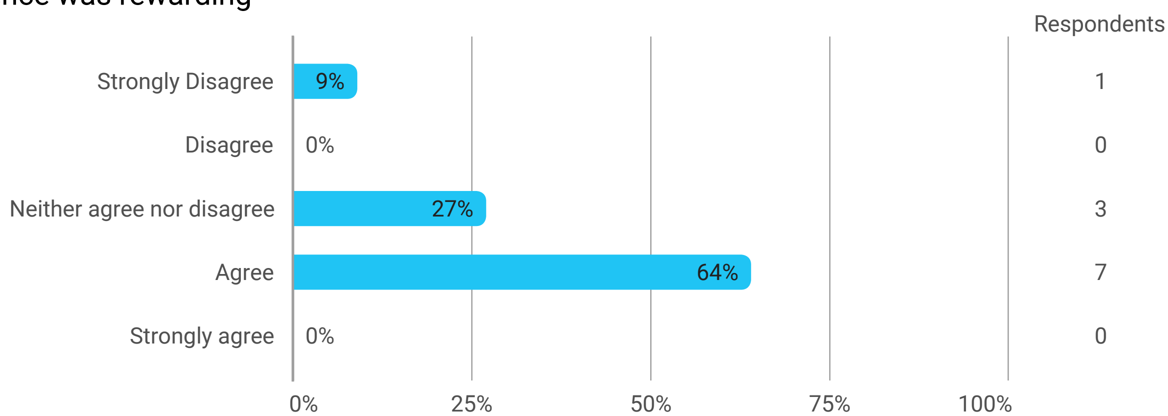
This VR game appealed to my senses



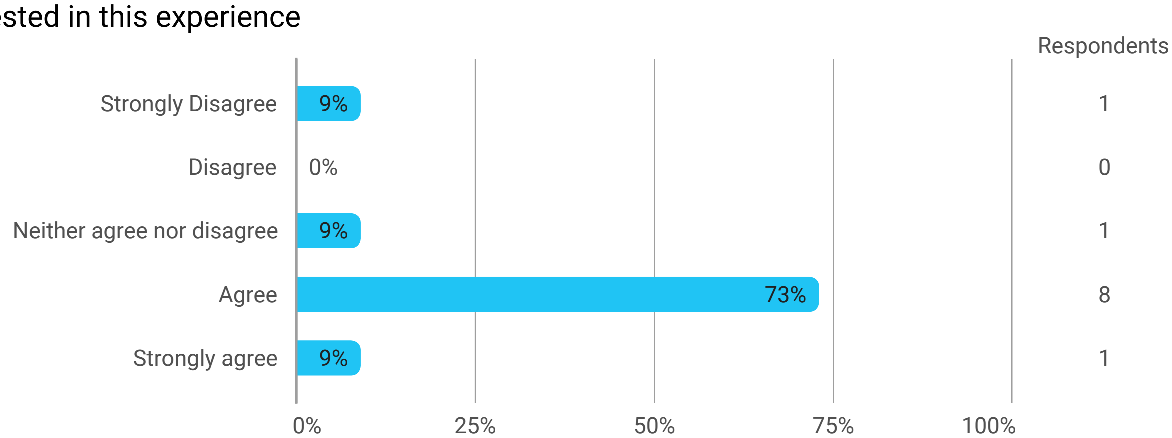
Using this VR was worthwhile



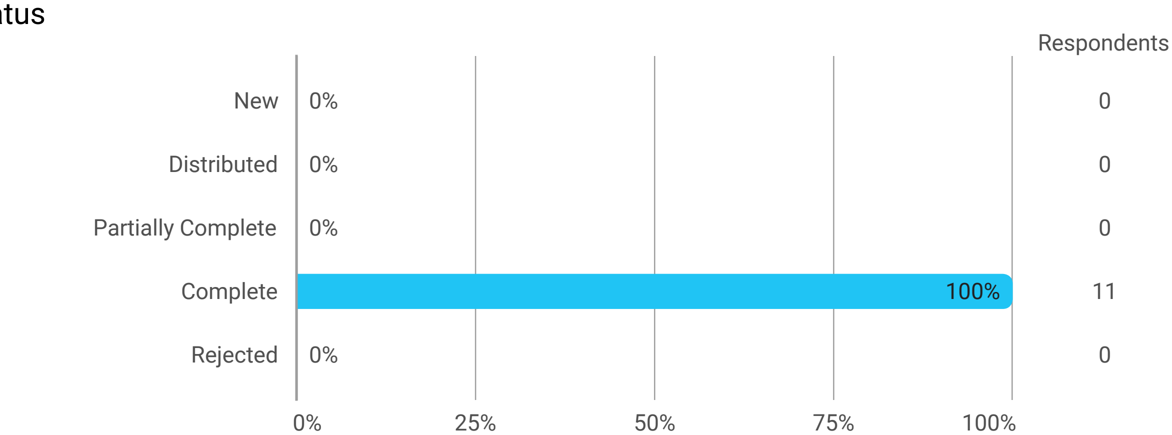
My experience was rewarding



I felt interested in this experience



Overall Status



(C) Primary Test Main

This the questioner results for the Main group during the primary test. this test was conducted in the ME lab at Aalborg university Copenhagen. the followed that first they played the implementation and then they would answer the the questioner. For the Main group there were ask about their engagement and their experience with the vibration.

Consent Form

I hereby give my permission for this research for the research of VR experience for a master thesis at Aalborg University to use my answers in the following questionnaire.

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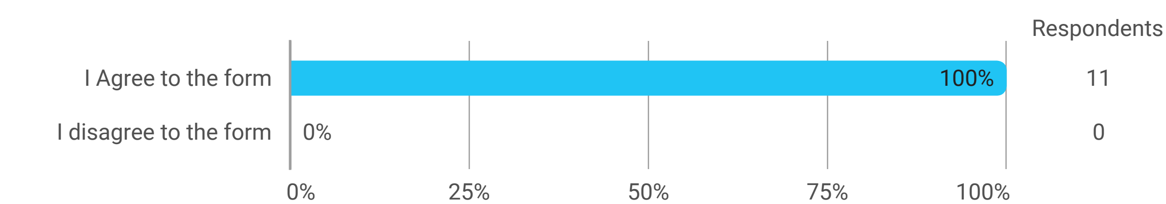
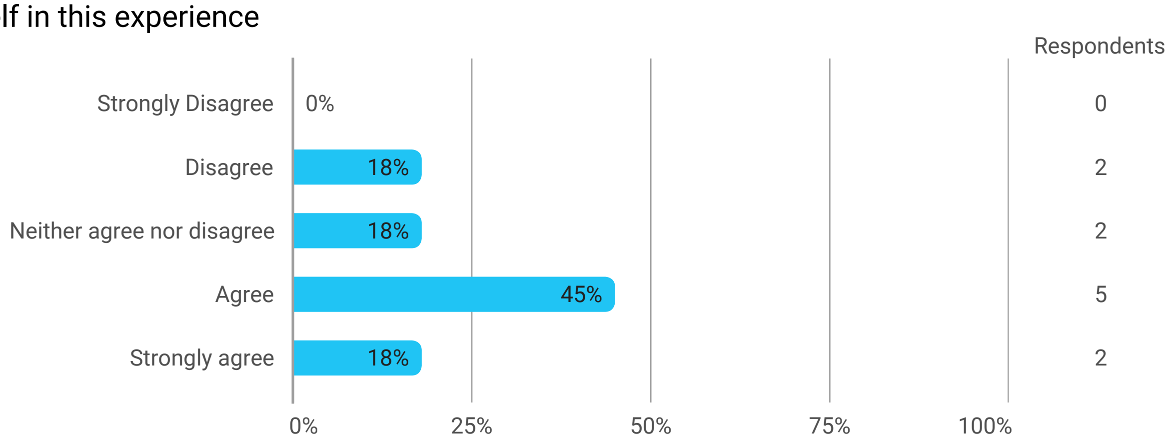


I lost myself in this experience



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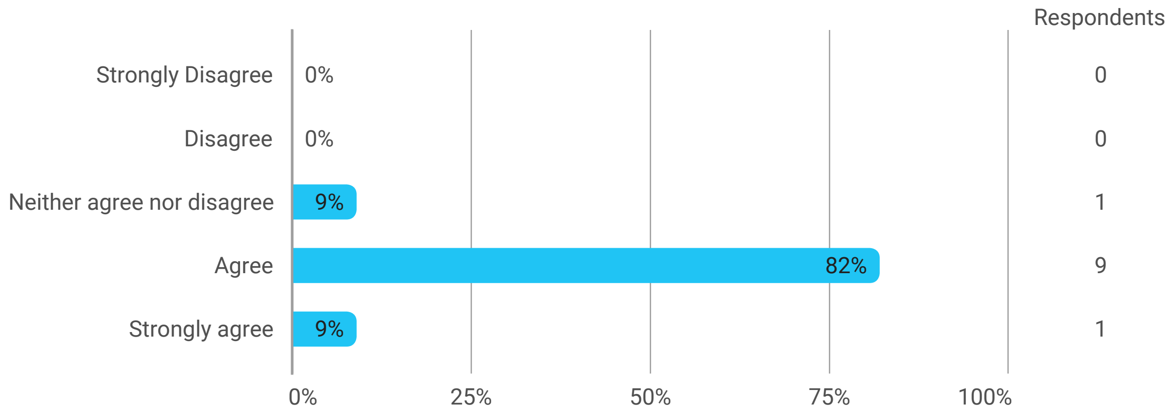

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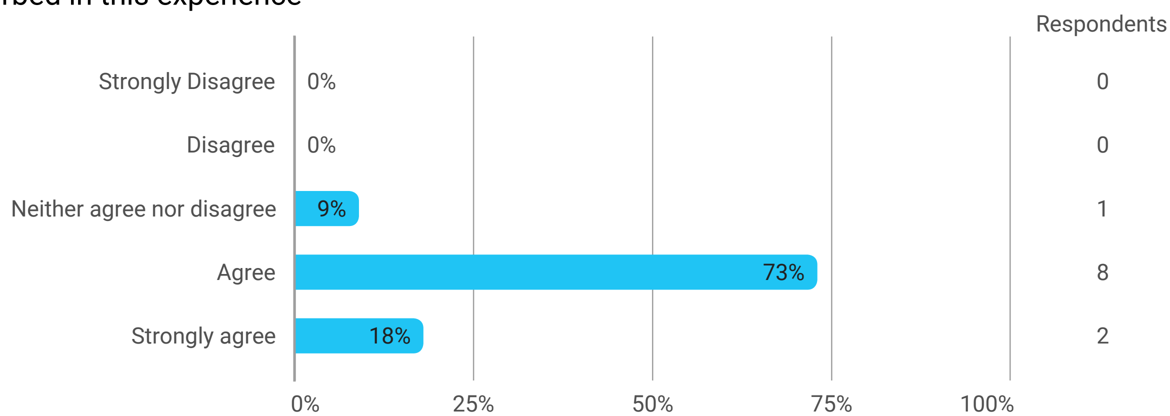

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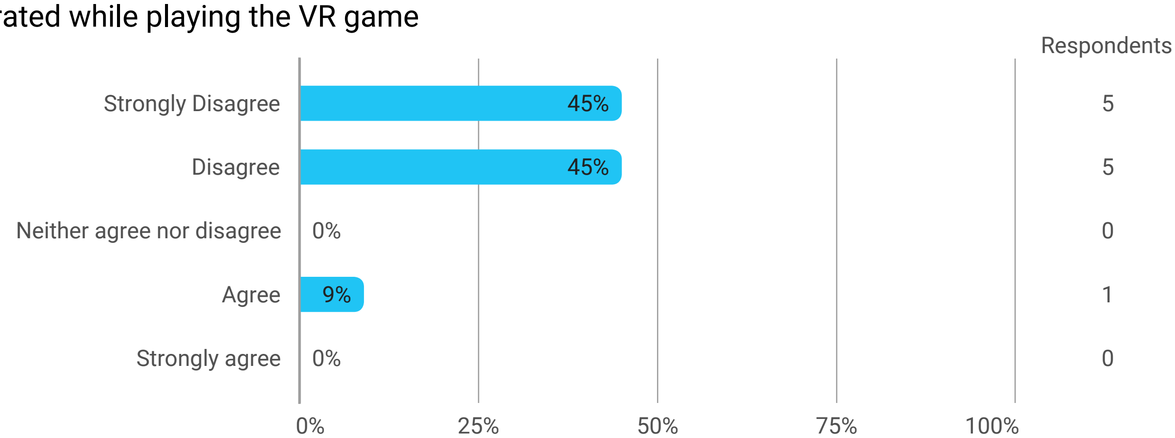

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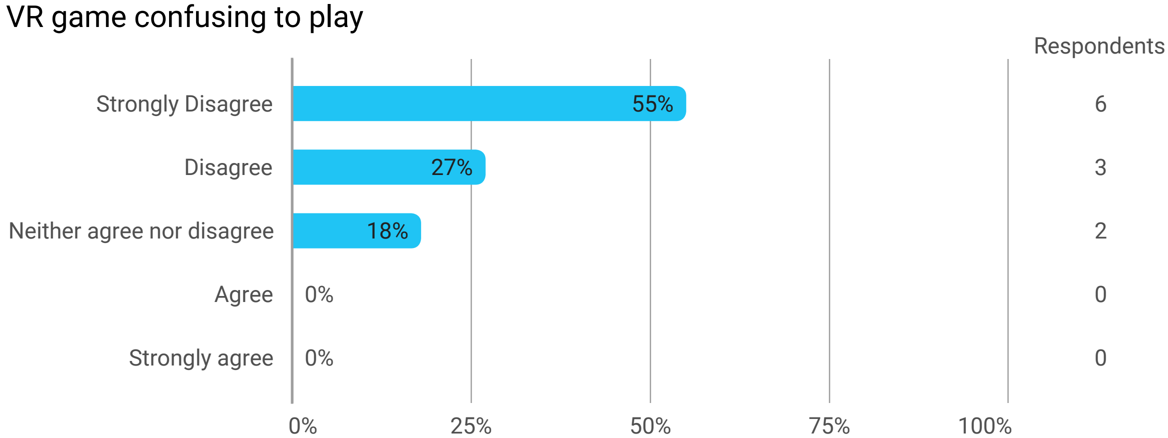

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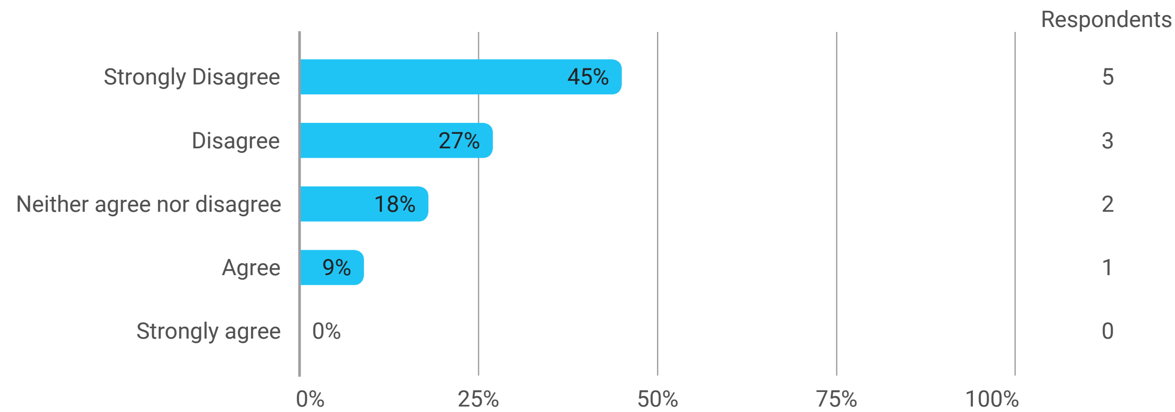
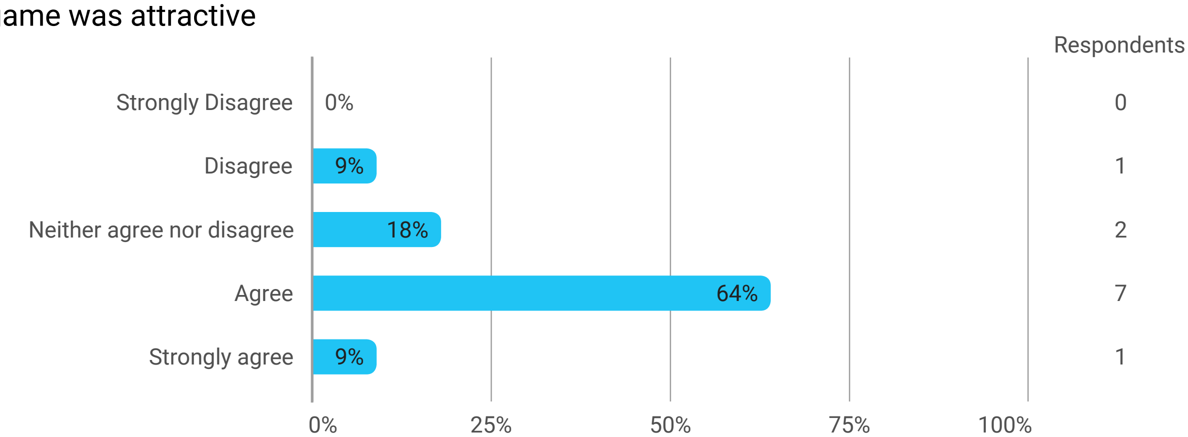
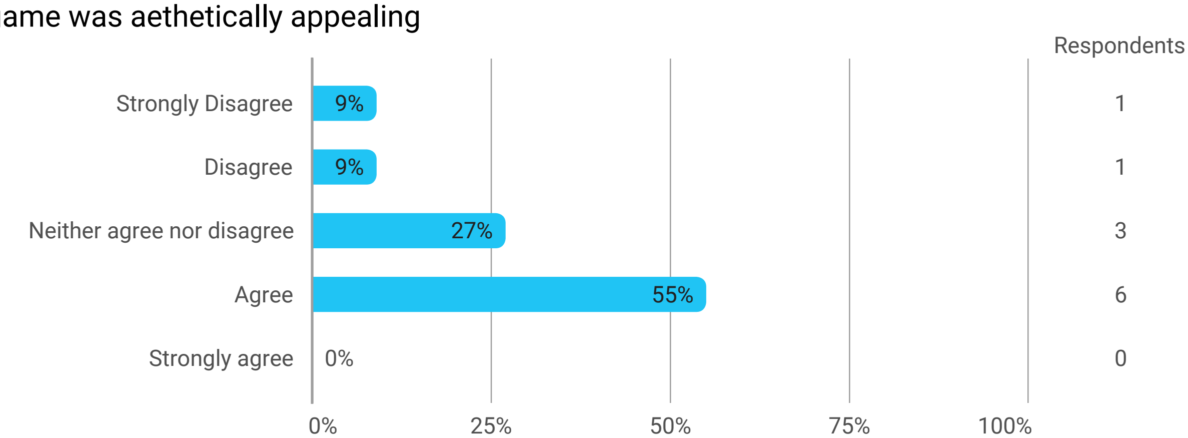


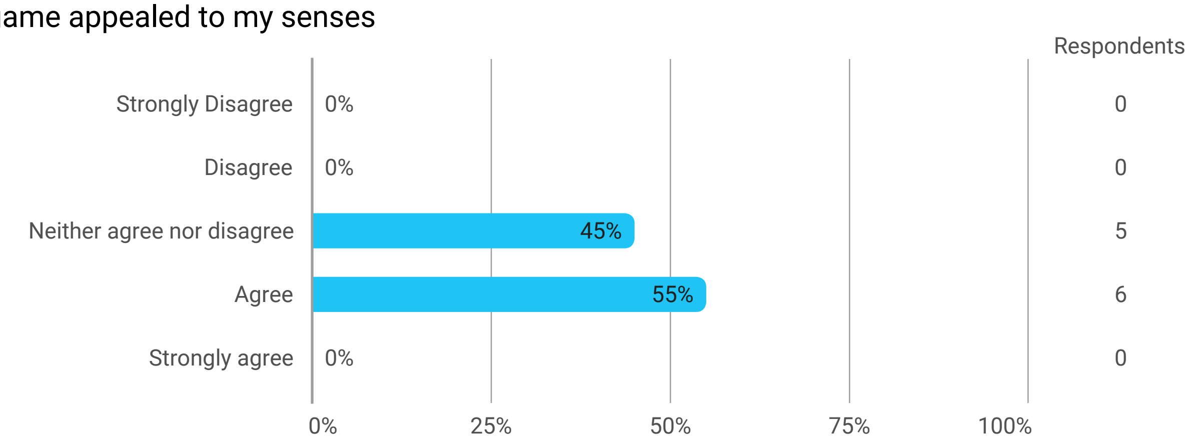
This VR game was attractive



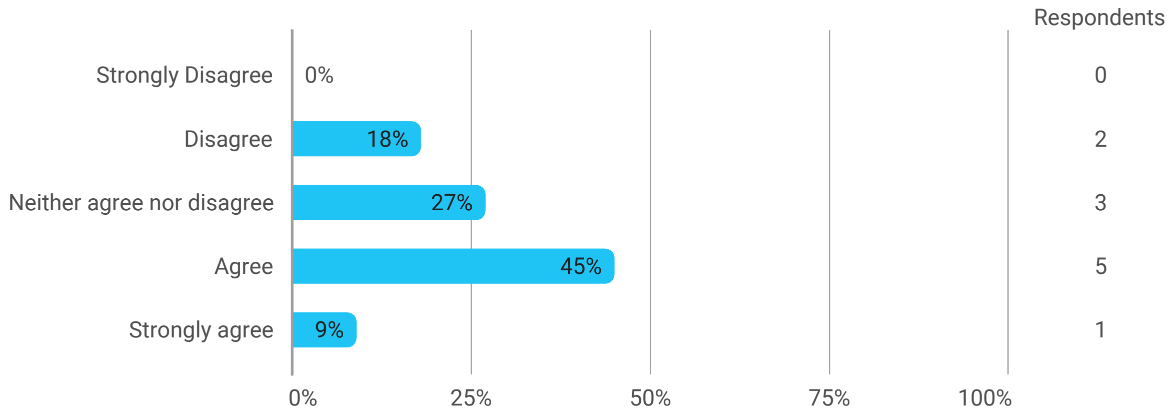
This VR game was aethetically appealing



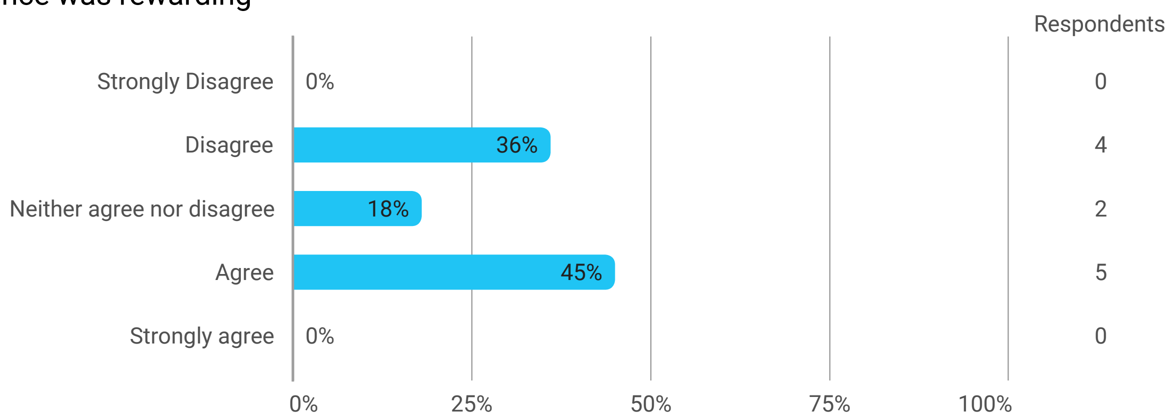
This VR game appealed to my senses



Using this VR was worthwhile



My experience was rewarding



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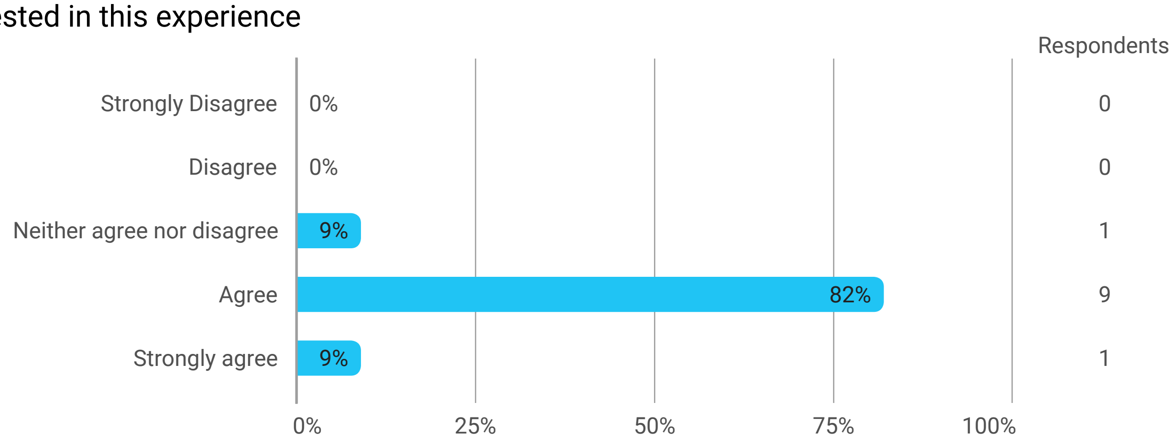
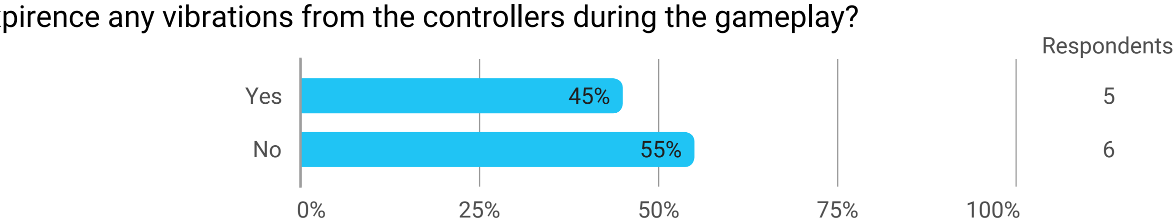
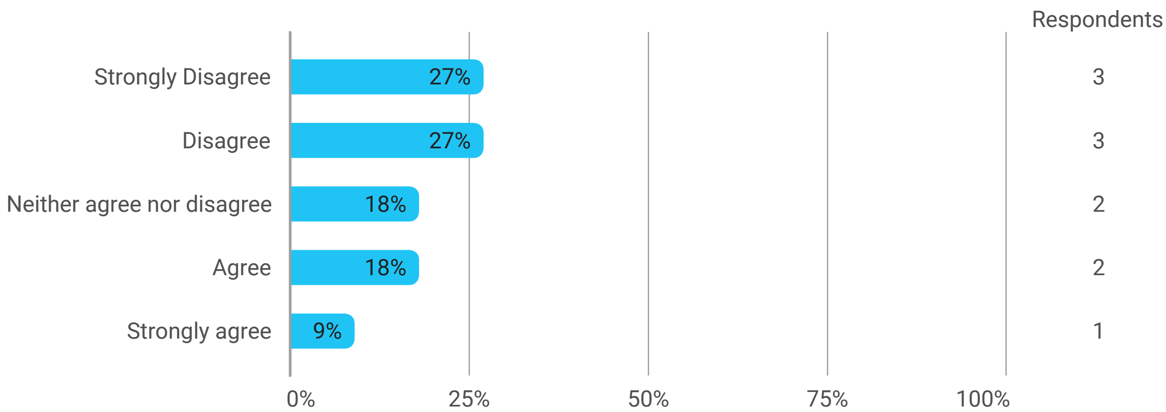


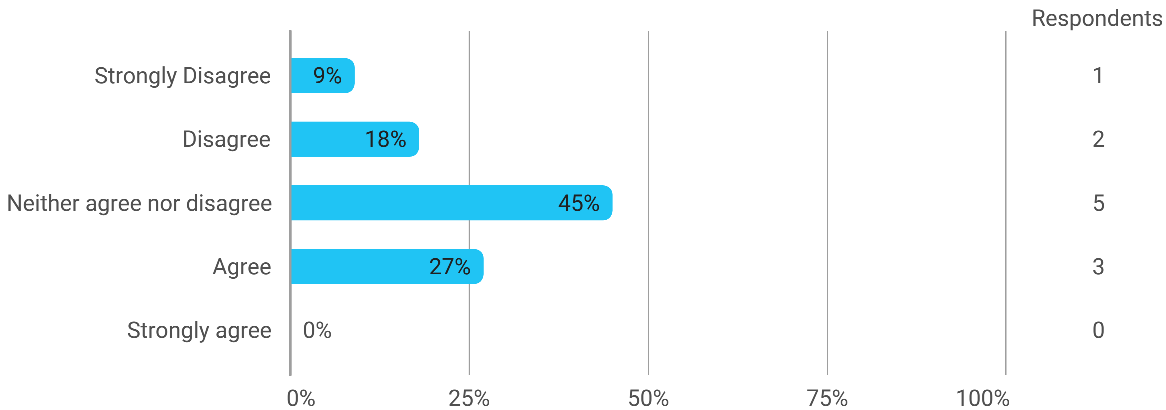
Did you expirence any vibrations from the controllers during the gameplay?



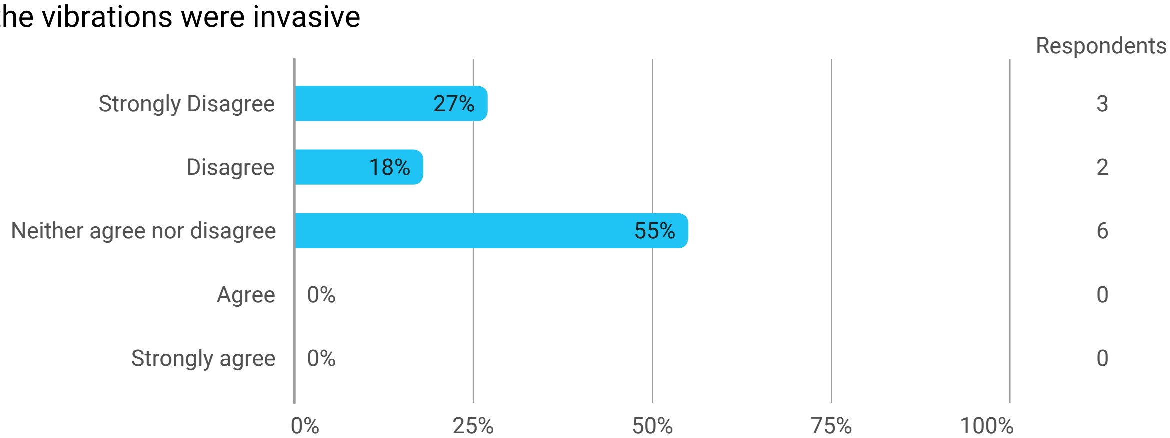
I could easily feel the vibrations during the game



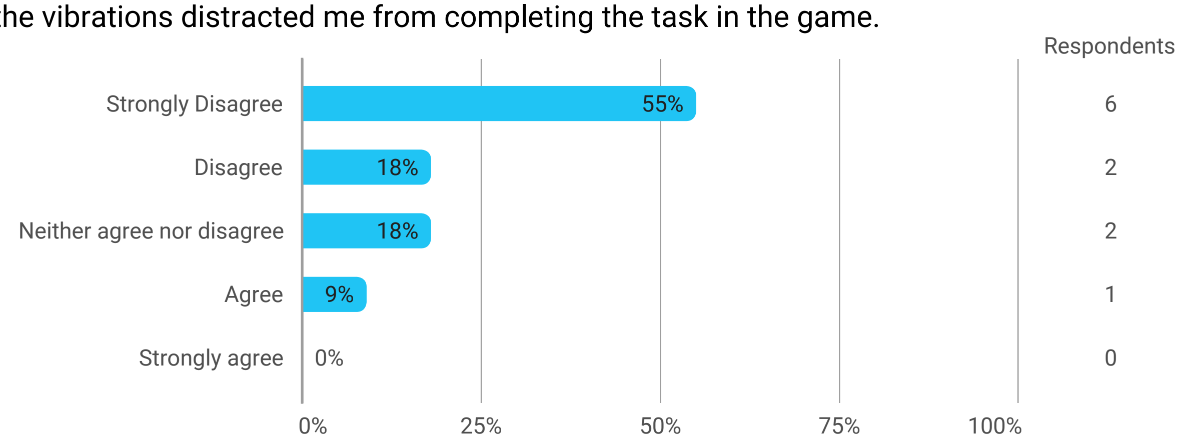
I understood what vibrations were meant



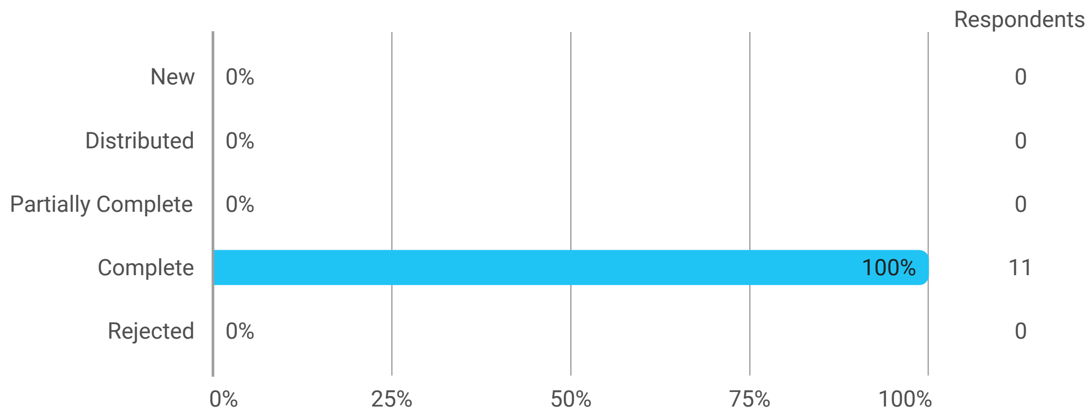
I felt that the vibrations were invasive



I felt that the vibrations distracted me from completing the task in the game.



Overall Status



Respondents
New
0%
0
Distributed
0%
0
Partially Complete
0%
0
Complete
100%
11
Rejected
0%
0
0%
25%
50%
75%
100%

(D) Follow-up Test questions and answers

Pre-Test, explain the purpose and explain how guardians function. What kind of experience do you have with VR?

- 1 Not much, never really tried.
- 2 Large experience with VR, owns a headset and uses it semi-frequent.
- 3 Don¨t own a headset, very little experience with long pauses between
- 4 Tried a few times, but very long ago.
- 5 Only once or twice, long ago.
- 6 Not played a whole lot of vr.
- 7 Zero experience, never really tried VR before.

After Test, Ask in depth questions about what they find to work or don't work. Out of the 5 different vibrations, which one do you believe would catch your attention the best?

- 1 Both pulses caught their attention the most, good because it's not constant, mimics blinking, associating it with caution. THis makes it very clear to them that they have to pay attention to it.
- 2 Number 4 and 1, the sheer power of it, proved the strongest in gathering attention, in contrast in a pure game sense, number 3 would work the best, but believes the downside is that it would be too frequent to the point of annoyance.
- 3 Number 4, was the most powerful as well as the constant, but would not prove efficient in game. Would be easy to mistake it as part of a vr experience. Here 1 would prove the best. Would personally want a mixture between 1 and , with lesser pause
- 4 Number 4, was the best in being attention grabbing, Would be viewed as a distraction, number 3 would work the best in a game setting, if distance based, as number 4 constant power would not be precise enough
- 5 Number 4, because it was constant in its vibrations and power, felt 2 was too weak. Also believe it would be good as a warning near the guardian.
- 6 Number 3, felt it was the one that left the strongest impression, and didn't feel a strong difference between 2 and 4, even if they were at different levels of power. Felt the idea of 3 being distance based would work the best.

- 7 Number 3 and 4, felt they were uncomfortable for them, but also the strongest one. Felt number 1 was almost like a hand massage. Felt the same for 3 and 4 in a game. Felt 5 was annoying, but also attention grabbing in that way.

Which of the 5 did you find to be the weakest at getting your attention?

- 1 Number 4 was the weakest, more annoying than attention grabbing, got annoying after a while, but it could also be helpful because it was so annoying they would pay extra attention to avoid it. Number 2 was not as annoying in the same way but lacked impact.
- 2 Found the pause in 5 to be too long, Number 2 was simply way too weak that it would be a struggle to register it happened while engaged.
- 3 Number 3 would take too long to ramp up to be noticeable, the duration to hit maximum is a big factor. It would be effective as distance based, but weak if time based.
- 4 Number 5, didn't make much sense to the participant. Didn't see any reasons that it worked. Was viewed more as something that would be too similar to something happening in-game. Haptic feedback if used in games could be troubling depending on how games use haptic feedback themselves. Would likely be combined with the guardian.
- 5 Felt 1 & 5 was too weird, didn't feel natural for them. Associated it with getting a notification. Personally wasn't a fan of them, but could see the value in a VR context.
- 6 Number 1, felt the weakest and didn't leave too much of an impression on them. The shorter pauses made it feel weaker than number 5.
- 7 Number 2, didn't leave any impression to them, didn't like 5, but agrees that it still succeeded in garnering one's focus.

Do you think this will help you be more aware of your surroundings during VR? Why, why not?

- 1 Easy to understand and helps in making one more aware of their surroundings by, doesn't break immersion as much as the traditional guardian.
- 2 Yes, it is rare that they notice the guardian, as it easily blends into the game, and is shown too late for them.
- 3 Yes, if it is successful in noticing before the guardian, it would have to be explained

so one is aware of its purpose to know the point off it.

- 4 Works best only from left and right, but is not precise enough for front and back. Would have to be much more precise haptic feedback to help alert for full 360 roomspace. Additional tools would have to be included to help provide more options to nudge one's current position.
- 5 Agrees that number 4 would be good in making one more aware of their surroundings as its constant strong vibrations serves as a good indicator for them. Felt 3 makes the best sense if it was distance based.
- 6 Both 2 and 3 would work the best to make them the most aware of their surrounding, didn't feel like the full power of 4 would make that much of a difference, as well as didn't experience a lot of difference between the two of them.
- 7 Number 4 was uncomfortable but good, and provided a strong desire to make it stop, by not being near the guardian. Believed that they would end up getting too familiar with 3 limiting its effect before being too late for them. 1 and 5, still didn't prove to be strong enough indicators for them.