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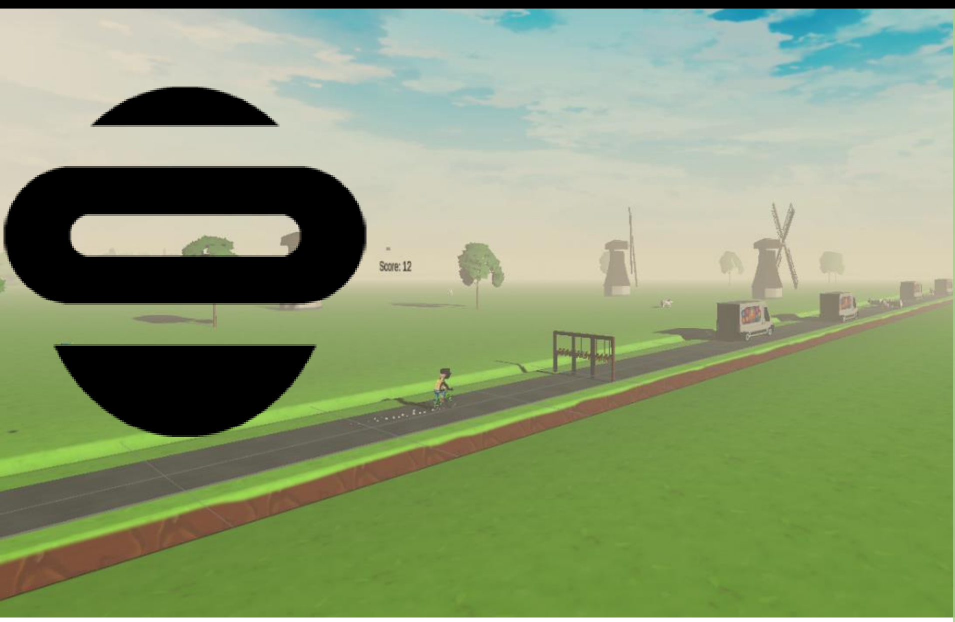
Developing a serious VR game for rehabilitating hand strength after stroke.



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Summary

In the Netherlands, there are thousands of people who need rehabilitation in the aftermath of a stroke. This often involves poor strength and coordination in one side of their body. At the moment, the exercises these people have to perform are simple and repetitive. It might consist of moving around a cube to practise coordination. However, videogames and Virtual Reality are powerful media that allow people to imagine themselves in another world, to have more motivation to keep going and much more. Would it be possible, in collaboration with physiotherapists and hardware engineers, to develop a therapy that takes advantage of these benefits? What strategies can be learned from?

This project explores the answers to these questions, as well as documenting the process of creating a video game to help the rehabilitation process of a patient's hand after a stroke.

Through analysing sources a number of inspirational ideas emerged. Eight principles of other therapies are explained along with how they might be used in a serious game, VR or not, for this purpose. Two of these principles; increasing difficulty and multisensory stimulation are highlighted as especially applicable within the current context.

The most important takeaway from these analyses is that visual feedback to the patient's actions is an effective tool for rehabilitation while that is also easily applicable in the context of a video game.

Motion sickness is a common side effect of the use of Virtual Reality. Therefore, it is important to understand the causes of motion sickness and ways of avoiding their effects. The two strongest causes of motion sickness are found to be, firstly, a disconnect between signals of the player's visual centre and their balance organ and, secondly, a stressful environment. This knowledge has be used to make sure the final product would not cause strong motion sickness.

The eventual product is a video game that can be played in both VR or on a traditional flat screen. The player will control the game using a custom controller that is designed to train the strength of the user's fingers. The game is a three lane runner comparable to games like Subway Surfers, where the player character rides a bicycle through the calm environment of the Dutch countryside.

Contents

1. Introduction

Strokes are common and cause a lot of hardship for thousands of people throughout the Netherlands. They can have significant and long lasting impacts on a victim's brain, their mental capacities and their motor functions. The purpose of this report is focused on the latter. For the lack of motor functions exist numerous different therapies. A patient would for example pick up and move a cube from one place to another. The patients are required to repeat this monotonous movement often. This is the cause of one of two main problems with this therapy that could be solved by the project described in this paper. It can be tough and boring for a patient to regularly practice their motor functions without being mentally stimulated. The second problem is that therapists do not get a proper insight into the progression of patients. They only see their progress whenever they have a session together. Being able to track more specific data could provide significant improvements in the effectiveness of treatment.

To solve these two problems, the Handforce project has been set up. Handforce consists of a number of schools, companies and organizations working together and sharing knowledge to use currently available technology to increase the quality of hand rehabilitation after a stroke. Some of the technologies they aim to use are serious games and Virtual Reality. (VR) Serious games are powerful tools that could help alleviate the problem of monotony in current therapies. Virtual reality's immersive qualities also have the ability to provide the therapy with even more advantages that traditional motor therapy does not have. The fact that VR feels so much like being in a different space means that is has a very strong neurological effect on the user. This neurological effect could be used to the advantage of the therapy.

This report is provided by MaMa Producties, a small Virtual Reality and design company in Eindhoven. The role of MaMa Producties is to create a game using Virtual Reality which helps solve the two main issues with current hand therapy. Two groups in the Handforce project are working on custom controllers that are meant to provide therapeutic advantages while controlling a video game. To help rehabilitate the strength and coordination of the patients in a fun and engaging way. While providing more advantages to the therapists and the patients themselves.

1.1 Assignment

There are two groups within the Handforce project creating controllers that are specially designed to be used to control a video game while getting the necessary training. These controllers are characterized by the fact that they can be used with one hand and can measure the applied strength of each individual finger while training their strength. The details of these controllers will be elaborated on later in this chapter. The controllers are able to control a video game while providing training for impacted hand. The task of this report is to research what would be necessary to realize this video game and to develop a prototype said game. To do this, it will also be needed to create a system that can interface with multiple controllers.

1.1.1 Goals

The introduction mentioned two major problems. The first being the monotony of the current therapies. Current hand therapy generally consists of the repetition of motor tasks. It's important to put in enough time practicing daily. This is difficult for many patients. They are often not motivated to do something that they found boring the previous day. The idea is that this can be alleviated through a video game. Their goal is to make a game that is fun to play for the target audience so they are motivated to keep playing while also rehabilitating the strength and coordination of their hand.

The second problem is the lack of insight of the therapists into the progress of the patients' therapy. Since video games are software, it is possible to precisely track how the training has been progressing. The therapist could be able to see how long a patient has been training, how many times they train. They could also analyse more specific details of the status of their hands. Furthermore, the videogame could supply insights on the force each finger has applied, how many times this has been done and how long this force has been applied. The goal is to give therapists more insight into the progress of the patients on a more continuous level.

1.1.2 MaMa Producties

This report is made as a graduation assignment during an internship at the company MaMa Producties. Mama Producties is a small company. It describes itself as combining technology and creativity. They use the advantages of Virtual Reality and Augmented Reality (AR) to solve a wide array of problems, ranging from social issues and medical applications to the preservation of history and art. MaMa Producties has been tasked to construct the software aspects of the Handforce project.

1.1.3 Audience

Since many victims of stroke become cognitively impaired, the game should be accessible to cognitively impaired people who are inexperienced with video games. This means the game should be easy to understand and to play. Learning a new game can be daunting and demotivating when someone just wants to enjoy themselves. So it's important to consider a proper learning curve that give the players the ability to play as soon as possible.

The game should also not provide too much visual or auditory stimulation to the players, since this could easily overwhelm stroke victims.

Strokes are more common with elderly people. This means that the game should be appealing to them.

Validating the appeal of the game with the target audience is important, since the target audience is not largely represented in the people who are working on Handforce.

1.1.4 Therapists

Therapists want a more detailed insight into the rehabilitation of their patients. They don't just want a momentary snapshot of the patients progress whenever they have a therapy session but they want to see data from the continuous progress of the patients.

The game should also be able to remember the previous actions of players and use them to make sure they train each finger enough. This information should be saved so that the therapist gains insights in their patient's progression.

1.1.5 Questions

This report will attempt to answer a number of questions aimed at the optimal way of creating a video game for therapeutic purposes. Specifically the purpose of rehabilitating the strength of the hands of a stroke patient. The central question will thusly be: "What is the optimal way to create a serious game to rehabilitate the hand strength of stroke patients." This main question results in many smaller questions. Some of these will be answerable through literary research, while some will need to be answered through other types of experimentation like play-testing.

The first sub question that should be answered is: "What is a stroke?" Together with related questions: "What are common side effects of a stroke?" and "What specific qualities of the patient's hand should be rehabilitated."

To gain a stronger idea of what should exactly be improved, we need answers to the question: "What are current therapies for hand rehabilitation after a stroke?" This could inspire the concepts that will be turned into a game.

While it is important to know what current therapies exist, it is also important to understand the underlying principles that make them work. "What are the most effective principles when designing a therapy?" Of course it should then be answered which of these principles would be applicable in Virtual Reality.

After the current therapies have been examined, the next question that should be answered is: "What advantages do serious games have over traditional therapy?" There have been previous medical applications of video games that could be inspected to gain inspiration for the current project.

As the eventual product would have an implementation of VR, it is important to consider the disadvantages of VR as well.

- People are completely shut off when they have their eyes covered by a headset.
- A common side effect of VR is an experience of motion sickness. Resulting in the question "What should be considered to reduce motion sickness in our target audience?"

Another possible consequence of serious games worth mentioning is the fact that there is a moral consideration when it comes to video game addiction. The game will be designed to be engaging and to compel players to come back. But this has the possibility to tread into addiction. To make sure that this won't become an issue with any of the patients, we will first answer the questions: "What design patterns cause video game addiction?" "What groups are most vulnerable to video game addiction?" and "What are the best ways to design a game to avoid addiction?"

When these questions are answered and there is a working prototype of the game, the design of the game should be tested as well. Ideally, the following questions would all be answered by this report:

- "How effective is this game at rehabilitating the target audience?" "
- Is the game engaging enough for the target audience to want to return to the game regularly?"
- "Is the game accessible enough for the target audience?"

However due to issues relating to scope and a lack of access to stroke patients for testing, only the latter two questions will be tested.

The questions that can be answered in advance will be elaborated on in the previous knowledge section of this report. The remaining questions will, as far possible within the scope and resources of this project, be answered through playtesting or interviews.

Of course the answers to these questions should be used to implement a prototype of a video game that fits the assignment. The designers will implement new features based on the theory that can be tested to see if they have the desired effect. The resulting game and its special features, along with their thought processes will be showcased within this article.

1.1.6 Controllers

Two parties working on the Handforce project are creating prototypes for custom controllers with a number of purposes. These goals will not be pursued by the current report, but understanding them will be useful when considering how to work with them.

The controllers should be useful tools to train the user's hand strength and the individuation of their fingers. Individuation being a person's ability to move individual fingers separately and consciously. The controllers would be able to engage the user's individual fingers by either measuring how much force each finger applies, or how far the user is able to bend that finger at a certain level of resistance.

The controllers' developers want to make them in such a way that they can provide inputs into a computer so that these inputs can be registered. This way, the therapists will be able to closely monitor the patient's progress. They would be able to see how much a specific finger has been used, how strongly said finger can apply force and how long that force has been applied.

These controllers are designed to control a video game. Hopefully, for the user, their experience is less like therapy than it is like just playing a game they like. That their hands are trained at the same time should feel incidental.

Image 1 shows one of the prototypes in action. It works by measuring the amount a finger has been flexed. The controller has small electronic motors that resist the movement of the hand and push back when the user releases the force applied. The amount the fingers have rotated can be interpreted by a computer.

Figure 1: One of the custom game controller prototypes being used to play the game.

One task of the current project is to create an interface between these controllers and the game, so the game can be controlled through them.

1.2 Approach

To realize the goals outlined in this chapter, a number of steps will be taken. Firstly the questions will, where possible, be answered through literature research. These questions will be discussed and answered, along with discussing the takeaways that can be applied when designing the game itself and how they could be applied.

Using the answers to these questions, a general outline of what the game will be like will be laid out, followed by the features that result from the lessons learnt from the prior knowledge chapter.

The design questions, their answers and the thought processes behind them will be laid bare in the design chapter. This will give insight in the reasons for and the inspirations behind several design decisions. When these elements are implemented, they will be showcased in the implementation chapter, along with the process of realizing these elements.

The next two chapters are dedicated to validating the design decisions and implementations. An expert will give their general feedback on the design of the game through an interview and a playtest will be set up to validate one aspect of the project. The results of this test will be elaborated in the report for the future developers of this project. The test chapter will ask new questions that should be answered in future development.

2. Prior knowledge

Since the current project is therapeutic, it's useful to have an understanding of the topic and ones that will be useful in the development of this project. It will be useful to have a baseline understanding of related topics. Topics discussed this chapter will include: the characteristics of the problems that need to be rehabilitated, the advantages of serious games and VR, the therapeutic principles used in previous therapies, the causes of motion sickness in VR and the causes and issues with video game addiction. Having proper knowledge about these topics will provide the needed context in order to conceptualize a video game for rehabilitation.

2.1 Strokes

To understand the problem that Handforce is trying to treat, the question to initially answer is: "What is a stroke and what inhibitions are we trying to rehabilitate?" Understanding strokes provides context for the topics of this project and understanding the inhibitions gives clearer goals and restrictions.

A stroke results from a problem of the blood flow to or in a person's brain. (*What Is a Stroke?*, 2023) There are two types of strokes. A stroke can occur because the blood flow to the brain is blocked. This is called an ischemic stroke. A stroke that occurs because of sudden bleeding in the brain is called a hemorrhagic stroke.

The lack of proper blood supply means that brain cells start quickly dying. This means that strokes often cause lasting brain damage and long-term disability. (What Is a Stroke?, 2023) A page from the National institute of Neurological Disorders and Stroke (NINDS, n.d.) lists some of the most prevalent effects of a stroke on survivors. Problems with muscle movements are common. This can result in having difficulty with some of the most basic daily activities. Reducing the impairment of hand movement is one of the primary goals of this report.

Something that is important to consider when designing a game for stroke survivors is the problems that many have with cognitive tasks. "Stroke may cause problems with thinking, awareness, attention, learning, judgment and memory"(NINDS, n.d.) It is imperative that anyone who designs a video game for stroke survivors keeps these limitations in mind when designing the gameplay and menus.

2.2 Hands

The game will be controlled by an input system that measures the strength of each individual finger of the player. It will be useful to have an idea of the more specific characteristics of the way that people's fingers function. There are a few questions that should be answered for this purpose. How strong are fingers generally in relation to each other? How much does this differ per person? These questions will help when figuring out how sensitive each input must be.

There are three metrics that could individually be trained in the progress of a patient's hand. These are: individuation, strength and coordination. Individuation is a person's ability to move their individual fingers separately, strength is how much force each of the person's fingers can apply and coordination is the precision and consistency with which a person can move their hands.

When programming the inputs a player can use in a game it will be useful to know how strong each finger is. An article from 2004 (MacDermid et al., 2004) found that there are quite consistent differences between different fingers. “The percentage contributions of the index, middle, ring and small fingers to grip were approximately 25%, 35%, 25% and 15%, respectively.” (MacDermid et al., 2004) It might be useful to set these numbers as a standard target in the game’s implementation and to make sure that the player doesn’t have to disproportionately apply force with their fingers. The study does mention that the grip strength of the middle- and index finger quite consistently provide approximately 60% of the grip strength, whereas the ring- and pinkie finger provide the remaining 40%. That distribution seems to be quite consistent between individuals.

Finger individuation is something that is often more difficult than we expect. Even for those of us that aren’t affected by a stroke. When first trying the live long and prosper greeting from Star Trek, most people have to take a second to think about what signals to send to their fingers. This problem is exacerbated when the individual has had a stroke since the communication between someone’s brain and their hand is often damaged. When designing and implementing the interactions of the users’ hands with the game, the general characteristics of people’s hands need to be kept in mind.

2.3 Serious games and Virtual Reality

Virtual Reality is one of the strongest media we have in this time. This strength manifests itself in specific aspects. It doesn’t seem advisable to just blindly replace everything with virtual reality since some applications might be better suited to other media. What are these specific strengths? What are these specific weaknesses? What is the best way to implement these techniques? Can Virtual Reality be used to increase the effectiveness of therapy? What are the most effective techniques of doing so? Understanding the answers to these questions is necessary to creating an optimal game for rehabilitation.

The current task is to design and develop software to help people recover the strength of their hands after suffering a stroke. People often lack control and strength of their hands. Normally, they recover from this through therapy and practise. There are some problems with this, however. It’s sometimes difficult to find the motivation for the patients to do those exercises every day. On top of that, according to the members of Handforce, therapists want a way to track the progress of the patients’ individual fingers. Serious games might be a useful tool to fulfil both of these wishes.

Serious games can be defined as games with education or rehabilitation as a primary goal. (Doumas et al., 2021) “These games combine entertainment, attentional engagement and problem solving to challenge function and performance.” Gaming is motorically quite similar to certain forms of neurorehabilitation, and it can be rather useful in this context. It is clear that serious gaming can be an asset for rehabilitating patients, but the reasons for this advantage are still somewhat vague. It seems there are some principles that, when followed, improve the amount the patient improves their abilities. The following paragraphs will look into different examples of serious games to understand how they work and what lessons can be learnt for the Handforce project.

VR has been shown to be able to reduce people’s experience of pain. VR as a medium engulfs your vision and your hearing. Both of your primary senses are covered by goggles or headphones. An efficient way of reducing pain is to distract the patient. VR is very effective at distracting people from the signals from their bodies. (Bailenson, 2018) A good example of this is the VR game Snow World, (Selby & Potter, 2015) which was made especially for this purpose. Patients will play a game while nurses are working on them. Which distracts them from the pain that results from that. David Patterson a professor at the University of Washington said the following:

> "We do have some patients, that will go into the virtual world and be totally oblivious that the nurses are working on them. They'll finish up and they'll come out of snow world and ask: "Have you started yet?""(Snow World, 2016)

Figure 2: Patient playing Snow World.

While this is interesting and understanding the effects of VR is useful. Pain negation is not a current goal. Knowing this fact helps understand the severity of the immersive qualities of the medium. It's also worth considering that it is sometimes useful to be aware of pain. It should be considered that a person might disregard pain they would otherwise be feeling.

VR has been shown to improve the patient's motor rehabilitation after stroke. (Domínguez-Téllez et al., 2020; Saposnik & Levin, 2011) But they do point out that the use of video games are likely not a universally applicable therapy for all patients. Most studies assessed patients with mild to moderate stroke symptoms. More severe patients might not have the same advantages from the use of VR gaming. Another limitation here might be the fact that these papers were done on older VR hardware like the WII or the PlayStation move which did not incorporate a VR headset.

VR gamification might help with making the therapeutic game. There are however a few things to keep in mind when creating an implementation making use of VR. (Domínguez-Téllez et al., 2020) The rules seem to apply quite similarly to general compelling video game design. The players should get clear feedback for meaningful play with a clear goal. The difficulty should be adapted to the players' abilities. Various types of feedback can be used to promote motor learning. Examples are visual, auditory and haptic feedback. All these elements should be considered when designing a VR video game.

There are also disadvantages to using VR in this manner. (Domínguez-Téllez et al., 2020) It is important to measure the amount of time and the intensity with which the patient is playing the game. Which can be more difficult in VR. Some patient's might not know how to- or have the physical ability to put on the headset and navigate to the proper programme. Finally, the effects of the training might not have the desired real life effect.

In summary, VR can be a very useful tool in many therapeutic and medical applications. Its ability to shut out the rest of the world makes it easier for patients to forget about pain. The immersive qualities of VR are strong tools for the human brain. Gamification can help with the motivation of the patient to regularly practise. But it is important for the developer to make sure that the game itself is the proper difficulty for the player and provides ample feedback of the patient's agency. It is important to make sure that the VR is easy to set up and use for the player. It's also paramount to understand the ways in which motion sickness affects a person when using VR.

2.4 Therapeutic principles

To understand the different ways therapy can be applied it is good to understand the ways previous therapies are implemented. This subchapter is dedicated to the different principles that are used when designing motor therapy, alongside consideration of how each principle can be used when making a serious VR game.

A paper from 2019(Maier et al., 2019) established fifteen different principles of motor learning. These principles have different advantages and disadvantages. Following is a list of the principles that can teach something useful to the making of a serious game with the goal of providing therapy for stroke survivors.

- Massed practice is the act of practising repeatedly with no or not many rest periods. In this case, the number of repetitions of the action don't seem to have much influence as opposed to the amount of time invested and the number of sessions.
- Spaced practice does make use of rest periods between repetitions. Increasing the time between repetitions seemingly has a positive influence on the amount the patient improved their functions. There is a limit to the effects of these increases, however. It might be advisable to look into different amounts of time between repetitions to find the optimal pacing of practices.
- Dosage is generally defined as the amount of time spent in therapy, the frequency of training sessions and duration of sessions. Usually, the higher the dosage, the higher the intensity of the training. The advantage of increasing dosage is somewhat controversial. However, neurologically there should be an improvement to motor function.
- Task specific practice assumes that differing conditions of a task might require a change in abilities needed to execute it. (Maier et al., 2019) It might be wise to give the user a group of differing tasks.
- Goal oriented practice can be useful because it allows the patient to adjust their complex bodies to the specific tasks.(Maier et al., 2019) When they don't just have to train a body part, but if they train to complete a task, they can often more easily become more well-adjusted to said task.
- Variable practice has two forms. By varying an existing training sequence. Or by randomizing the presentation of individual training sequences. Both methods are proven to lead to better retention and both methods seem quit possible to implement into a video game.
- Increasing difficulty is something that translates well to the general way that video games are designed, since most video games implement some kind of increased difficulty in their design. This could come in multiple forms such as amount of force the patient will have to use to

successfully play the game and in how difficult the game will be to play. *"The optimal challenge point lies where functional task difficulty leads to a balance between information processing demands and performance, which is optimal for learning…"* (Maier et al., 2019) This reflects the way that "flow theory" works in video games. Where there is an optimal balance of challenge for the player. This engages the player more thoroughly and likely results in stronger effects of therapy.

- Multisensory stimulation might also be a factor to improve the effectiveness of the therapy on the patient. One sensory input can influence how another sensory modality is perceived. This means that the use of haptic feedback might be useful to the player. This, however, does not apply to the current project, since this is software focused work. This information is utilised in different parts of the Handforce project where teams are designing new forms of haptic feedback.

All these principles give us a pretty good idea of different techniques that might be used. To be researched now is if enough of these principles are applicable in a VR serious game. Some of these are already mentioned but the principles that are suitable for VR are: Spaced practice, goal oriented practice, Variable practice, increasing difficulty and multisensory stimulation.

2.5 Inspirational therapy

There are several techniques used for rehabilitation of hand strength after a stroke. Taking a look at those techniques and understanding their effective components is likely an important part of creating our own game for such an intervention.

Mirror therapy is a method that aims to increase the visual feedback of the patient's actions. Mirror therapy is a form of therapy where the patient sees a mirror that is positioned in such a way that they see their functional hand in the position of their affected hand. When they move their It's been shown to have many different applications with different types of patients. Originally it was discovered that mirror therapy could help ease the effects of Phantom Limb disorder. (Ezendam et al., 2009)

Mirror therapy can also be used for stroke victims. It has a positive effect on the motoric limitations people who had a stroke often suffer from. (Ezendam et al., 2009) The exact mechanics through which these effects manifest themselves are not entirely clear. However, there is speculation on the way this might work.

> "A possible working mechanism of mirror therapy in stroke patients is based on the fact that in mirror therapy movement of the unimpaired upper limb is used to improve the motor control of the impaired limb. This bilateral movement suggest a bilateral transfer as an origin of the effects of mirror therapy." (Ezendam et al., 2009)

If this is the case, we could implement it into the game by making the player move both of their hands at once. We could also have the player's unaffected hand do the actions in the game while we show the player's affected hand performing those actions.

Another explanation might be that it is the combination between motor activity and visual activity that has the effect on the user. This is something that is quite baked in into many video games where visual feedback is often a valuable tool within game development. Proper visual and audio feedback is almost completely essential when learning to play a video game.

Bilateral arm training is an intervention in which the patient uses both limbs at the same time to perform identical movements at the same time. The most important part of the effect of this is interlimb coupling. "This is thought to rebalance the interhemispheric inhibition, activate the affected hemisphere and improve motor control within the affected limb." (Pollock et al., 2014)

A small study from 2014 looked into something quite similar to the goal of the current project. (Thielbar et al., 2014) They made what they called the Actuated Virtual Keypad. (AVK) This keypad registers inputs per finger to train the patients finger individuation. This should help with their coordination and motor skills. The most significant difference with the current project is that applied force of each finger will be measured in the current project, rather than just the position.

In summary, mirror therapy is found to be rather effective and it is likely that the process that gives mirror therapy its power could translates well through the immersive properties of Virtual Reality. Bilateral arm training should also be translatable to a serious game. Although bilateral arm training would be implemented outside of the mechanics of the game itself. While the mirror therapy needs to be considered when making the game itself.

2.6 Motion sickness in VR

Motion sickness is a problem that is common for people when they spend time in a Virtual Reality environment. Motion sickness is something that should be avoided since it is unpleasant and will demotivate patients from continuing the game. There are several factors that might have influence on the players' experiences with this issue. These factors will be discussed in the rest of this subchapter while trying to understand what causes motion sickness and what can be done to avoid it.

Perhaps surprisingly one of these factors is gender. (Chattha et al., 2020) Women tend to be more susceptible to motion sickness than men are. Since this project is not gender specific, it will be important to test the game with both men and women to make sure that there are no surprises when people play the game.

Then there is Visually Induced Motion Sickness. (VIMS) Stress factor has influence on VIMS. (Chattha et al., 2020) The same goes for heart rate and blood pressure. Since dark areas give players more stress it might be wise to make sure visibility is rarely a problem for the player. Visual fidelity does not seem to have a strong impact on VIMS for players.

Unsurprisingly, moving the player in virtual space does have influence on the experienced motion sickness. (Chang et al., 2020) players seem to experience more motion sickness if they move faster through the world. This goes up until about 10 m/s. After which, the user's experience of place started to decrease and so the cognitive dissonance between their different senses was less pronounced as well.

A factor that has significant influence on a player's discomfort is rotation (Chang et al., 2020). This issue gets worse when more rotational axes are involved. When rotating the player unnaturally inside the VR world, motion sickness is a likely consequence. It should be possible for the game to be played without any rotation that doesn't happen in real life. Games that do want to give the player the ability to rotate without rotating in the real world make use of something called snap turning. Where the player does not move continually from one rotation to another, but they instantaneously snap from one angle to another.(Valve, 2020) This approach significantly reduces motion sickness. Rotating the player should generally be avoided, but if it is necessary, snap turning should be an option for the player.

All in all the significance of motion sickness seems to be strongly impacted by a disharmony between what the player sees and what their inner ear senses. These differences are greatest when the player accelerates or decelerates or when they rotate. That effect is still there when they are moving when they shouldn't. But instantly accelerating and snap turning when rotating the player seem to be useful elements, since rotation and acceleration would be the only thing that one would feel in real life.

Other games have of course created their own solutions to these questions. Half Life Alyx (Valve, 2020) made use of snap-turning. A method where instead of continuously rotating a player, they instantly rotate for example 45 degrees to the left or right.

Elite Dangerous is a game that wasn't originally built with VR in mind. This might not be surprising when you see the impressive amounts of rotation and acceleration that the player can perform in that game. Many games implement snap turning because people's visual processing has a strong sense of movement, but especially of acceleration and rotation. Continuous rotation is known as one of the most significant causes of motion sickness in VR games. Despite that, this problem does not seem as severe when it comes to Elite Dangerous.

Based on previous knowledge about motion sickness, it could be hypothesised that this difference lies mostly in the fact that Elite Dangerous gives the player a static reference frame. In that game, you sit inside of a small cabin that is, for the player, static. Only the world outside that cabin moves. This would give the player a lessened experience of simulated movement. If motion sickness would turn out to be a significant problem for players, the developers of the game could consider adding a static reference frame for the player, so they theoretically do not have as many issues with motion sickness as they otherwise would.

When making a VR game, there are several factors to consider when it comes to motion sickness. Firstly, people have different levels of tolerance when it comes to motion sickness. So it's important to validate that every person in the target audience can play the game, regardless of age or gender. Secondly, it's important to steer away from things that the player's inner ear could sense. Most notably being acceleration and rotation. If the player moves in the game without moving in real life, it should be continuous without accelerating or decelerating. If the player rotates without rotating in the real world. It should snap from one angle to another. Motion sickness is something that should be validated and thought about throughout the project.

2.7 Video game addiction

A common problem for people who play video games is addiction. The purpose of this project is to create a game that is engaging and motivates the player to keep playing. It is however important to consider video game addiction in this project. Creating an urge for the player to keep playing the game can have many negative side effects and should always be kept in tow. It does occur that playing a video game gets in the way of taking care of one's self or their home.

Secondly making sure the player doesn't play too much has a therapeutic purpose. It would be bad if the patient were to keep playing the game too long and were to over-exert their hand. Especially since, as shown by Snow World (Selby & Potter, 2015) VR games can make a person unaware of the pain they are experiencing.

According to a paper from 2020 (Domínguez-Téllez et al., 2020) there are several groups that are more likely to become addicted to video games. Gender seemed to play a significant role, with men being more likely to become addicted than women. Additionally, single people, younger people and people with psychosomatic disorders were too more likely to form an addiction

The only takeaway from this that might be applied on the current project is the fact that older people are less likely to become addicted to video games than younger people. This would possibly mean a slight reduction of danger when it comes to the current audience, since strokes become more likely as a person becomes older. However, there doesn't seem to be any research about a relationship between being a victim of stroke and becoming addicted to video games. Further research would need to be done in order to confirm or deny any relation between the two.

An article from 2017 (Klemm & Pieters, 2017) mentions a number of factors that can lead a MMORPG like world of warcraft to being addictive. It mentions its endless nature as one of the causes. While many games or movies can be finished. This is not the case for some video games. Where there's always something new to do. Another mentioned factor is a sense of progression. Progression can either be expressed through the player gaining skill or it can be through the game mechanics themselves. Through rewarding the player for playing the game. A gameplay-loop that revolves around playing and progressing through playing can become quite addictive.

The current project will likely be endless and use progression in order to motivate the player to keep playing. It will however, not have the breadth of content present in bigger games due to a lack of development time. An effective strategy of increasing engagement could be through a reward system. That does mean that the effects of this reward system need to be considered and tested.

While it does not seem that significant video game addiction is likely to be caused by a small scale game such as this, it is important to make sure that players will not be playing the game for too long at a time. While addiction is unlikely, there might be individuals that still find themselves playing too much. There needs to be a system in place to make sure they don't overexert themselves. This can't just be done by therapists since patients will be expected to play the game on themselves. Players need intermissions to examine how they feel. They need a limit to how much they can play during a day. The effects and causes of addiction should be considered when designing, making and testing the game.

3. Concept

3.1 Requirements and limitations

There are quite some technical limitations and requirements for this project. These will need to be laid out before the concept of the eventual game can be established. The game needs to be easy to understand and simple to play. The player will use a controller with 5 analogue inputs one for each finger. The player should be required to use all inputs. These inputs need to all be used about equally. If not the game needs to adjust itself to make sure the player uses all their fingers enough.

Even though VR has a lot of advantages, there are no controllers that do everything that would be required for this game on top of being complete virtual reality controllers. VR controllers generally take the hands of the players' positions and rotations into account, but they don't usually track the positions of the players individual fingers. For this project, not only the positions, but the applied force of each finger needs to be tracked. Such a controller is not available to us during the entirety of development. Designing such a controller would take a lot of time, money and expertise that is not available within the Handforce project. Therefore, the game needs to be designed for the controllers that will be available. The previously mentioned controllers with 4 or 5 analogue inputs but no positional tracking of the controller itself will be used.

So, while the game could be in VR it is not possible to make use of all of VR's advantages. It won't be possible to create a world that the player can seamlessly and intuitively interact with. That doesn't mean however, that we can't take advantage of the other parts of VR. As discussed earlier, VR can have significant influence on the therapeutic effect of serious games. We could use VR to reduce the amount of stimuli by removing the player's real environment as stimulus. We could exaggerate the movements of the players' fingers and create a mirror therapy like effect. On top of this, making a game that doesn't require a VR specific input for the player would allow us to make a game that could be played both on traditional flat screens and in VR. Allowing for the advantages that come with VR and making it possible for the game to be more accessible by removing the requirement of a VR headset and the possible disadvantages that come with that, like motion sickness or difficulty with putting a headset on.

The VR implementation of the game will be built and tested to be playable on the Oculus Quest headsets. Ideally, the game should be playable without being attached to an external computer using the internal processing of those devices. However, it is unclear if it will be possible to use a custom made controller to control a game with an Oculus Quest headset.

3.2 Three lane runner

Given these requirements and limitations we decided to make a three lane runner game. A three lane runner game is a game where the player character has to evade oncoming obstacles they do so by moving on one of the three lanes that has no obstacles or by dodging said obstacles in any other way.

In this game, the player would ride their bike through the relatively low stimulation environment of the Dutch meadows. There are several reasons we decided to make a three lane runner. Firstly, it's easy to understand for the player. Moving forward and not bumping into upcoming objects is a quite simple concept but it has a lot of room to become more difficult in time. Secondly, it's possible in a three lane runner to control what kinds of actions the player has to do through code, which allows us to influence which finger gets trained more. This also gives us the ability to dynamically adjust the difficulty by changing the speed at which the player moves or the distance between and complexity of obstacles. Lastly, it would be quite easy to reduce or increase the amount of required inputs to play the game properly. It's possible to enable or disable obstacles that relate to specific actions in the level which means that if you only want to train two fingers for example, you just let the level generate a level for going left and right. Or only jumping and ducking. This is useful for increasing the complexity of the game over time while also focusing on training the most important fingers first.

Something that is important to consider when making a VR game is motion sickness. There are numerous ways of making sure that that doesn't have too an big impact. Firstly, we'll place the player camera outside of the bicyclist themselves. Which means that we can move the VR camera at a constant rate without moving said camera from left to right or rotating it. We won't accelerate or decelerate the VR camera but only either move it or keep it still. We won't rotate the VR camera either. All these elements should make sure that there is no dissonance between the player's visual stimuli and the players sense of balance. We will test with people of different ages and genders to make sure that this doesn't result in motion sickness. If it still does, we will create an environment like a car cabin that is static around the player. Giving them another static reference point, similar to the way Elite Dangerous VR (Elite Dangerous, 2015) has a cabin of a spaceship around the player.

3.3 Elements of the game

The following paragraphs will summarize the elements of the project.

The player will, while playing have a maximum of 5 different abilities, one for each finger. These being: go left, go right, jump, duck and brace yourself. Most of these are fairly obvious, but the bracing is somewhat less intuitive. This means that the player character will brace themselves when going through the tall grass obstacle, which will be growing out of the road. It can't be certain however, that the player will be able to use each finger so it must be made sure that it is possible to disable or enable different input requirements when necessary, or rebind them to different inputs.

While initially designing the game's mechanics, there were two pitches for the way that the game will interpret the player's analogue inputs. The advantages and disadvantages of either method should be thought through and the decided method should be implemented into the game.

The game needs a tutorial that is easy to understand and forgiving for the player. The tutorial should present the player with an input, give them some room to experiment with this input and when they press it, the related obstacle should present itself a fair distance away from them. This gives the player time to experiment with the input and learn how to use it. The explanation of the mechanics should be simple and short. To hopefully account for the cognitive impairments, the explanation of the mechanics will be provided through both readable text and will be told to the player through audio as well.

The tutorial should be modular, since the inputs and bindings are not rigidly bound together. This means both the readable text and the audio explanation will need to automatically adjust itself to provide proper explanations of the mechanics.

There should be an easily useable user interface (UI) for the user. They need to be able to play the game both in and outside of Virtual Reality. So there needs to either exist two user interfaces, one designed for a flat screen and one for a virtual reality environment, or the UI should be useable in both Virtual Reality and on a flat screen. In VR, it should be considered that there won't necessarily be a virtual reality controller available to the player. So the player needs to be able to intuitively use the menu through either the specialized controller they will use to play the game, or through the hand tracking provided by the Oculus Quest headsets.

Since the game will have to be very modular, it has been decided that the levels the players will have to play will be procedurally generated. This can account for the different inputs that can either be enabled or disabled. But it can also keep the specific user in mind by making sure that the game isn't too difficult and they use each finger about equally. This can be done by decreasing the duration between obstacles or increasing the complexity of said obstacles. There should be a level generation system that keeps the player's previous actions in mind and balances the upcoming obstacles to make sure one finger is not used too much or too little.

There will be a virtual hand, inspired by the previously mentioned mirror therapy. This hand will be in sight of the player during gameplay and it will emphasize the movements of the player's real hand. It will also have the ability to highlight specific fingers based on which one they will need to press in order to progress in the level.

The two teams that are working on a hand controller are both creating different pieces of hardware that will need to interface with the game. This interface needs to be made modularly, so multiple types of custom controllers can interact with the game. Since the current projects both use Arduino code, for which it is possible to write custom code, there can be a standardized form of communication between the game and both controllers. The game can then remember how hard players would need to apply pressure in order to play the game.

The program should also collect and save the data of the progression of the therapy. The program should register each player action, what finger was used and how much force was applied so this can be used by therapists afterwards.

The rest of this report is dedicated to the design, implementation and iteration on these elements.

4. Design and implementation

In the previous chapter, the general design of the game has been laid out. This chapter will focus on every specific part of this design.

Games like this one are generally categorized as ‘three lane runners’ the player usually automatically runs away from the camera whilst having to dodge a variety of obstacles. The player character is at all times on one of the three different lanes. They can change what lane they’re running on by moving left or right. Sometimes they have to jump over or duck below other obstacles. Often these games are endless, that is, they last until the player crashes against an obstacle. This can however result in longer play sessions than intended. The length of the play session should be controllable in order to make sure the patient does not practice for too long at a time.

One of the first things that will be designed and developed for this game will be the player actions. These are the most basic actions the player has access through. The user interface will also be discussed, which should be easily useable for the target audience in both VR and outside of VR. There will be a virtual hand in the game with two purposes, it will provide visual feedback to the player’s actions and it will give hints to the player as to which finger they will need to use. Finally the decisions that were made on the environment and visual style will be justified.

Figure 3: Screenshot of the game made for this project.

4.1 Player actions

The player will have a maximum of 5 different actions available at a time, one for each finger. The first four actions are easy to come up with. Games in this genre generally have 4 different actions for the player: Go left, go right, jump and crouch. There will need to be an additional action to give use to the last finger. This action will be called ‘brace’. If the player braces, they will get ready for an upcoming obstacle. If they don’t and come in contact with said obstacle, they will crash. It is important to make sure that these basic actions feel nice for the player to perform. The rest of this subchapter will be dedicated to planning what could be done to make sure that they feel right. In this game, we want to emphasize two main effects: The feeling of control and readability. To make sure the game is clearly readable, the player character will never teleport from one place to another or move so quickly that keeping track of their movements will be difficult. On the other hand, their movements should respond quickly to the players' actions.

4.1.1 Optimal input method

There are two proposed ways of designing the system of moving left and right and jumping. This subchapter will describe both proposals, identify their advantages and disadvantages and decide which of the two will be used in the final product.

The game will in either case be controlled by pressing with one's fingers on a controller. The player will be expected to progressively press harder as their fingers become stronger. The question then becomes what is done with the inputs that result from this and how do they scale when the strength of the player increases.

The most intuitive method might be to activate any given action in the game whenever the corresponding finger's applied force reaches a certain threshold. This way the player character only starts moving when said threshold is reached. Due to the fact that there are only two possible results to the player's input this will be called the binary method.

The other method would then be called the analogue method. In this implementation, the player's actions would always have effect on the game, but the environment itself would change based on how great the player's challenge should be. The size of obstacles would increase. Therefore, the amount the player has to move left, right, down or up would increase as well as the game became more challenging. Both the binary and the analogue method have merit. To decide which one will be implemented the advantages and disadvantages of either method will be discussed.

The binary method has the advantage of clarity in how much force is enough and how much isn't. There will be no confusion over whether they pressed hard enough to initiate the jump high enough since it either did or it did not activate. For the analogue method, it might be pretty easy to implement the left, right and crouch inputs into the game. But it's a little more difficult to imagine what it would be like to jump higher based on how hard you press. Normally, when someone jumps and leaves the ground, they don't influence the height of that jump at that point anymore. Which would mean that there is no elegant way to implement the variable jump heights based on how much pressure the player can put on the sensor. This would either result in very unnatural movements where the character does not remotely adhere to the laws of physics. Or it would result in a very delayed input as the character would only jump when the jump input is released, since it can only start moving when the game knows how high the player would have to jump.

Additionally, we don't know exactly what kind of controller will be used by the players. We don't even completely control this since prototypes of multiple controllers are still being made by different teams. This means we should make sure that the game's inputs are easily adjustable to different kinds of controllers. The simplicity of the binary method is likely the most appropriate version.

This doesn't mean that there is nothing to say for the analogue method. Directly implementing the amount of strength the player applies into the mechanics of the game would give that player a much stronger sense of progression. The game itself doesn't change in the binary method, only how hard they have to press to play it. It would be nice for the player to compare the height they are able to jump compared to when they started playing.

Although there is appeal to the analogue method, we have decided to go with the binary method anyway. The binary method is easier to understand for the player, easier for development, more modular and generates fewer difficult design questions.

4.1.2 Jump

Something that is thought about a lot in games is the *game feel*. Game feel is a subjective quality of a game related to how good it feels to play a game. (Game Maker's Toolkit, n.d.) This might be influenced by response time, visual or audio feedback, or acceleration and deceleration of movement. One factor in many games is the *Jump arc* of the player. The jump arc is the way that a jump functions. How quickly you move up, how long it takes to slow down, how long you stay at the apex of your jump, and how quickly you move down to the ground again. Generally, in games where *game feel* is important, gravity is carefully tuned to optimize the subjective quality of the game feel.

Something that should be considered is the way in which these qualities are controlled. It might be done by manipulating physics under certain conditions or by exactly controlling what arc the jump of the player is going to follow. The optimal ways of achieving these effects are likely best found by experimentation. This will be done in the implementation chapter.

When designing a jump in a game, many different aspects need to be considered. Firstly, it is important to consider how much time should be between the moment that the player presses the jump button and that the player character launches into the air. In games that adhere more to realistic physicality, it is useful if the player does not suddenly fly into the air but, for example, crouches down first and then jumps up more naturally. This kind of action before the desired action is called 'anticipation'. Using anticipation does however, increase the time between the player's input and the desired action happening. Games that adhere less to realism usually accelerate the player character upwards in an instant. This is likely the approach that applies best to this project due to the added responsiveness. It is possible to consider a hybrid approach between the two for this project, where the anticipation starts whenever the player starts pressing down on the custom controller and the jump only happens when the player pushes down enough to actually start moving up. This would improve the physical continuity of the player characters' actions while not technically delaying any of the player's characters actions. Although the initial opposite movement might make it more difficult for the player to internalize what button will do what. It would be interesting to, if time allows, create a version of the character that, in anticipation for jumping, starts crouching first when the player starts pressing the controller.

Another important aspect to consider when designing a jump in a game is how the character moves when they are in the air. How quickly does the character move up? How quickly do they come down again? How much control does the player have over how long the character stays in the air? How much control does the player have over the character moving from side so side in the air? Unity usually manages many of its physics with the RigidBody component. The RigidBody has a gravity system built in. The strength of this gravity is set to $9.81 m/s^2$ by default. This number can of course be increased, but many games where the jump is a primary mechanic, there are different techniques used to make it feel better. In Super Meat Boy (Team Meat, 2010) for example, you stay in the air longer if you hold down the jump button, but if you release the button you quickly start falling down. This gives the player control to land more precisely if they want to. The developer can play around with the values of gravity in different moments of the jump. They can lower gravity if the player hits the jump button longer, they can make the gravity higher when the player character is moving down so the player will not be ungrounded for too long. This allows them to jump again if they so wish.

The jump implemented into the game gives the player the ability to jump higher and stay in the air longer if they hit the jump button for a longer amount of time. When the player lets go of the jump button, the player character accelerates more quickly to the ground than away from it to ground the player character earlier.

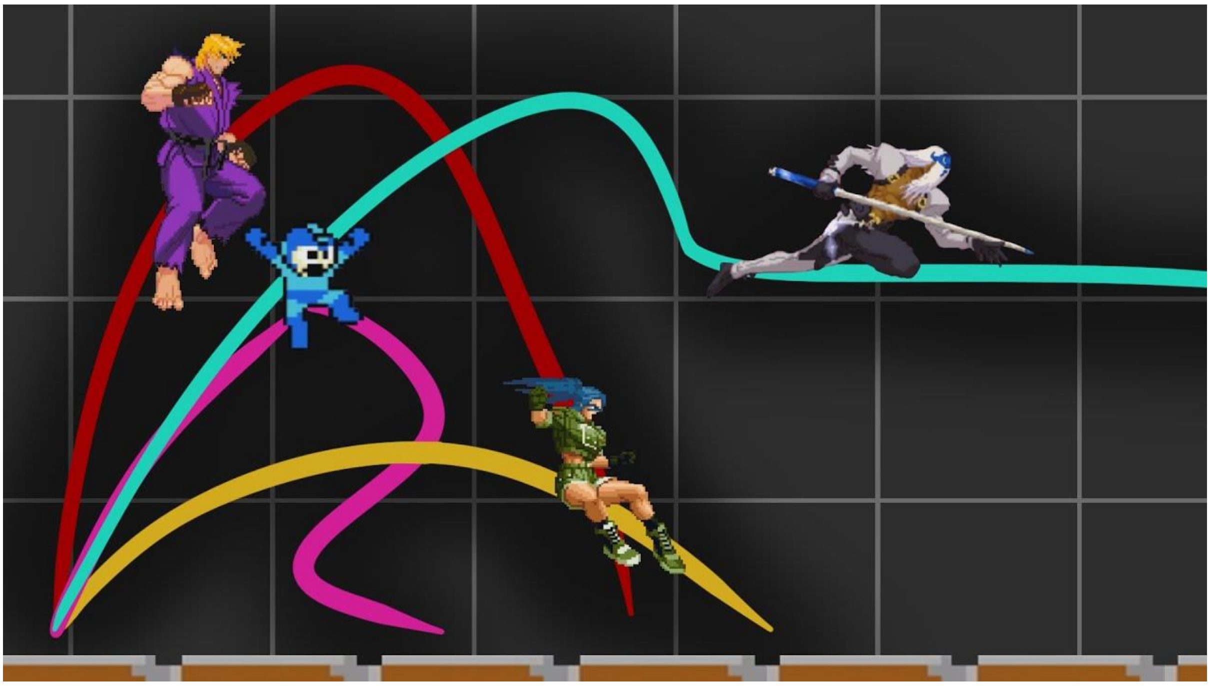

Figure 4: Image to clarify the concept of a jump arc.

While in more realistic games the player occasionally not able to control their character's horizontal movement at all when they are airborne, it is important in this project to give the player as much control over their character as possible at all times. Therefore, it has been decided that the player will be able to fully control their horizontal movements when they are airborne.

4.1.3 Moving left and right

The goal for each input was to make sure that there is some kind of physical continuity maintained in all movements. The question then becomes: "How can the player's side to side movement be optimized to maintain physical continuity and responsiveness." There are several ways elements can move from position to position on a screen. In animation, the technique used for people is generally 'ease in, ease out'. This is where a movement first accelerates and at the end decelerates as opposed to starting to move and stopping moving in an instant. The player character should definitely never teleport from one place to another and ideally, the player character should not instantly accelerate or decelerate when moving side to side. Implementing this is more complicated than it might initially seem. Usually, when creating an easing animation, the animator knows exactly where the movement will begin and end. But this will not necessarily be the case for this game. The player could for example decide to change direction halfway through moving, or they could move two lanes at a time. In this case, just playing a preset animation could result in delayed or unnatural movements if the player does something else while the previous transition is still playing.

To make sure both the responsiveness and readability of the player's movements are maintained a system has been created. The player uses their inputs to change which lane the cyclist should be riding on. The cyclist then accelerates towards the target lane, when they get close enough, the cyclist will slow down to more naturally stop. When the player changes direction, the cyclist will stop moving immediately and move towards the intended lane instead, this is done so not too much time is spent to stop moving, which would result in slow and unresponsive movements. This all results in gameplay where the player is able to easily move from lane to lane without the cyclist moving in a way that seems very unnatural. This is also aided by the several ways that the cyclist bodily motions are animated.

4.1.4 Cyclist animation

The animations were made by one of the 3d artists at MaMa Producties. The animations of the cyclist were split up between the upper half of the man and the lower half. This way, the lower half could keep cycling whilst the upper half is doing something else. Crouching for example. This is the way that the crouching has been made readable and understandable for the players.

Figure 5: Player character riding normally.

Figure 6: Player character crouching down.

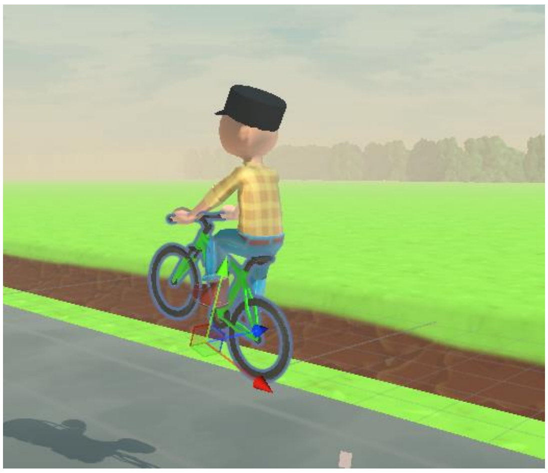

Figure 7: Player character jumping up.

Figure 8: Player character moving from left to right.

In figure 7 and 8, you can see the way the cyclist rotates towards the direction they are moving. To emphasize the cyclist's movements from left to right, the cyclist is rotated in such a way that they always point towards the direction they are moving. This simple solution works surprisingly well alongside the way the cyclist moves. While, if more closely examined, these movements don't look perfect, these added flourishes to the animation go a long way to making the player's actions feel and look good.

To make sure that the bracing effect is visually distinct enough from the crouching animation, this was made with an entirely different visual tool. When the player braces, small dust particles appear around the cyclist.

This is how all player actions have been implemented. Now the question becomes how to properly communicate to the player how to play the game.

4.2 User interface

The user interface of this project has a number of requirements. The UI needs to be easy to use for people who are inexperienced with virtual reality or video games in general. It will also need to be easy to understand for people with cognitive impairments. The UI needs to be useable in both Virtual Reality and on a traditional flat screen.

User interfaces have always been a very important part of the user experience. On flat screens there are a surprising amount of examples where the UI has been perfected. Especially through touch screens, which are so intuitive and easy to use that small children can, without anybody explaining them how, easily learn how to navigate a phone or a tablet.

This intuitiveness is less common in virtual reality. There is also little standardisation in the way UI has been implemented in previous VR games.

The goal is to create a UI that is easy to use by stroke victims without the use of a VR controller. The aspects we might be able to use would be the Quest's hand tracking, the user's voice and the position and the rotation of the user's head. These inputs lack the precision and reliability of buttons, but they might be as intuitive as, or even more intuitive than our cell phones' touch screens. This is due to the fact that new users won't be required to learn to understand a touch screen.

In VR there are two general techniques that are often used when navigating a UI. The most common is to shoot a laser beam out of the player's hand that can interact with any button it hits when the player presses a button on their controller. The other option is to have virtual buttons the player can interact with by moving their hand to touch said button. Each implementation has advantages and disadvantages. Needing to touch buttons is more intuitive as it more closely emulates the ways people interact with things in the real world. However, it does require the player to stand close enough to said buttons in the virtual world. If they can't reach the button, the button can't be interacted with. This issue is mitigated in the implementation with the laser beam that shoots from the player's hand.

To get an idea of the different options, the following three subchapters will analyse the UI of one game. The techniques they used, the advantages and disadvantages of their implementations and possible lessons that could be learned from them. This will give insight into the ways that VR can be implemented.

4.2.1 Jet Island

Jet Island VR (Tereshinski, 2018) is a relatively old VR game from 2018. It sets the player in a vast, dreamlike world where they are tasked to take down colossal beasts. It was made by a single developer. While that might show slightly in the minimalist, almost retro art style and the short duration of the game, the amount of work put into making the UI work well in such an action-packed game is very impressive. The game provides the player with a button on both their hands inside the game world that they can press with the other hand. When pressed, a menu of buttons comes up and follows the hand in question.

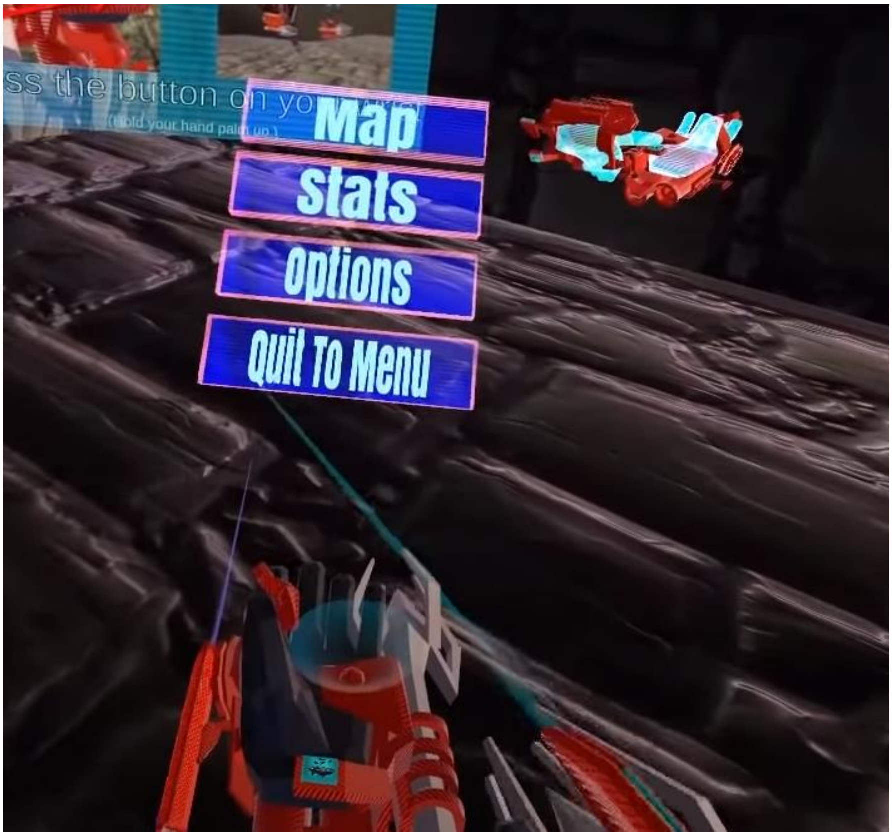

Figure 9: Example of Jet Island's in-game user interface.

The buttons in that menu can in turn be pressed with the other hand. The buttons are slightly transparent, have a 3-dimensional shape and respond to the player's input by being visually pressed.

This method has several advantages. The fact that the buttons follow the position of the player's hands allows the UI to be in reach of the player, since the player can move the UI towards them instead of the player having to move towards the UI themselves. It's in a form that people are generally quite familiar with, a vertical row of different choices with the most used one on the top. The 3-dimensional shape of the buttons and their physical responses help it feel more like actual buttons rather than options in a menu. Additionally, this method fits the game's aesthetic itself quite well. The buttons are stylised as science fiction style holograms. While not an absolute requirement, it would be nice to find an implementation of UI that fit the theme of the game well.

4.2.2 Elite Dangerous

Elite Dangerous (Elite Dangerous, 2015) has already been discussed in the development of this game, because the player is similarly put in a position where they move through an environment while sitting down.

Elite Dangerous' user experience is somewhat confusing. It's a game that is difficult to learn. There are many complicated mechanics that go accompanied by a complex user interface. Since it is also a game that can be played on a regular screen, there is not much VR implementation into the UI. You can pretty much only use a traditional game controller, a custom joystick or a keyboard to play the game. However, in any one of those, VR is not completely integrated. The player can't just reach out and grab the steering wheel, or interact with any of the screens inside the cockpit. What VR does help with however is choosing which of the menus you will be using with the controller. The interior of the cockpit consists of a couple of different screens with different menus on them. The UI on those panels is only completely visible when the player is faced toward them.

When the menu is activated, the player can control that specific menu with their controller. It's a clever way of making a complicated game a little easier to navigate with the use of VR. This technique is however, best applied to complex games with a requirement for many menus, which would not fit with the target audience of the Handforce project.

Figure 10: Collage of different user interface elements in Elite Dangerous.

Figure 11: Elite Dangerous' user interface.

4.2.3 Cosmic trip

Cosmic trip's UI (Cosmic Trip, 2017) is impressive. The polish is immediately apparent. There are audio and visual effects that provide good feedback to the user, but it also uses some other techniques that might be interesting to consider. The game modes can be chosen from cylinders that have a distinct stylistic flair, they make use of text and icons, which is easiest for people to understand and the buttons for going to different categories are physical buttons that immediately do whatever you want them to when you come into contact with them.

This might be a good stepping off point when making our own implementation of a UI in VR. The physical 3-dimensional quality of the UI is nice and works well in VR as opposed to a translucent plane that does not fit into the world as well. It's also difficult to not make it feel like your finger is passing through a plane whenever you press a button in VR. 3-dimensional buttons could move independently of the other buttons. This would result in more expressive and immersive feedback for the player.

The buttons in Jet Island would be pressed down, whenever they reached their lowest point in that animation the button would be activated, and the related code would be run. The buttons in Cosmic Trip however, immediately snap down and are activated whenever your hand contacts the button. This might be more prone to mistakes, so it is probably useful to use this for navigation in a menu, instead of doing things that can't be reversed.

A con to this implementation is that, while the text and icons in the cylinders are easily readable, the icons by the navigation buttons are awkwardly floating above the buttons and they blend more into the background. They also lack text, while just using icons can be confusing for the user.

Figure 12: Cosmic Trip's startup menu.

4.2.4 Discussion

Cosmic Trip seems to be a decent starting point to designing UI that is easy to use and most of all, polished. The depth of the buttons is desirable, and their responsiveness is nice to use. Using a UI navigation based on these buttons seems like a good plan. However, we'll try to include more cohesion between the buttons, text and icons that belong together. Since the icons and buttons seem like separate elements in Cosmic Trip.

An idea that might be borrowed from Elite Dangerous VR is the use of the direction the player's head is pointed at to highlight the important element or even pause the game when the player looks at the UI. Jet Island uses a menu that floats along with the player's hand. This makes it more manageable to position a button in a place where it's easier to press and it might help people practise making their hands work together.

Using this inspiration, a menu will be made with buttons that can be animated to be pressed, the menus will also be able to transition from one state to another. While it is a nice idea that a UI would follow the player's hand, this will be difficult due to the lack of player controller that could be tracked. Therefore the UI will be static and strategically placed so the player will be able to easily reach the buttons.

4.2.5 Implementation

Figure 13: Implemented startup menu.

Figure 14: Implemented startup menu with one pressed down button.

The above image pictures the user interface system present in the game. It is a custom implementation useable on a flat screen by clicking with a mouse or tapping on a touch screen. But it's also useable by using your virtual fingers in virtual reality and touching the button with the tip of either index finger. While the first attempt had a small poof of particles to give extra visual feedback to the user, feedback from members of MaMa Producties lead to removing said poof to reduce the amount of visual stimuli for the patients. This meant that the most significant feedback of pressing the buttons became the flattening and discolouring of the buttons and the sound that plays whenever a button is pressed.

4.3 Level generation

The general gameplay should be quite modular. The players will not all be the same and while playing, their skill and cognitive abilities will likely improve. Additionally, the level should be adjusted to make sure that every finger gets about equal training. This means that each level will have to be procedurally generated.

The procedural generation needs to take into account what fingers the player has used in the past and use that information to make sure each finger gets used enough. The difficulty of the levels needs to easily be adjustable, just like the length. The game needs to be able to tell the player what finger they are going to need for the upcoming obstacle.

To make an algorithm like this one, it is best to split the problem up into smaller parts. The level generation could place different pre-made obstacles at regular intervals into the level. Each obstacle has certain information related to it: what actions are required to pass it and how complex the obstacle is. The required actions can then be used in the algorithm to make sure that every finger is used a proper amount of times. The complexity of the obstacles can then be used to dynamically increase the complexity of the gameplay by making simple obstacles more and more rare.

Simply implementing a system that works like this will result in some undesirable effects, namely the fact that this will often create repetitions of the same required actions in a row.

Figure 15: Previously, the game would generate the same obstacle multiple times in a row.

To alleviate this problem, a system has been put in place that remembers what the previously placed obstacle was. Each lane of each obstacle remembers what action the player will need to perform to pass said obstacle. This is then used to make sure that two of the same obstacles are not used twice in a row. It will also be possible to use this to signal to the player what finger they will need to use to pass the obstacle. This will be further discussed in chapter 4.4.3.

Figure 16: Now, the game will generate more varied obstacles.

This all results in gameplay where the player themselves hardly notice that the game tracks their actions, while they are prompted to use all of their fingers the proper amount.

4.4 Virtual hand

The game should have a virtual hand with two major purposes. As discussed in chapter 2.5, it would be useful to have a virtual hand in the game that shows the player the exaggerated movements of their hand in the game. This would presumably have a therapeutic effect similar to mirror therapy.

This hand might however have a secondary purpose as well. To avoid people forgetting which finger is related to what action, the hand could highlight which finger will be necessary for the upcoming obstacle while showing which action relates to said finger. This could make playing the game easier and it might reinforce the connection between an action and the player's finger in their mind.

4.4.1 Hand tracking

We want to have as few external tools as possible that the player is dependent on. Two components that are mandatory for our gameplay in VR are the VR headset and the custom made controller for the game. Ideally, everything outside of that could be omitted. Including the standard XR controllers. It would presumably be nicer to use Unity's built-in hand tracking to control UI interactions. That way the player can just connect the controller to the headset, put the headset on and play the game. The Oculus Quest controllers have a hand tracking function. Implementing this turned out a little confusing since the feature wasn't that well implemented in the original Oculus Quest. But it was possible to do eventually with Unity's XR toolkit. (Valem Tutorials, n.d.)

4.4.2 Hand visibility

To combat player confusion, a system should be created that can predict which finger the player will have to use next. This way, the player can see what needs to be done and do it themselves. One desire that comes from the developer with this is that the player can see at a glance which finger will have to be used. After all, the idea is to help the user, distracting the player would not help with this goal. We want to have an effect similar to the way that mirror therapy helps with rehabilitation. By giving the player the idea that they are moving their hand, and that their hand is actually what is being changed and what they are moving. It might be possible to use the hand tracking of the quest to track where the hand is, but then replace it with our custom animated hand in the same position when the player is playing the game. This way, the position of the player's hand in game is the same as in the real world.

Maybe we could have this in addition to a hand that is always in a visible position so we are sure that the hand is visible in any situation.

4.4.3 Hand implementation

Now that several goals of the hand have been laid out, it's implementation will be showcased. The player would be see a hand that would emphasize the movements of their hands and tell them what input would be required for the upcoming obstacle.

However, the challenge for the developer is that to do this, you actually have to create an algorithm that knows what buttons need to be pressed. Not only that, the AI must be able to take into account the player's unpredictability. Already, the game should at least be designed in such a way that the player is forced to do certain things because they should be required to train certain fingers. That means the required actions must be predictable to some extent. There are currently three *lanes* the player can be on. That means that the player's only choice to take into account is which *lane* they are on at the time. It would probably be quite doable to think out which lane the players will have to do what on. Since some buttons are required to get through the game.

To further understand how this prediction will be done, the level generation needs to be understood to some extent. Level generation consists of a few parts. There are "Elements" each Element has its own action that the player has to do to get past it. For example, an obstacle that must be jumped over. The program can see which of these elements the player is currently facing. There is a component in the player that detects what kind of element is in front of them. When the player got close enough to the upcoming obstacle, the corresponding finger will be highlighted so the player knows what they will need to do to succeed.

Figure 17: Example of the in-game hand prompting the player to jump.

4.5 Environment

The game needs an art style and a theme for the environment. The environment of the game has a few purposes and requirements. Of course the target audience should be kept in mind. It should be assumed that the player is not very interested in fantastical worlds and they can also be easily overwhelmed by a lot of stimuli. They are likely to be somewhat unfamiliar with VR and video games in general. Therefore the setting of the game should be kept simple and familiar, without too many moving parts or distracting features.

The setting should also, of course, fit the gameplay. It should be possible to set a character moving through the world, moving from lane to lane and doing so for a long time, in a straight direction.

At the same time the scope of the project should be kept in mind. This project is being made by few people. This should be reflected in the chosen art style and theme. While a detailed realistic visual style might in theory be more immersive for the players, this is unrealistic due to the limited scope, especially since that would make proper performance more difficult. So it is likely the wisest decision to go for an accessible, simplistic and cartoony art style. The environment shouldn't be entirely premade, but it should be possible to generate through code. This is most easily done through having a base environment where the models and surrounding elements are placed inside the world to give it a little bit more life.

It has been decided that the theme of the surroundings would be the Dutch meadows. Where the player controls a cyclist that moves through the world. The Dutch meadows were chosen because they were likely quite familiar to the players, because it is an environment without too many stimuli, because it wouldn't be too difficult to generate through code and because many parts could be repeated throughout the game.

4.6 Tutorial

The game consists of 3 distinct stages. The first two are made to teach the player how to play the game. The third is procedurally generated based on the required inputs of the player.

The first stage introduces all player abilities and what to use them for. The player is explained, one input at a time, which finger controls which action through written text and spoken word. When they press said input, a corresponding obstacle appears in front of them, along with some coins they can grab if they want to. When all bound mechanics have been introduced to them, they finish the level and go on to the next level. It is possible within the game that different actions are bound to different fingers. For example, the jump action might initially be bound to the thumb, but this could later be changed to another finger. This seems to become an issue because all tutorial voice lines are pre-recorded and describe a set in stone relationship between fingers and actions. The structure of these lines was made to be quite formulaic. This made it possible to cut the voice lines into separate parts for the finger the player is supposed to use and the action that this will perform. The same could then be done with the text that would appear to teach the player what finger does what action. This all resulted in the player being able to change what actions are related to what finger while having a properly effective tutorial.

Figure 18: The tutorial shows text to explain the functions of the fingers, alongside spoken text saying the same words.

The second stage has been made in order to challenge the player to remember each input and use them to get through the stage. Obstacles are placed so that the player is required to use each mechanic a few times to get to the end of the level. After this they are brought to the procedurally generated part.

The procedurally generated stage remembers what actions the player has done while playing so far, whenever the algorithm notices that the player has underused a specific finger, it will introduce more obstacles to make sure they use said finger enough. This way it always tries to balance itself while remaining balanced.

Currently, the procedurally generated level will loop until the player decides to stop playing. Future development could be spent to increase the difficulty of the game as the player gets more comfortable with playing.

4.7 Controller integration

The current prototypes for the controllers make use of Arduino to connect to the necessary sensors. Luckily, Arduino has a unified IDE for making these kinds of implementations. There needs to be a modular system that easily allows reading data sent from an Arduino and interpreting said data so the game can be controlled through different controllers.

To get the game working with actual sensors, we got a prototype from TU Eindhoven that can measure the user's strength. This prototype was designed to register only how hard someone is pressing without knowing what finger is pressing down. After a proof of concept connection between the game and this controller was made TU Eindhoven provided us with another test version with 5 inputs, one of which was broken, remaining 4 functional inputs. This meant that the game could be played with 4 different inputs at once.

Due to the poor performance and non-functional parts of the .NET.System.IO.Ports library, the implementation of this was easier said than done. The function: ReadExisting turned out to be the saving grace that both functioned and didn't result in grave framerate reduction.

Then, to extract usable data from this, more work needs to be done to interpret it than with the normal ReadLine(). For each new function, a function will have to be written to interpret the input and use it in a game. That, as shown here, is not exceptionally challenging.

```
/// <summary>
/// Gets the most recently written value,
/// </summary>
void TryUpdateInputValue()
{
    //Add most recent data to the input
    input += serialPort.ReadExisting();
    string[] inputs = input.Split(',');

    string mostRecent = "";
    for (int i = inputs.Length - 1; i > 0; i--)
    {
        if (inputs[i].Contains('<') && inputs[i].Contains('>'))
        {
            mostRecent = inputs[i];
            //Remove everything that isn't a number
            mostRecent = mostRecent.Remove(mostRecent.IndexOf('<'), 1);
            mostRecent = mostRecent.Remove(mostRecent.IndexOf('>'), 1);
            input = "";
            break;
        }
    }


    if (float.TryParse(mostRecent, out float value))
    {
        currentInputValue = value;
    }
}
```

As long as the inputs are given through the <0,0,0,0> format, any system sending strings through a port in the device could be used as a controller using this code. This system is easily adjusted for potential new controllers that make use of several linear inputs. Which means that this could be used for future additions.

4.8 Data collection

Therapists want the ability to see what fingers the user trained and how much and how effective this has been done. With this, many questions emerge. This is medical information. Therefore, privacy is very important. No one working on this project has expertise when it comes to cyber security. This means that it is difficult to set up a system that will send data through the internet while knowing for sure that this data is properly transmitted and cannot intercepted. If and when this part becomes necessary for this project, cyber security experts should come into play to make sure that everything is done properly. Instead this report will focus on the implementation of the back-end. The way that the data is collected and locally saved. Since the controllers that will eventually be used are not finalised yet and the required data is still open for change, it is important to make sure that the collected data can be changed in the future.

So a system has been made to collect data and save them in an excel file. These data can then be turned into graphs for better readability.

Hand	Finger	Strength
Right	indexFinger	0,4563
Right	indexFinger	1,335
Right	indexFinger	4,13219
Right	middleFinger	0,494
Right	middleFinger	0,61155
Right	middleFinger	1,11879
Right	middleFinger	3,4987
Right	ringFinger	2,45679
Right	ringFinger	4,16549
Right	ringFinger	1,16844
Right	ringFinger	2,9423

While the patient is playing the game, the program is monitoring each of their actions in the background. Currently, only the maximum amount of force they applied is saved, but in the future, things like the duration of the action could be tracked as well. Since these data automatically get saved in an Excel file format, all data analysis tools available in Excel can be used to gain better insights into the patients' rehabilitation.

4.9 Environment

The setting of the environment has been decided to be the Dutch meadows, with a simplistic cartoony art style. The production of the models and animations has been done by one of MaMa production's graphic designer at the time. These assets were then used by the lead developer of this project to assemble a scene in which the game could play out.

The core asset that was created was the field of grass and the road itself. Dotting either side of this asset are far away trees that obstruct the player's view so they do not see that there is nothing beyond.

Figure 19: Screenshot showcasing the base meadow environment that makes up the ground

To add some visual interest that fits the theme to the surroundings, a few additional models were created that could be reused. These elements would make the surroundings slightly more interesting than simply a barren field of grass.

Figure 20: These models are used to decorate the landscape.

These models were then used in an algorithm that placed these elements next to the road. To reduce the visual monotony, their rotations and distance from the road is randomised.

Figure 21: The decorative models are dotted across the meadows.

There were also models made that could be used to serve as obstacles. They could then be ridden under, through, past or jumped over.

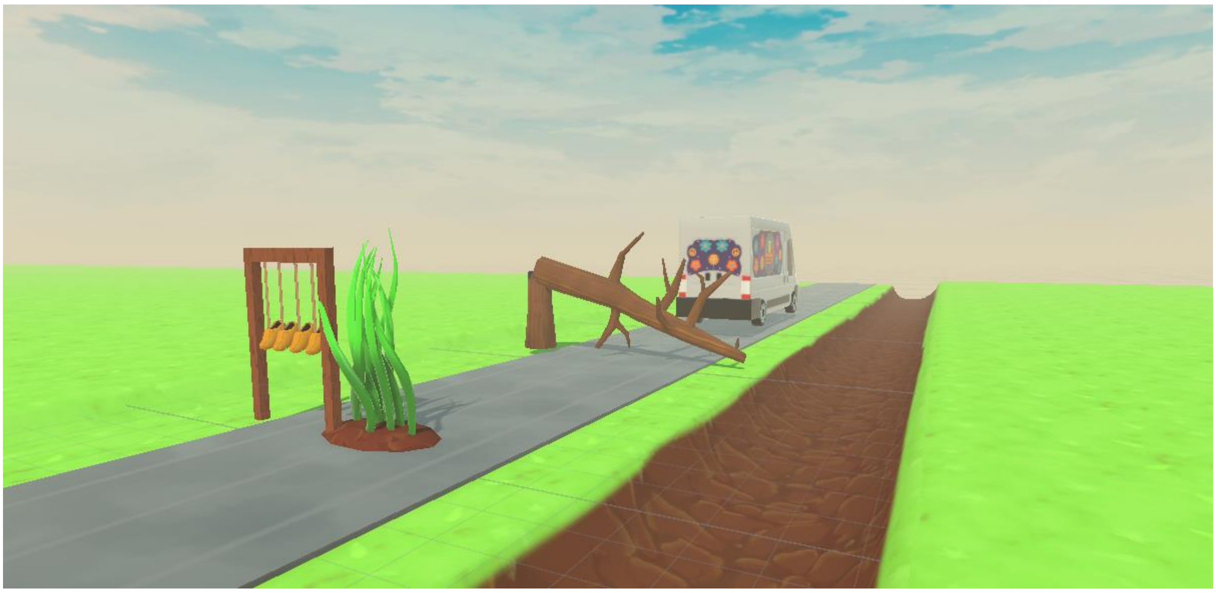

Figure 22: these models are used to form the obstacles the player has to dodge.

The sky has been chosen to have a consistent colour at the horizon. This way this same colour can be used for the fog that often covers the fields early in the morning without it looking strange. This fog has a number of purposes, it obscures distant objects, negating a need for them to be rendered, this is important because one can often see very far in the Dutch countryside, it works to make the things that are more immediately important visually stand out and it fits well into the theme of biking across the Dutch meadows, which are in the morning often topped with a light fog.

5. Expert interview

The skills required to complete this project come from different areas of expertise. Unfortunately, this project was not started off by conducting a thorough conversation with experts in different fields, namely an expert in therapeutic serious games. Instead, the following interview was conducted a number of months into development of the project, mostly to verify the validity of the project so far and to provide feedback on what could be improved.

5.1 Kiki Coppelmans

On the 30th of January 2024, an interview was conducted with Kiki Coppelmans, a psychomatic physiotherapist employed at the company InMotion VR. She was asked a series of questions relating to the best ways to execute this project and what mistakes should be avoided. She helped provide insight in what to take into account when designing the game and helped validate many choices that were already made. The following paragraphs are a summary of the conversation that was held with Kiki, along with considering how her advice might be applied in the eventual game.

To avoid confusion, Kiki was first explained what the goal of the project was and how it would approximately be realized. After this, she was asked whether it could be advantageous to make use of VR in this context. She plainly, said that she thinks it would be very possible to get use out of a VR version of the game. The next question she was asked was: “What would be good principles to keep in mind when making a VR game for rehabilitation.” In answering, she started off with mentioning that it would be a good idea to have some kind of representation of the patient’s hand in the VR environment. As mentioned earlier, visual feedback can be a very important thing when it comes to the effect of rehabilitation. This also relates back to the ability to make the VR experience a game, rather than only a tool for rehabilitation. Games usually have the feedback of success and failure. Any kind of feedback of the player’s actions is welcome. One way to implement this feedback would be to exaggerate the movements of the player’s fingers. To make sure that the fingers of the user move more in the VR world than they do in the real one.

Kiki repeated the sentiment that, due to the lack of coordination of the patients it might be difficult for them to do complex things when they want to start up the game. The game should be as easy as possible to set up. It should ideally be possible to put on the headset and start to play the game with only one hand.

Some people have trouble with many stimuli at once. The information density needs to be low to make sure people won’t get overwhelmed. At the same time, some people don’t like shutting themselves from the world entirely. It is difficult to estimate how people will respond to it. So it’s useful to make a game that can be played both in VR and on a regular flat screen.

Kiki also mentions that, when making a game like this, one should make sure that there is a clear effect and cause relationship between different things. Even for people who don’t have much experience in playing games. A developer should check their own logical biases when making a game. While collecting coins seems very intuitive for instance, this has been enforced by literal decades of previous game design.

The next question Kiki was asked was: “What should be taken into account when designing to properly regard a player’s sensitivity to stimuli?” To which Kiki answered that epilepsy needs to be considered. It’s not entirely sure whether VR can activate light sensitive epilepsy. Therefore, it should be made clear that people with epilepsy shouldn’t use the app in VR.

As Kiki explains, some people can become nauseated from VR. This can have two causes. One being motion sickness. When a user has motion sickness, this can be slowly trained away. One should take breaks every few minutes to check in on how they’re feeling and to give their bodies time to get used to this new environment. This is mirrored in the way some VR enthusiasts coined the term ‘VR legs.’ Which is the amount your body is trained to not become motion sick when playing games in VR. As Kiki explains, people don’t always intuitively know how to distance themselves from the VR world. So a therapist should explicitly explain to them that, if the VR world becomes too much for them, they can simply close their eyes or take the headset off.

As opposed to motion sickness, some people get sick from problems with their eyes. In that case, they have to solve those problems first, since the nausea will maintain as long as they haven’t done so.

5.1.1 Conclusion

It needs to be tested whether the required actions of the player are clear for them. This is also similar to the general way that games are developed. The design needs to be constantly validated with the target audience to make sure there won’t be confusion when they actually start playing the game. Testing this could be done with patients themselves, but they are difficult to get ahold of through the proper channels. It’s also possible to simply test with older, less experienced acquaintances of the test conductors.

This interview gave quite some insight into the ways the game should be designed and what to consider when designing a game like this for actual patients. We need to make sure to make the game as accessible as possible. The target audience of this game has very little experience with video games and doesn’t learn easily. We should also not just think in terms of the game itself, but we should think about what a therapist should communicate to the patient and how they should do so.

6. Testing

6.1 Introduction

Ideally all the goals of this project would at the end be validated. To make sure these goals have been fulfilled. Or if they haven't been, where they could be improved in the future. There are four aspects that would ideally be verified. The effectiveness of the therapeutic elements, the ease of use of the interface between the game and the controllers, the attention retention of the players and how effectively new players learn to play the game. Due to limitations related to focus, scope and availability of testers, the first two will not be tested in this report. The focus of this test will be the effectiveness of the tutorial and, to a lesser extend, the attention retention will be tested through playtesting.

Firstly, it should be tested if this project would have the desired therapeutic effects. Whether playing the game with the controller would actually increase the hand strength and coordination of the target audience. Additionally, specific aspects of the experience could be tested. Like the influence of the in-game hand or what the effects of other elements of the game are on the players' rehabilitation. Doing this would however require two large groups of patients to compare to each other. One performing traditional therapy as control group and one practicing with the renewed serious game. To find a significant difference, there would need to be a substantial sample size. Testing with actual patients is also, understandably, restricted and takes a lot of effort. These two issues make it all but impossible to properly validate the therapeutic effects of this project within its scope.

The second goal that could be validated is the effectiveness of the connection between the controllers and the game. The goal of this interface was to make a system that was useable for third parties to externally create a device that could connect to the computer to control the game. It could be examined whether it is easy to connect these two together and other developers could verify whether this system allows them to do all that they want to do. This part has however been a secondary aspect of this project. More of a means to an end than a goal of the project itself. Testing this will be important in the future, but it is more essential to examine whether the primary goals of the project have been fulfilled.

The third goal to verify is whether the game has the desired effect of keeping the attention of players, allowing them to have intrinsic motivations to keep playing. A lot of attention has been put into making the game as fun as possible for the player, which is why this is what will be tested within this report. Noteworthy is that, when a game is properly designed, learning to play is often very fun in and of itself. This can mean that, when a player knows how to play a game, they lose interest, as there is nothing left to learn. This means that both the learning part of the experience must be examined and the more long term enjoyment of playing the game. To make sure the most important bases are covered, the following two questions must be answered: "How easy is it for a player to learn to play the game." "Is there enough long-term enjoyment for the players to play the game for a longer time."

The first of these two questions is likely best answered through playtesting. Where observing the player's actions and listening to what they have to say while playing gives insight into the process of learning to play the game. The second question is a bit more difficult to accurately answer, since it requires a longer timespan to be completely answered with a playtest. Since doing a reoccurring playtest with multiple subjects is out of scope, the focus of this test will be on the accessibility of the game, and we will try to verify the enjoyment of playing as much as possible through a questionnaire.

6.2 Pilot playtest

To make sure the tests will give data that is as useful as possible, the tests will be initiated by a pilot test. Where one subject will play the game and answer some questions. This will hopefully highlight some of the mistakes still present in the way the test is performed, along with bigger issues currently present within the game.

The test will be initiated by a more traditional playtest. The subject will play the game with a specific goal in mind. They will be observed and filmed while doing so. It will be noted where they crashed, what confusion they express and where they seem more disinterested. From these observations and the answers to their questions, conclusions can be drawn about changes that should be made in the game. Afterwards, the effectiveness of the pilot playtest will be reflected upon, which will then be changed where necessary in order to optimize the eventual priorities in the continuation of the project.

6.2.1 Questions

After letting the player play the game they will be asked the following questions:

- Did you enjoy playing this game?
- Would you like to play the game again tomorrow?
- Did you find it difficult to understand how the game functions? If yes, what parts did you find difficult?
- What did you think of the visual presentation? IE, the surrounding meadows and the person on the bike.
- Do you have any other comments?

6.2.3 Execution

The test was performed on a 62 year old woman with little experience with video games. She was explained: the context of the assignment, the different inputs she would be required to use to play the game, that she would get little information from the tester, as they would just observe and that she was expected to voice her thoughts out loud to give the tester insight. Unfortunately, while testing, no working prototype of a specialized controller was available to test with. This meant that the subject played with a keyboard instead. As she later expressed, this did lead to some confusion and testing with a proper controller likely would have lead to a more useful test result.

6.2.4 Observing the player

From observing the subject, a couple of insights were gathered. Firstly, she expressed confusion about the coins, which she called “those yellow clouds”. This is likely due to her inexperience in video games. As has been speculated earlier.

The difficulty curve was imperfect for this player. The first stage took quite a long time, this was exacerbated by the fact that she did find it difficult to not crash into obstacles. Whenever this happened, she was forced to go back to the beginning of the tutorial. This meant that she had to repeat the same part quite a lot.

The second stage seemed to result in some boredom. There were quite long stretches of emptiness where the subject started to show signs of disinterest.

She crashed quite a lot in the third stage. It took her 24 attempts to finish the third stage without crashing. When starting that stage, she quickly expressed that she found this part much more difficult than the previous parts. However, she was told that she was free to stop playing whenever she felt like it and did not stop until she overcame the stage. She also expressed joy when passing an obstacle that had previously seemed too difficult for her.

6.2.5 Interview

The first question asked was whether the subject enjoyed playing the game. She answered that, apart from a few specific problems, she did. She noted that she knows that she can quite easily get addicted to these kinds of things and she felt some of that urge in this game.

The second question asked was if she would be willing to play the game again tomorrow. She answered that she would like to if given the opportunity.

The question of if she understood the game's functions was quite insightful. She found the introduction somewhat confusing. Saying: "I didn't understand the coins, maybe I could have read that in the explanation. I thought I had clicked the explanation but the game just started. I kept thinking I needed to avoid the coins, but that was impossible. In the beginning I found it confusing that the game told me to go left or right. Okay, and? What then? I would have liked some more clarity about the purpose of the game."

She also expressed confusion about the purpose of the hand itself. The purpose of the hand was to give the player clarity about what was to do within the game, but it seemed like this didn't have the desired effect.

She would have liked to play with one of the controllers made for the game since playing with he keyboard added to the confusion. She placed her hand incorrectly once, which resulted in her pressing the wrong buttons accidentally.

She found the visual environment nice. It wasn't too much, but it did add enough to make her think: "Oh fun, there's some cows and a windmill." Aside from this she did not think there was too much to add.

6.2.6 Discussion

This test lacked two significant parts of the game's eventual implementation. The virtual reality aspect which could potentially have a quite transformative effect on the experience. It is important to test the game with virtual reality in the future, while also testing on a flat screen, since the game should be playable in both contexts. The lack of a specialized controller did not prevent this test from acquiring valuable insights, but future tests should mostly be conducted with one of the specialized controllers to get a more wholesome image of the remaining issues within the experience.

The feedback on the tutorial was insightful. The subject expressed that she would prefer a more explicit explanation of how different aspects of the game work. Her confusion about specific elements would, according to her, be alleviated if they had been explained to her. Her confusion might also be alleviated by changing specific parts of the game's design. Clarifying the purpose of the coins gives a more immediate reason to use the inputs that were explained to her. Since just being presented with something she could do without any reason to do so did not motivate her to experiment with the mechanics.

Coins are common within video games. So common that it might seem very intuitive that when there are coins in a game, they should be collected by the player. This is not necessarily the case. But it's also worth considering that, since the subject did not recognize the coins as being coins, changing the way the coins look to be more easily recognized might be an efficient way of alleviating this problem. Since, even outside the video game world, coins are rarely seen as something to avoid. It is wise to, before future testing is conducted, improve the appearance of the coins to make it more clear what they are.

The negative perception of the tips given through the in-game hand was somewhat surprising. In-house testing has not shown negative feelings towards this hand. The fact that it was perceived to be confusing is important to consider. Future testing should be done to investigate the validity of the tips of the hand through A-B testing, where one version gives the player tips and one version does not. It should also be tested if this is perceived differently when playing in Virtual Reality or on a traditional flat screen.

The difficulty curve should also be considered in future development. There are several values that can be altered for the procedural generation of the levels. For example, the distance between obstacles, the speed of the player character and the complexity of the obstacles the player has to deal with are variables that could be changed. The developer should make sure that these values start off to make the game easier for the player. Then, there are multiple ways to make the game more difficult over time. The game could automatically adjust its difficulty to the success or failure of the player. It could also have an option for the player to increase or lower the difficulty at will. This gives the player a stronger sense of progression since they can explicitly compare their current skill to how it was in the past.

Also notable is the great motivation with which the player kept playing the game. When making a game that tries to optimally motivate a player to keep playing. It is important to not go overboard and addict the player to the game. It needs to be made sure that the player stops playing at a certain point to not over-exert their hand and to make sure they don't spend all their time playing the game.

6.3 Iteration

For the eventual playtest, a couple of changes should first be made within the game itself, after which, the test itself will be reiterated.

6.3.1 Game iteration

Based on the feedback obtained from the first playtest, a few changes have been made. Two changes have been made to reduce the players' confusion about the coins.

Firstly, the model and texture of the coins has been changed in an attempt to make them more easily recognizable. Hopefully, this will help to create less confusion about the coins for players.

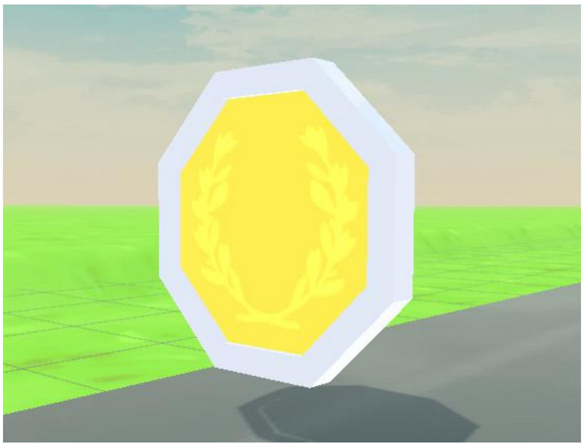

Figure 23: The renewed coin model.

Secondly, the tutorial has been expanded with a voice clip that, when translated, says: “Collect coins for a higher score.” The line is played at the moment the first coins appear. Presumably, players will connect these coins to the fact that they are hearing about them at that point.

Secondly, there was a problem remaining with the tutorial obstacle spawning and the buttons related to each finger. This issue has been fixed. The tutorial obstacles now also properly appear after the player presses the corresponding button. As opposed to only working with the prototypes of the custom controllers.

Lastly, the initial distance between obstacles in the procedurally generated level has been increased. This will make it easier for players to finish the first level. Having made these changers, it’s time to reexamine the tests themselves.

6.4 Primary playtest

6.4.1 Test iteration

Since the gameplay of the players itself will be split into distinct parts, the previous test was too focused on seeing the game as a cohesive whole, where the feelings of the player were examined collectively. The experience of the player is split up into three different stages, firstly, two tutorial levels, followed by a looping procedurally generated level. The first level explains all mechanics step by step and allows the player to calmly learn how to use every input. The second level challenges the player to remember each input one by one and makes sure that every mechanic is repeated. The third level is the actual game. Here, a level is generated based on what inputs they should be using in order to balance the amount of exercise each finger gets.

Due to a lack of access to either of the custom controllers, the game can only be tested through the controls that have been used during development. In development, five buttons on the computer’s keyboard were designated as buttons that would control different actions in the game. The spacebar to be used by the thumb and the J, K, L, and semicolon buttons for the index- middle- ring- and pinkie fingers respectively. This is in accordance with the way one’s right hand is meant to be placed on the keyboard while typing with ten fingers. This is however a lot more difficult to maintain whilst having a VR headset covering your eyes. So instead, the subjects will be asked if they are comfortable typing with ten fingers. If they are, they will be asked to initially test in Virtual Reality, if they are not, they will be asked to play using the VR headset.

Because women are, on average, more sensitive to motion sickness in Virtual Reality, it needs to be ensured that the game will be tested in VR by both men and women. So if there are not enough people that are initially comfortable enough with a keyboard to play in VR, some of the other testers will be asked to play in VR afterwards. At this point, they have presumably gained some comfort with the controls, so they can play the game in VR without too many issues with finding the right button.

To make sure the issues of one stage don't taint the results of the others, the results of each stage will be examined separately. The time to complete and amount of crashes of each stage will be noted for each user. After each stage, the player will be asked to wait before they continue in order to answer a few questions about their feelings on the previous stage. This will give more specific feedback of each individual level instead of a more general examination of the entire experience. At the end of each stage, the player will be asked the following questions:

- Did you enjoy what you just played?
- Did you have issues with remembering what button did what?
- Do you think what you just played was too difficult, too easy or just right?

While the primary goal of this test is to verify the effectiveness of the tutorial, this is an opportunity to gather some information on how engaging the game is to players, along with their general feelings on different aspects of the game. To do this, the same questions used in the pilot test will be asked to the subjects.

To document the responses of each participant, a form has been made in which each question can be answered. This will be filled in by the person who observes the test when they ask the questions.

Half of the subjects will be asked to play the game in Virtual Reality. They will initially be warned that motion sickness is a possible side effect of using Virtual Reality and that there are multiple ways of distancing themselves from the virtual world were they to feel unwell. They could close their eyes or use their hands to take the headset off their head.

To collect all these data, a form is set up with all questions and a table with the level-specific data. This form will, when possible, be filled in by the person conducting the test while the test is ongoing. The test will also be filmed so missing data can be filled in later.

Excluding the pilot test, five people were tested. The ages of the subjects ranged from 59 to 68 years old. Of the subjects, two were men and three were women. Two of the subject had suffered some form of a stroke in the past. One of these had had a minor stroke 13 months earlier. They did not have to go through rehabilitation since his symptoms had been minor and short lasting. The second is a woman who had had a stroke 12 years before this test. She had gone through rehabilitation and has now largely adjusted. Two out of five subjects played with the VR headset from the beginning. Two people also played the game in VR after initially learning to play on a flat screen.

6.4.2 Limitations

There are a number of limitations in this test that need to be considered. The first limitations is the small sample size. While a very large sample size is uncommon in single-player video game testing, the more objective metrics used in this test are less reliable because there are only five subjects.

Secondly, while the bulk of the game worked properly, the third stage would occasionally bug with the procedural level generation. Where, instead of presenting the player with a number of different obstacles, the stage would consist of one specific obstacle time and time again. The test conductor could interrupt, restart the game and thus fix this issue. This was however not the intended experience and what influence it exactly had on the experience is unclear.

Thirdly, people's enjoyment might have been influenced by the fact that they were not doing this for themselves, but they knew playing this game was helpful for someone else. This fact might have made it easier for subjects to enjoy the game or it might have influenced their enjoyment negatively as they felt obliged to play the game.

The remaining limitations are due to the problems found in the way subjects would answer the questions they were asked. There sometimes seemed to be a discrepancy between the expressions of players during gameplay and the answers they gave afterwards. There are three explanations for this discrepancy. The first explanation is politeness. Subjects might not answer truly honestly because they are, consciously or not, trying to be polite and more positive than their feelings would reflect.

The second explanation is that they only were asked these questions at the point that they had just succeeded. This might have influenced their feelings to be more positive, since the success had been more recent than the failure.

Finally, subjects tended to phrase their thoughts more from a more general perspective than their own specific feelings. They might say: "Well the game was hard for me, but my kids would have picked this up easily." Or a player would try to imagine their feelings if they were rehabilitating. While the goal of this test was to learn what their own feelings were. This tendency to distance their opinion from their current feelings has likely influenced some of the answers to the questions given.

6.4.3 Results

6.4.3.1 Data

Following is a table summarizing the results of the individual levels during the playtest. Due to the differences in length of each stage, it won't be useful to compare the durations and amounts of crashes between stages. Therefore the duration and amount of crashes will only be compared between the subjects.

Stage	Tutorial 1	Tutorial 2	Regular game
Duration (avg, seconds)	355	275	81
Duration (min, seconds)	245	201	40
Duration (max, seconds	441	422	140
Crashes (avg)	5.2	6.0	3.8
Crashes (minimum)	1	3	0
Crashes (maximum)	14	14	8

There is a big discrepancy between players in how many times they crashed in tutorial 1. This is mostly due to one subject who misunderstood how to pass the car obstacle and kept wrongly timing the jumps. The person who crashed the second most did so 7 times, as opposed to 14. The duration of the stage was longer than expected. But none of the players expressed that they were especially bored while playing this tutorial.

In tutorial 2 is an even bigger offset between the person who crashed the most and the person who crashed the second most. They did so 14 and 5 times. 9 of the 14 crashes happened at the second obstacle where she did not timely figure out which button she had to press to go to the left.

It is notable that there is a bigger difference in completion time between the subjects for the third stage. However, it might be unwise to jump to any conclusions from this fact due to the bug remaining in the level generation in said stage.

6.4.3.2 Questions

Stage	Tutorial 1	Tutorial 2	Regular game
Q1 (yes/mixed/no)	4/1/0	3/1/1	3/1/1
Q2 (yes/mixed/no)	3/0/2	3/2/0	5/0/0
Q3 (easy/just right/difficult)	0/4/1	1/1/3	1/2/2

The questions answered in the sections marked Q1, Q2 and Q3 are the following:

- Q1: Did you enjoy what you just played?
- Q2: Did you have issues remembering what button did what?
- Q3: Do you think what you just played was too easy, too difficult or just right?

The answers to the questions are possibly unreliable due to the reasons given in the limitations. Comparing the stages is likely a lot more useful in this case. The amount of enjoyment the players had did technically vary from level to level, but that variation is too little to draw any actual conclusions from.

The second question gives some more insight. It shows a pattern of people slowly becoming more confused about what button does what. This is likely due to the subjects' response times needing to become shorter from level to level.

After the subjects played the game, they answered four questions about their opinions on the experience. The first was: "Did you enjoy playing this game?" 4 out of 5 subjects answered that they would, 1 answered that they hadn't enjoyed it a lot.

The second question: "Would you like to play the game again tomorrow." had similar results. 3 people said that they would enjoy playing again the next day. 1 said that they didn't feel much motivation to continue. 1 did not express much immediate enthusiasm about playing the game again, however if they would much prefer this over traditional therapy as it would likely motivate them to keep playing.

The third question was about what parts of the game were confusing to the players. The conductor would also ask the subjects about specific parts of the game where they thought the player seemed to not understand these parts. Two main points of confusion emerged.

The first point of confusion is related to the way the tutorial is structured. The obstacles the player would have to avoid in the initial tutorial would only appear when the player hit the corresponding button. The assumption was that players would get prompted with a button input, press that button to find out how it works and get confronted with the obstacle they needed to cross. Not one player found this out on their own. Most players would, when prompted, experiment with the button said button. But they would not make the connection that they were required to press said button after they had crashed and had to start again. One player did not even press the button when prompted. They waited for an obstacle to appear for several minutes until they were told by the test conductor that they had to press the button first for something to happen. This confusion was reflected in both the observations made during the playtest and the comments made while answering questions after playing.

The second point of confusion was the nature and purpose of the coins in the game. As stipulated after the first playtest, collecting coins is something that is firmly established within the language of video games. The target audience of this game is however largely unfamiliar with this language. It was unclear to 4 out of 5 subjects what the purpose of the coins was. All 4 at some point assumed that the coins had to be avoided. The coins also were not recognized as coins by 3 of the 5 subjects.

Along with these two main points emerged a number of less consistent points of confusion. A reoccurring theme was obstacles where the player did not understand how to cross them. 2 players assumed that they could jump over the bus obstacle instead of moving past it. 3 players assumed they could jump over the fallen tree instead of crouching through the hole on the right side. Some players also did not understand the purpose of the finish when they saw it. This did not lead to significant issues with the experience since there was no mistake to make as a result of this misunderstanding.

The fourth question was about people's general opinion of the visual style. The sentiment was generally positive or indifferent. Except for 1 subject, who felt the surroundings were boring. 2 people expressed that they appreciated the lack of distraction in the surroundings. One of these people was the woman who had had a stroke 12 years earlier. She recounted how she wasn't able to deal well with a lot of stimulation and that she liked the familiarity and the simplicity of the visual presentation.

While not a primary point of focus, two subjects expressed frustration in the first tutorial that, each time they had crashed, they needed to start all the way from the beginning. One of them also expressed frustration at needing to hear the same tutorial voice clip time and time again. While one other subject expressed appreciation for the fact that the explanations kept being repeated.

These results showcase a few bigger issues and a number of smaller problems that should be addressed in future development of this project. The biggest points of confusion were what button did what, what the purpose of the coins were and the function of the tutorial.

6.4.4 Discussion

Now that these issues have been established it is time to understand what the causes of these issues are and what can be done to mitigate them. From this playtest came three main takeaways and one area that requires more work. People do not understand the nature and purpose of the coins, people don't understand that they have to press a button in order for an obstacle to start appearing and people had trouble with remembering what button did what.

The confusion about the coins jumped out even in the pilot test. Almost every single player in the target audience showed confusion about at least the purpose of the coins. A common issue was the fact that the players just did not recognize the coins as such. This was true with both models for the coins. After conversing with the subjects it also became clear that "collecting the coins" does not intuitively mean "hit the coins with your bike" if you aren't familiar with common video game language. This problem needs to be addressed. "Collect coins for a higher score." does not properly communicate the necessary information. An alternative phrasing could highlight the fact that the coins are currently present. These two changes would mean the sentence would, when translated, be phrased as: "Hit these floating coins for a higher score." Clearer visual and audio feedback could be implemented to make sure the players understand that collecting coins is a good thing. This could be done in the form of a '+1' appearing when a coin is collected. A more noticeable audio cue could also highlight that hitting the coins is a positive thing. Increasing the clarity of the coins should be a priority since the coins had a secondary purpose of improving clarity of the obstacles.

The clarity of the obstacles are, after all, another issue found through this test. This was most noticeable with the fallen tree where players have to go left and under. One purpose of the coins was to guide players towards the proper way of passing obstacles. Since the coins were not properly communicated, fixing them might lessen the remaining issues with the obstacles. If not, another solution must be applied. The models of the obstacle might need to be improved to increase visual clarity.

The lack of understanding of the tutorial is another issue. Players tended to wait for an obstacle to come their way before pressing the corresponding button rather than experimenting with said button when prompted. This meant that players often waited a long time for the obstacles to appear for them. This means that this design of the tutorial does not work as intended. Several solutions to this can be considered. The mechanics of the tutorial could be explicitly explained to the player through more tutorial text. Where a voice would explain to inactive players that the game is waiting for them. However, this approach runs the risk of still being confusing. It also requires the player to actively learn information that they will then use to learn to play the game. This is inelegant, especially since they will not need to understand this for the rest of the game. Ideally, the players themselves don't think about the structure of the tutorial at all. They just play and learn through playing.

A more elegant solution is likely a redesign of the way the player is confronted with the obstacles. When doing this, the purpose of this design must be maintained. This tutorial was made like it was in order to make sure that players aren't forced to do something before they are ready to do so. They were expected to first prove that they could make it past the obstacle before they would move on to the next part of the tutorial. Two of the test subjects expressed annoyance at the fact that they had to keep being explained what each button did if they failed once. Maybe adding an absolute fail state into this tutorial was a flawed decision. The alternative solution would be to make the tutorial in such a way that the player cannot crash. Instead they only progress when they correctly pass the obstacle.

Another issue that was common among players was the binding of the fingers to specific actions. To many players the connection between the fingers and the actions related to it were unintuitive. It would be wise to add the ability to change what finger corresponds to what action in the game. Luckily, some of the background work for this has already been done. While this ability would be nice, it is likely not desirable to require every player to set up their own navigation. Therefore some effort should also be put into forming an intuitive standard setup for the action bindings.

6.5. Conclusion

The tests resulted in two main issues with the current game. Firstly, the current implementation of the tutorial needs to be overhauled. None of the subjects implicitly understood the fact that they had to press a button in order for the next obstacle to appear. Secondly, what the coins are and what the players are supposed to do with them is largely unclear. There needs to be some clarity for the players in this regard. A much requested feature is the ability for players to be able to freely change the relationship of fingers and the actions related to them.

No issues with motion sickness were detected through this testing process. This, and the lack of issues found with motion sickness during development leads to the current conclusion that motion sickness is not an issue with this game.

These conclusions were made without availability of either of the prototypes of the custom controllers, so future testing will need to be done with said controllers. Future testing should also be done with actual stroke patients.

Conclusion

The goal of this project is to increase the effectiveness and enjoyment of hand rehabilitation of patients after a stroke through a serious game. This has been done as a part from the HandForce project. Which is dedicated to increasing the quality of hand rehabilitation after a stroke. As it stands right now the project is playable, testable and proves an interest in a serious game to help with rehabilitation. However, the project is unfinished, a number of changes should still be made to increase the ease of use for the target audience.

The game made is a ‘three lane runner’ in which the player has to time button presses to help a player dodge obstacles. The game is playable in Virtual Reality and on a traditional flat screen. Which allows it to make use of all the advantages that virtual reality bring without excluding those who are unable to play in Virtual Reality.

The possibilities in this project were somewhat limited by its scope. The goals of rehabilitation were somewhat limited by only being able to focus on the patient’s strength and selectivity of their fingers, while coordination is generally broader. An ideal rehabilitation game could be made with a controller that is able to track the player’s hand’s position, rotation, the orientation of their fingers and the amount of applied force of each individual finger. Unfortunately, such a controller does not currently exist.

The current game could presumably be used in order to help thousands of people. People who are in a difficult situation. It could help them to enjoy their rehabilitation more, to rehabilitate quicker and better. Hopefully this project succeeds in turning the rehabilitation of stroke patients from something good, into something that is as good as it can be.

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